APPROVED BY

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REPORT

ON

SS RIVNE NPP ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

Book 1

Basis for EIA.
Physical and Geographical Characteristic of
SS Rivne NPP Area

Version 2

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ABSTRACT

Book 1 of this Report contains 173 pages, 16 figures, 44 tables and 7 attachments.

The object of consideration is the operating enterprise Separate Subdivision “Rivne NPP” (SS “Rivne NPP”) of the State Enetrprise “National Nuclear Energy Generating Company “Energoatom” (SE “NNEGC “Energoatom”) which includes operating power units, facilities and structures, integrated into technological complex located at SS Rivne NPP site, as well as other facilities within the power complex, which have impact on the environment in the vicinity of the plant (sanitary protection zone and observation zone).

The purpose of SS Rivne NPP environmental impact assessment is the assessment of the environmental impact during SS Rivne NPP power units operation upon the results of implementation of environmental actions, long-term environment monitoring, and comparison of environmental state around NPP before and during power units operation (taking into account available information regarding SS Rivne NPP power unit 4 impact on the environment), and prediction of the expected impact levels during further operation of Rivne NPP units.

Book 1 considers the basis for SS Rivne NPP environmental impact assessment, sources and types of environmental impact of the plant activity, the list of ecological, sanitary and epidemiological, city-planning and fire protection constraints, information on the attitude of the public and other stakeholders to the planned activity; provides characteristic of physical and geographical features of SS Rivne NPP location area, distribution of all negative factors in the areas of impact of planned activity. The result of this report is the environmental justification of the acceptability of SS Rivne NPP operating facilities economic activity and identification of environmental safety conditions under further activity.

Key words: SS “Rivne NPP”, SS RNPP, EIA, ENVIRONMENT, PUBLIC, SAFETY REVIEW, SOURCES OF IMPACT, PHYSICAL AND GEOGRAPHICAL FEATURES, IMPACT AREA, NATURAL IMPACT FACTORS, MANMADE IMPACT FACTORS.

Conditions of the report distribution: according to the contract.

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LIST OF SYMBOLS, UNITS, ACHRONIMS AND TERMS

Achronims	Description
ALARA	As Low As Reasonably Achievable
ASAD	Additional safety analysis documents
CA	Sanitary protection zone
CCSUP	Complex (Consolidated) Safety Upgrade Program
CDF	Core damage frequency
DBA	Design Basis Accident
DL	Dose Limit
EBRD	Bank for Reconstruction and Development
EC	Europeam Commission
EH	External hazards
EIA	Environmental Impact Assessment
FA	Fuel Assembly
HVAC	Heating, ventilation and air conditioning
IAEA	International Atomic Energy Agency
IE	Initiating event
LRW	Liquid radioactive wastes
MGO	Main geophysical observatory
NASU	National Academy of Sciences of Ukraine
NPP	Nuclear Power Plant
NT-Engineering	Limited liability company "NT-Engineering"
OJSC	Open joint-stock company
PSA	Probabilistic Safety Assessment
PSRR	Periodic Safety Review Report
RNPP	Rivne Nuclear Power Plant
SF	Safety Factor
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SRW	Solid radioactive wastes
SS "Rivne NPP"	Separate Subdivision "Rivne NPP"
SE "NNEGC "Energoatom"	State Enterprise "National Nuclear Energy Generating Company "Energoatom"
OZ	Observation zone
TOR	Terms of Reference
VVER	Water-cooled water-moderated power reactor
WANO	World Association of Nuclear Operators

GENERAL PROVISIONS

The service: “SS Rivne NPP Environmental Impact Assessment” has been rendered in accordance with the contract No. 347, dated March 27, 2018, concluded between the State Enterprise “National Nuclear Energy Generating Company “Energoatom” (SE “NNEGC “Energoatom”), its Separate Subdivision “Rivne Nuclear Power Plant” and NT-Engineering LLC.

The work has been performed for environmental impact assessment the of SS Rivne NPP activity, which it carries out as an operating nuclear power plant within the framework of RNPP power units 1 and 2 reassessment, upon the results of implementation of environmental actions, long-term environmental monitoring, and comparison of environmental state around NPP before and during power units operation (taking into account available information regarding the environmental impact assessment of SS Rivne NPP power units 3 and 4), and prediction of the expected impact levels during further operation of the mentioned power units.

Information data used when providing the service include baseline materials, monitoring results, power unit operating experience, implemented and planned environmental actions etc., based on which the calculation and research of SS Rivne NPP impact on the environment and public including that in a transboundary context has been carried out. This document is elaborated after the collected information has been analyzed, systematized and unified.

The basis for providing the service is the Energy strategy of Ukraine for the period to 2030 [1], approved by the Order of the Cabinet of Ministers of Ukraine No. 1071-r, dated July 24, 2013, which defines the operation of Ukrainian nuclear power plant units, Strategic plan of the State Enterprise “National Nuclear Energy Generating Company “Energoatom” development for 2017-2021 [2], the Decision VI/2 of the 6th meeting of the Parties to the Convention on the Environmental Impact Assessment in a Transboundary Context (Espoo Convention) [3], Minutes of the meeting of the Interdepartmental Coordination Board regarding issues on the implementation of Environmental Impact Assessment in a Transboundary Context in Ukraine (Espoo Convention), dated December 15, 2016 [4], Letter of SE “NNEGC “Energoatom” No. 3313/18, dated March 07, 2017 [5], Letter of SE “NNEGC “Energoatom” No. 13391/18, dated September 28, 2017 [6], and the Law of Ukraine “On the Environmental Impact Assessment” [7], Directive 2001/42/EC of the European Government and Council, dated June 27, 2001 “On the Environmental Impact Assessment of Certain Plans and Programs” [8], and requirements in accordance with the Resolution of the Cabinet of Ministers of Ukraine “On the Approval of the Public Hearing Procedure in the process of the Environmental Impact Assessment”, dated December 13, 2017, No. 989 [9], Resolution of the Cabinet of Ministers of Ukraine “On Approval of the Procedure of Documentation Transmittal to provide the conclusion on the Environmental Impact Assessment and the Procedure for Maintaining the Unified Register of Environmental Impact Assessment” No. 1026, dated December 13, 2017 [10].

Facility, which activity has been assessed in terms of impact on the environment, includes operating power units, facilities and structures integrated into technological complex located at SS Rivne NPP site, as well as other facilities within the power complex in the vicinity of NPP (sanitary protection zone and observation zone).

In compliance with the Law of Ukraine No. 2861-IV, dated September 08, 2005 “On the Procedure of Decision Making on Siting, Design, Construction of Nuclear Installations and Facilities for Radioactive Waste Management that are of National Importance” [11], the decision regarding the operation of NPP power units is taken by the State Nuclear and Radiation Safety Authority based on the conclusion of the State Nuclear and Radiation Safety Expert Review.

To provide reliable protection of the personnel, public and environment from the effect of ionizing radiation and maximum possible reduction of the impact of anthropogenic factors on the environment a number of general measures have been established by SS Rivne NPP of SE “NNEGC “Energoatom”:

– fulfilling the requirements of the Environmental legislation of Ukraine, international agreements of Ukraine, standards and regulations in the area of the use of nuclear energy, environmental management and environmental protection;

– planning of work in the area of environmental protection and monitoring of observance of environmental impact standards;

– environmental support of NPP power units operation;

– development and implementation of environmental protection management system;

– compliance with the technological parameters of SS Rivne NPP operation;

– consideration of quantitative and qualitative indicators of releases to atmoaphere, discharges to water, waste management for the rational use of natural resources;

– implementation of environmental policy by way of organization of environmental training of the personnel, enhancement of environmental training level;

– constructive interaction with supervisory authorities, public organizations on environmental safety issues.

In the course of NPP economic activity SE “NNEGC “Energoatom” prepares annual reports on radiation safety, non-radiation factors of environmental impact, implementation of environmental actions etc.

Radiation safety issues are monitored in compliance with corresponding instructions and specifications developed and approved for each structural department of SE “NNEGC “Energoatom” in accordance with current legislation in this area.

Emergency response issues are defined by the Emergency plans developed and put into effect in compliance with par 10.13.1 of НП 306.2.141-2008 “General Provisions for Safety of Nuclear Power Plants” [12] for each plant, including Rivne NPP.

In order to determine the environmental substantiation and effectiveness of SS Rivne NPP power units operation, the compliance of the operation with the requirements of environmental protection legislation, in 2015 the environmental audit has been carried out, that meets the requirements of the Law of Ukraine “On the Environmental Audit” No. 1862-IV, dated June 24, 2004 [13].

In addition to this, the Reports on Safety Review are periodically developed (in compliance with the regulatory requirements).

Power unit Periodic Safety Review Reports (PSRR) contain the analysis of 14 Safety Factors (SF):

– SF-1 “Power unit design”;

– SF -2 “Current state of power unit systems, structures and components”;

– SF -3 “Equipment qualification”;

– SF -4 “Structures, systems and components ageing”;

– SF -5 “Deterministic safety analysis”;

– SF -6 “Probabilistic safety analysis”;

– SF -7 “Analysis of internal and external impacts”;

– SF -8 “Operational safety”;

– SF -9 “Use of other NPP experience and scientific research results”;

– SF -10 «Organization and management»;

– SF -11 “Operating documentation”;

– SF -12 “Human factor”;

– SF -13 “Emergency preparedness and planning”;

– SF -14 “Impact of NPP operation on the environment”.

The mandatory element of all Ukrainian NPPs operation is the “Complex (Consolidated) Safety Upgrade Program for Power Units of Nuclear Power Plants” (CCSUP) [14], approved by the Resolution of the Cabinet of Ministers of Ukraine No. 1270, dated December 07, 2011.

EIA has been carried out in compliance with the “Recommendations on the Content of Materials for Environmental Impact Assessment of operating Facilities ” [15] and ДБН А.2.2-1-2003 “The Structure and Content of Materials on the Environmental Impact Assessment (EIA) During the Design and Construction of Enterprises, Buildings and Structures” [16] with consideration of the requirements of legal, regulatory and methodological documents.

Within the Environmental Impact Assessment of SS Rivne NPP the following have been provided:

- The description of planned activity, place of its implementation, goals, characteristics and implementation, description of main characteristics of planned activity, type and amount of materials and natural resources to be used.
- The assessment by releases and amount of expected wastes and releases.
- The description of justified alternatives of the planned activity, main reasons for choosing the proposed option taking into consideration the environmental consequences.
- The description of the current state of the environment (baseline scenario) and description of its probable change without carrying out the planned activity within the limits of how natural changes from the baseline scenario can be assessed based on the available environmental information and scientific knowledge.
- The description of the environmental factors that are presumably influenced by the planned activity and its alternative options, including public health, the state of flora, fauna, biodiversity, land, soils, water, air, climatic factors (including climatic changes and greenhouse gas releases), material objects, including architectural, archeological and cultural heritage, landscape, social and economic conditions and the interrelations between these factors.
- The description and assessment of possible environmental impact of the planned activity, particularly the size and scale of such impact (size of area and population that may be affected), character (transboundary, if any), intensity and complexity, probability, anticipated beginning, duration, frequency and inevitability of the impact (including direct and any indirect, side, cumulative, transboundary, short-term, medium-term and long-term, permanent and temporary, positive and negative impact).
- Preparatory and construction works and the planned activity has been implemented, including (if necessary) dismantling work after completion of such activity.
- Usage of natural resources, specifically lands, soils, water and biodiversity during the implementation of the planned activity.
- Releases and discharges of pollutants, noise, vibration, light, heat and radiation pollution, emissions and other influencing factors, as well as waste management operations.
- Risks for people health, objects of environmental cultural heritage, including due to the possibility of emergency situations.
- Cumulative impact of other existing facilities , planned activity, with consideration of all existing environmental problems related to the territories having specific environmental significance, which can be affected or which can be used in terms of natural resources.
- Influence of the planned activity on climate, including character and scales of greenhouse gas releases, and activity sensitivity to climate change.
- Used substances and technology.

- The description of prediction methods used for Environmental Impact Assessment and assumptions that laid the groundwork for such prediction, as well as used data on the state of the environment.
- The description of envisaged measures aimed at prevention, avoiding, reduction, elimination of the significant negative impact on the environment, including (if possible) compensatory measures.
- The description of expected significant negative impact of the activity on the environment caused by the design vulnerability to the risks of emergency situations, measures to prevent or mitigate the emergency situation impact on the environment and emergency situation response measures.
- Identification of all difficulties (technical deficiencies, absence of sufficient technical means or knowledge), revealed in the process of Environmental Impact Assessment.
- Comments and proposals submitted to authorized regional governmental body, authorized central body after the disclosure of the planned activity information to the the public. A table with the information about complete consideration, partial consideration or justification of comments and proposals rejection received during the public hearings.
- The content of the environmental impact monitoring and control programs during the implementation of planned activity, as well as (if necessary) plans after the design monitoring.
- Non-technical information summary designed for wide audience.
- List of references indicating the sources used for descriptions and evaluations contained in the Environmental Impact Assessment Report.

“SS Rivne NPP Environmental Impact Assessment” is presented in 7 books.

This book provides information on the documents which are the basis for EIA development, the characteristic of sources and types of potential environmental impact, list of activity constraints, physical and geographical features of the region, characteristic of negative natural and man-made impacts on SS Rivne NPP activity.

1. BASIS FOR EIA

1.1 Information about documents which are the basis for EIA development

SS Rivne NPP is a separate subdivision (structural unit) of the State Enterprise “National Nuclear Energy Generating Company “Energoatom” (SE “NNEGC “Energoatom”). SE “NNEGC “Energoatom” operates according to its Statute and reports to the Ministry of Energy and Coal Industry of Ukraine, which forms the state policy in the industry. In compliance with the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety”, by the Resolution of the Cabinet of Ministers of Ukraine No. 1268, dated October 17, 1996 “On the establishment of National Nuclear Energy Generating Company “Energoatom”, NNEGC “Energoatom” was assigned the function of the operating organization responsible for safety of all NPP in Ukraine.

Rivne NPP is located in the Western Polissia, to the north of Rivne region, near the river Styr. In 1971 the design of West-Ukrainian NPP began, which was later renamed as Rivne NPP. The power plant is designed to cover electric loads in the western part of the country.

Rivne NPP is the first NPP in Ukraine with water-cooled water-moderated power reactors of VVER-440 type. The construction of the plant began in 1973. Two first power units with VVER-440/213 were commissioned in 1980-1981, the third power unit with VVER-1000/320 was commissioned in 1986.

The construction of the fourth power unit of Rivne NPP began in 1984, and it was planned to be commissioned in 1991. But due to the introduction of moratorium of Verkhovna Rada on the construction of nuclear facilities in Ukraine, the construction works completed to 85% were suspended.

The construction was restarted in 1993. After the moratorium was lifted the examination of power unit 4 was carried out, the program for its modernization and project completion file were prepared. On October 16, 2004 power unit 4 of RNPP was commissioned.

In recent years RNPP generates about 11-12 billion kW of electricity which is 16% of production at nuclear power plants.

The basis for the implementation of “SS Rivne NPP Environmental Impact Assessment” is:

- The energy strategy of Ukraine for the period to 2030 approved by the Resolution of the Cabinet of Ministers of Ukraine No. 1071-r, dated July 24, 2013.
- Strategic plan for State Enterprise “National Nuclear Energy Generating Company “Energoatom” development for 2017-2021.
- Convention on the Environmental Impact Assessment in a Transboundary Context ratified by the Law of Ukraine No. 534 – XIV, dated March 19, 1999.
- Minutes of the meeting of the Interdepartmental Coordination Board regarding issues on the implementation of Environmental Impact Assessment in a Transboundary Context (Espoo Convention), dated December 15, 2016.
- The Law of Ukraine “On the Environmental Impact Assessment” (Verkhovna Rada bulletin, 2017, No. 29, page 315).
- Directive 2001/42/EC of the European Government and Council, dated June 27, 2001 “On the Environmental Impact of Certain Plans and Programs” (EU Official Gazette, L 197, July 21, 2001).
- The Contract No. 347, dated March 27, 2018, “On the Implementation of SS Rivne NPP Environmental Impact Assessment”, concluded between SE “NNEGC “Energoatom”, its Separate Subdivision “Rivne NPP” and NT-Engineering LLC.

- Technical requirements to the service: “Implementation of SS Rivne NPP Environmental Impact Assessment”. 083-01-TB-COHC, approved by Chief Engineer – First Deputy Director General of SS “Rivne NPP”, dated February 06, 2018 (Appendix A).
- The Law of Ukraine “On the Environmental Impact Assessment” (Verkhovna Rada bulletin, 2017, No. 29, page 315).
- The Law of Ukraine “On the Environmental Protection” No. 1264-XII, dated July 25, 1991 [17].
- The Law of Ukraine Law of Ukraine “On Protection of Human from the Influence of Ionizing Radiation” No. 22-BP, dated September 09, 1998 [18].
- The Law of Ukraine “On the Permitting Activities in the Area of Nuclear Energy Use” No. 1370-XIV, dated January 11, 2000.
- The Law of Ukraine “On the use of Nuclear Energy and Radiation Safety” No. 39/95- BP, dated February 08,1995 [19].
- The Law of Ukraine “On the Main Principles (Strategy) of the State Environmental Policy of Ukraine for the period to 2020” No. 2818-VI, dated December 21, 2010 [20];
- The Law of Ukraine “On the Objects of Increased Hazard” No. 2245-III, dated January 18, 2001 [21].
- ДСТУ ISO 14001:2006 Environmental Management Systems. Requirements and Regulatory Principles [22].

EIA is developed in accordance with the “Recommendations on the Content of Materials for Environment Impact Assessment of Operating Facilities” [15], ДБН А.2.2-1-2003 “The structure and content of materials on the Environmental Impact Assessment during the design and construction of enterprises, buildings and structures” [16] and a Manual for the Development of Environmental Impact Assessment Materials (to ДБН А.2.2-1-2003) [23] with consideration of the requirements established in legal, regulatory, methodological and reference materials on the issues related to environmental, radiation and nuclear safety and environmental protection given in the Sections “The list of References”.

1.2 The list of sources of operating enterprise impact on the environment

The main activity of SS “Rivne NPP”, which produces electricity for the needs of consumers of national economy of Ukraine, is the electricity and heat generation. The enterprise includes such departments and production sections which have sources of releases into the atmosphere:

- Hydraulic engineering department;
- Power equipment repairing subdivision;
- Turbine department;
- Chemical department;
- Heat ventilation and air conditioning department;
- Repair and construction department.

Departments and sections are organized to ensure normal and uninterruptable operation of power units.

Rivne NPP was designed as NPP with 6 power units with total capacity of 4880 MW. At the moment SS Rivne NPP operates 4 power units which produce approximately over 18,0 billion kW of electricity per year and which capacity is increasing.

During its operation SS Rivne NPP releases the most common contaminants such as carbon monoxide, suspended solids, dioxide and other sulfur compounds, nitrogen compounds, metals and their compounds, non-methane volatile organic compounds, fluorine and its compounds, chlorine and its compounds, freons, emulsol. The potential amount of contaminants released into the atmosphere by SS Rivne NPP is 86,2 t a year.

SS Rivne NPP power units operate water-cooled water-moderated power reactors (VVER) of two types: VVER-440 and VVER-1000. Power units with VVER reactors have two circuits which are not connected to each other. NPP operation is based on the controlled chain reaction of ^{235}U nuclei fission, which is a part of nuclear fuel.

The primary circuit includes:

- Reactor,
- Steam generator,
- Main coolant pumps,
- Pressurizer,
- Main isolation valves.

All the primary equipment is installed in sealed compartments. The coolant and the neutron moderator is chemically demineralized water.

The coolant, used to remove the heat produced during uranium nuclei fission in operating reactor, is pumped through the core by main coolant pumps and transfers the heat to the secondary circuit water in the steam generators.

The reactor core is comprised of hexagonal fuel assemblies (FA) assembled from fuel rods.

A fuel rod is a rod made of zirconium alloy, filled with uranium dioxide fuel pellets (UO_2). The primary circuit water is heated up to 300°C, but it does not boil since the pressure, maintained by the pressurizers, is 12MPa for VVER-440 and 16MPa for VVER-1000.

The secondary circuit is non-radioactive, it comprises:

- Steam generators,
- Steam lines,
- Steam turbines,
- Separator-reheaters,
- Feedwater pipelines with feedwater pumps, deaerators and regenerative heaters.

Saturated steam produced in the steam generators is fed to the turbine driven by the electric generator.

Electricity produced by SS Rivne NPP is transmitted to the integrated power grid of Ukraine through the outdoor switchgears of 110, 330 and 750 kVt electric transmission lines.

The discharge of low potential steam energy is provided through the water cooling system operating in the inverse scheme. Cooling system comprises spray cooling ponds and cooling towers, natural cooling water reservoir is not available at Rivne NPP. The water from the river Styr is used to replenish the turbine condenser return cooling system.

The NPP operation inevitably goes with production of gaseous, solid and liquid products containing complex chemical and radioactive substances that are released into the environment.

The list of main sources of potential environmental impact of SS Rivne NPP includes the following:

− radiation impact sources;
− chemical impact sources;
− physical impact sources (including thermal impact).

1.3 The list and brief characteristic of the types of SS Rivne NPP impacts on the environment

The main types of possible impacts on the environment during power units operation and impacts of facilities and structures included to the technological complex located at SS Rivne NPP site, as well as other facilities within the power complex in the vicinity of the plant (sanitary protection zone, observation zone) based on the production technology are as follows:

- radiation impact;
- chemical impact;
- physical impact.

SS Rivne NPP of SE "NNEGC "Energoatom" implements the following measures to minimize environmental pollution:

- in accordance with the established procedure, the demercurization of spent fluorescent lamps, lead from used batteries, oils and other raw materials is carried out;
- the permits for storing and use of toxic substances in NPP technological process are maintained valid;
- annual receipt of limits and permits for formation and placement of non-radiation wastes, for releases of contaminants into atmosphere from stationary sources;
- primary accounting of releases, water use and wastes is carried out, as well as monitoring of the environmental impact of radiation and non-radiation factors.

1.3.1 Radiation impact

Radiation impact of the power complex is possible in connection with the release of radioactive substances produced during the NPP production cycle into environment.

Main types of the possible radiation impact are caused by:

- radioactive gaseous releases into atmosphere;
- solid radioactive wastes (SRW);
- liquid radioactive wastes (LRW).

Radioactive gaseous releases are produced due to release of radioactive gases and aerosols from liquid radioactive media. Radioactive gases are released into atmosphere under normal power unit operation by special ventilation systems through vent stacks of reactor compartments and auxiliary buildings.

Solid radioactive wastes produced during operation are collected, sorted, conditioned and temporarily stored in the solid radioactive waste storage facilities. Solid radioactive wastes are collected in the place of their formation, sorted according to the activity categories and technological properties.

By the relative activity level solid radioactive wastes are divided into three categories:

I – low-level;

II – medium-level;

III – high-level.

There is a general solid radioactive storage facility for power units 3 and 4 of SS "Rivne NPP", wastes from power units 1 and 2 are stored separately. Solid radioactive wastes are mainly generated in the form of:

- contaminated dismantled equipment;
- dismantled pipelines and valves;
- contaminated tools and devices;
- spent filters and filtering materials of special ventilation system;
- dismantled fragments of thermal insulation materials;
- immobilized liquid radioactive wastes;
- materials used for wiping;
- used overalls and additional personal protective equipment not subject to decontamination.

LRW are mainly produced in the process of water purification systems operation and contamination of oil pump systems of reactor compartment.

LRW includes:

- non-controlled primary circuit leaks;
- radiation contaminated oil;
- water used for decontamination;
- laundry and hot shower drain water;
- water from hydraulic filters;
- evaporator sludge of evaporation plants;
- spent filtering materials of water purification system filters;
- sludge.

Minimization of radioactive releases and discharges and their impact on the environment and the public is provided by the following main engineering solutions:

- decontamination of air which is removed and which contains radioactive isotopes using aerosol and iodine filters;

- decontamination of process vent on filters-absorbers, where gas is held up in order to reduce relative activity (radioactive decay of the major part of inert noble gases isotopes (xenon (Xe), Krypton (Kr);

- air releases from the premises of reactor compartment controlled access area and auxiliary building through vent stacks of 150 m high, that provides necessary dispersion of radioactive substances in atmosphere;

- establishment of barriers to prevent propagation of radioactive substances by way of the reactor compartment containment, lining of the premises with LWR sources by corrosion resistant steel;

- implementation of closed process and component cooling systems to prevent discharges of liquid substances containing radioactivity;

- implementation of special system for SRW collecting, as well as SRW and LRW storage;

- prevention of non-controlled releases and discharges;

- arrangement of NPP sanitary protection zone (CA);

- organization of continuous technological dosimetry monitoring of discharges and releases, air, soil, vegetation, water contamination monitoring in the CA and observation zone (OZ).

1.3.2 Chemical impact

Chemical impact on the elements of the environment can be made by chemical elements and substances that are part of releases and discharges. The permissible amount of harmful components contained in releases and discharges to the environment is regulated by the sanitary norms and rules depending on the degree of their impact.

During SS Rivne NPP operation the non-radioactive solid wastes are produced which can cause chemical pollution of the environment.

Waste management at SS Rivne NPP is carried out in compliance with the requirements of laws and sanitary and hygienic standards of Ukraine. Solid domestic wastes are transferred to the public utility landfill of town of Varash. In the fourth quarter of 2017, in compliance with the "Provision on the Interrelations of SS "Warehouse" with SS NPP, SS "AtomKomplekt", SS "AtomProjectEngineering" and the Directorate for Organization of Internal Inspection of SE "NNEGC "Energoatom" ПЛ-Д.0.45.551-13, the wastes of spent luminescent lamps, monitors, batteries, spent and worn buses were transferred to the specialized enterprises for further disposal through RV VP SG.

Spent oils and lubricants (motor, turbine, industrial, transformer), spent storage batteries, broken glass, waste metal and paper (except for technical documentation, accounting and other documents to be destructed) have been transferred to Rivne department of SS "Warehouse" as raw-materials. Transfer of wastes as raw-materials is carried out based on the "Provision on the Organization of Work with Raw-materials" ПЛ-Д.0.45.541-15.

The major amount of wastes produced at SS Rivne NPP is located at MVV [48], namely: at the moisture proof sludge collector and at the landfill of industrial and construction waste in designated areas. Environmental monitoring near the sludge collector and landfill of industrial and construction waste is carried out according to the approved schedule.

A number of wastes which can be categorized as "raw-materials" are temporarily stored prior to being transferred to the specialized facilities.

The sources of non-radioactive impact are both main production facilities (main building, auxiliary buildings) and auxiliary facilities and structures.

The sources of chemical impact on atmosphere under normal operation and emergency situations are gas releases during process equipment operation through the ventilation systems and smoke stacks.

It shall be noted that operation of the above mentioned installations is periodic and has almost no impact on the environment.

The main harmful elements released into atmosphere, the amount of which does not exceed the regulatory limits established for concentration and gross indicators, are: nitrogen dioxide, sulfur dioxide, carbon monoxide, soot, dust, vapors of oil products.

Chemical and chemical and biological impact on the water environment is possible due to discharges of industrial, purified domestic and rain drain water to the Styr river.

Chemical impact on soil and vegetation can take place due to precipitation of chemical elements and compounds from atmosphere.

The amount of chemical (non-radioactive) releases of harmful substances from SS Rivne NPP sources and their concentration in the atmosphere are currently limited by the following documents:

- boundary gross release – "Project standards for maximum permissible releases from stationary sources of Rivne nuclear power plant".
- concentration of harmful substances in the atmosphere – "State Sanitary Rules for Protection of Atmospheric Air of Populated Areas (from chemical and biological contamination) ДСП-201-97, approved by the Order of the Ministry of Health of Ukraine No. 201, dated July 09, 1997 and State Environmental Safety Administration in Rivne region, dated April 09, 1999.

- “The list of harmful substances released into atmosphere and those subject to monitoring in the area of environmental protection” approved by the Resolution of the Cabinet of Ministers of Ukraine No. 343, dated March 09, 1999.

Main chemical pollutants are carbon monoxide, nitrogen dioxide, hydrocarbons, sulfur dioxide, substances in the form of suspended solids. In addition, ventilation emissions can contain non-methane volatile organic compounds, gasoline, acids, hydrazine etc.

Waste water of SS Rivne NPP include:

− industrial effluents: service cooling water from auxiliary buildings equipment, unit transformer oil coolers, conditioners of training center and administrative-household complex, nitrogen-oxygen stations, automatic fire extinguishing system;
- clarifier blowdown water of water treatment facilities;
- mechanical filter wash water;
- regeneration and wash water of ion-exchange filters of chemical treatment, emergency and unit demineralization plants;
- oil-containing waste water;
- drain water;
- domestic waste water.

Discharge of industrial, drain and domestic waste water from NPP into public water bodies is not carried out.

1.3.3 Physical impact

Physical impact of SS Rivne NPP site on the environment is characterized by:

- thermal impact on the air environment associated with operation of NPP process equipment cooling systems (spray cooling ponds and cooling towers);
- increased humidity due to the evaporation of water into the atmosphere from spray cooling ponds and cooling towers;
- thermal impact on the water environment associated with the discharge of blowdown water from the main cooling system with the temperature: winter - 25°C, spring – 41 °C into the Styr river;
- impact on the water environment (the Styr river) associated with the irretrievable water consumption in the amount up to 2.0 m^3/s;
- impact of the electric field of 330/750 kVt transmission lines;
- noise during equipment operation and traffic.

The complex of planning, technical, technological (process), organizational measures and decisions regarding the limitation of negative impact is aimed at providing regulatory indicators for environmental protection.

1.4 The list of constraints (sanitary and epidemiological, environmental, city-planning and fire protection)

1.4.1 Exposure limitation for the personnel and the public

SS Rivne NPP operation is regulated by the environmental and sanitary and epidemiological constraints stipulated by regulatory documents on the environmental safety.

The boundary values of the following main criteria are established at the plant:

- Size of sanitary protection zone (CA);
- Internal and external exposure of the personnel and the public;
- Maximum boundary values of radioactive and non-radioactive substances releases and discharges into environment;
- Level of open ionizing radiation sources impact;
- Ways of disposal and storage facilities of solid and liquid wastes shall comply with regulatory requirements and approval documents.

Observation zone (OZ) is an area which can possibly be affected by NPP discharges and releases and which is subject to radiological monitoring including measurement of radionuclides content in the environmental objects, food etc.

Sanitary protection zone is an area around NPP where the level of the public exposure can exceed the dose limit quota for category C. Within the sanitary protection zone it is prohibited to live, the restrictions on production activity not related to NPP are established, and radiation monitoring is carried out [12].

The size of SS Rivne NPP SPZis 2.5 km, and OZ area is 30 km (Appendixes A and B). The size of SPZand OZ are officially introduced in accordance with SS Rivne NPP document, namely the “Decision on the size and boundaries of sanitary protection zone and observation zone of Rivne NPP” No. 132-1-Р-11-ЦРБ [26].

The boundaries of SPZand OZ are established based on the following criteria:

- Internal and external exposure of the personnel and the public;
- Maximum permissible amount of releases and discharges of radioactive substances into environment.

The boundaries of sanitary protection zones are established around each power unit. Figure 1.1 shows the boundaries of sanitary protection zones of power units 1, 2, 3, 4 and the boundary of Rivne NPP sanitary protection zone.

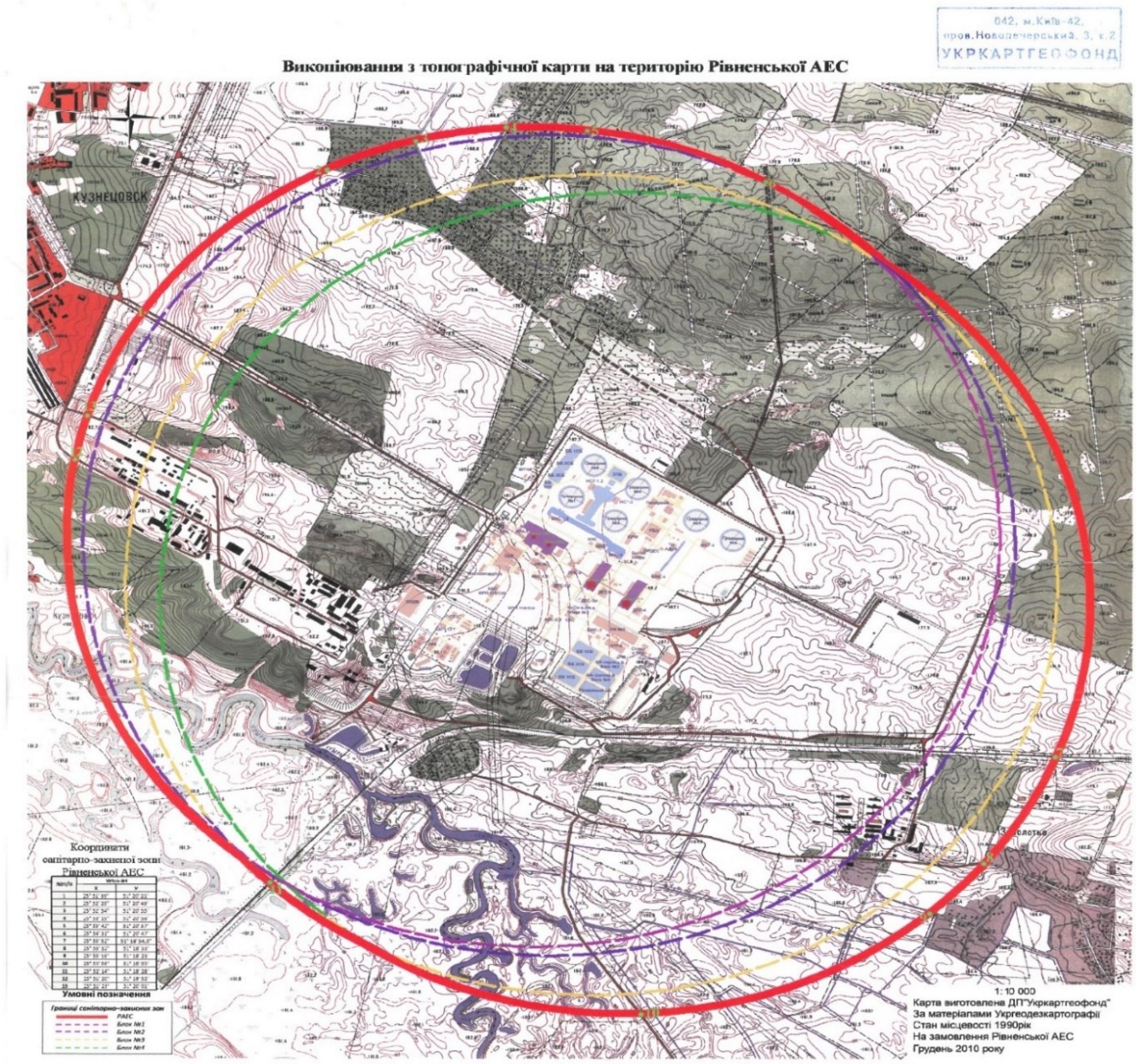


Figure 1.1. The boundary of SS”Rivne NPP” SPZand the boundaries of SPZof power units 1, 2, 3, and 4.

The main regulatory document ДГН 6.6.6-6.5.001-98 (НРБУ-97) [25] classifies the following categories of exposed individuals:

- Category A – individuals from amongst the personnel who continuously or temporarily work with ionizing radiation sources.
- Category B – individuals from amongst the personnel who are not directly engaged in work with ionizing radiation sources but due to the location of workplaces in the premises and sites of the facilities with radiation-nuclear technologies may receive additional exposure.
- Category C – all the public.

Numerical values of external exposure dose limits for a calendar year depending on the group of organs or tissues, as well as total external and internal exposure in compliance with the requirements specified in ДГН 6.6.6-6.5.001-98 (НРБУ-97) [25] are given in Table 1.1.

Table 1.1– Exposure dose limits (mSv/year).

Organs or tissues	Category of exposed individuals		
	A a)b)	B a)	C a)
Effective dose limit	20 c)	2	1
External exposure equivalent dose limits:			
- DLlens (for eye lens)	150	15	15
- DLskin (for skin)	500	50	50
- DLextrem (for hands and feet)	500	50	-
[1] On average for any consecutive 5 years, but not more than 50 mSv for a single year			

a) - the distribution of radiation dose during a calendar year is not regulated;

b) - for women of childbearing age (under 45 years of age), and for pregnant women, the restrictions in paragraph 5.4;

c) - on average for any consecutive 5 years, but not more than 50 mSv for a particular year (LD_{max}).

The list of radionuclides and the values of permissible release into atmosphere, as well as limit values of radioactive substance discharge into the river are established by the documents effective at SS “Rivne NPP”:

- Permissible radioactive gas-aerosol release of Rivne NPP (radiation hygiene regulation of Group 1) 132-2011-ДВ-ЦРБ, agreed upon by the letter of the Ministry of Health of Ukraine No. 7.03-58/56, dated February 23, 2012;
- Reference levels of gas-aerosol release and liquid discharge of SS Rivne NPP (radiation hygiene regulation of Group 1) 132-2016-КР-ЦРБ, agreed upon by the letter of the Ministry of Health of Ukraine No. 7.03-58/171-16/29017 dated November 09, 2016.

In accordance with the Main Sanitary Rules for Ensuring Radiation Safety of Ukraine (ОСПУ-2005), in order to protect the personnel from external exposure during processes under power operation and maintenance work, the design dose rates are established for all the premises of NPP controlled access area, SPZand OZ. The dose rates are given in Table 1.2.

Table 2.1. Equivalent dose rate used under the design of protection from external ionizing radiation.

Category of exposed individuals	Premises and zone designation	Exposure duration, man-year	Dose rate, µSv/year
A	Premises of permanent personnel presence.	1700	14
	Premises in which personnel is present not more than half the working time.	850	29
B	Premises, offices and SPZwhere there are individuals referred to Category B.	2000	1.2

Category of exposed individuals	Premises and zone designation	Exposure duration, man-year	Dose rate, µSv/year
	Any premises and territories within OZ.	8800	0.3

Permissible annual external exposure limits for the personnel living near NPP are regulated by the NPP sanitary rules [28]. Dose limits established by these rules for different sources and different groups of critical organs are given in Table 1.3.

Table 1.3. Annual exposure levels for the public living near NPP.

Radiation impact sources	Group of critical organs		
	I	II	III
Gas-aerosol releases	0.2	0.6	1.2
Radioactive substances with liquid discharges (impact under all types of water use: fishing, fishery, irrigation, drinking water supply etc.)	0.05	0.15	0.3
Heat supply	0.01	-	-

NPP safety systems, which ensure protection of the public during accidents, including design basis accidents with the most severe consequences, are designed so that the values of equivalent individual doses calculated for the worst weather conditions at the border of SPZand beyond it do not exceed 3 mSv/year to the thyroid gland for children due to inhalation intake and 1 mSv/year to the whole body due to external exposure [28].

According to the same document [28], daily average permissible releases of gas-aerosol radionuclides are given in Table 1.4.

Table 1.4. Permissible daily release

Nuclides	N=1000-6000 MW(el.) $\frac{\text{Ci}}{\text{day}\cdot 1000\ \text{MW(el.)}}$
Inert radioactive gas (any mixture)	500
I-131 (gas + aerosol phase)	0.01
Mixture of long-lived nuclides	0.015

Monthly average permissible releases of radioactive aerosols are given in Table 1.5 (permissible release does not refer to the sum, but to each separate nuclide). If radionuclides which are not specified in Table 1.5 are identified in NPP releases, and their value exceeds

$15\frac{mCi}{month \cdot GW(el)}$, they should be monitored.

Table 1.5. Monthly average permissible release of radioactive aerosols

Release	Radionuclide					
	^{90}Sr	^{89}Sr	^{137}Cs	^{60}Co	^{54}Mn	^{51}Cr
N=1000-6000 MW(el) $\frac{mCi}{month \cdot 1000\ MW(el.)}$	1.5	15	15	15	15	15

It is allowed to discharge radioactive waste water into the household sewage with the concentration not exceeding PC_b (permissible concentration) for water more than 10 times, provided their ten-fold dilution with non-radioactive waste water in the NPP collector. Reference release level for SS Rivne NPP is 1.5×10^{-10} Ci/dm^3.

Numerical values of permissible releases and discharges, reference and administrative and technological levels are given in Tables 1.6 and 1.7.

Table 1.6. Permissible, reference, administrative and technological release levels.

Radionuclide (group of radionuclides)	Reference, GBq/day
Long-lived radionuclides	0.37
Inert radioactive gases	67 000
Iodine radionuclides	5.5
^{51}Cr	620
^{54}Mn	3.0
^{59}Fe	9.9
^{58}Co	9.4
^{60}Co	0.17
^{89}Sr	23
^{90}Sr	0.48
^{95}Zr	13
^{95}Nb	25
^{110m}Ag	0.49
^{134}Cs	0.40
^{137}Cs	0.35
^{3}H	930

Table 1.7. Permissible, reference, administrative and technological release levels.

Radionuclide (group of radionuclides)	Reference, GBq/day
^{3}H	2 400 000
^{51}Cr	53 000
^{54}Mn	490
^{59}Fe	290
^{58}Co	450
^{60}Co	52
^{65}Zn	270
^{89}Sr	6 700
^{90}Sr	130
^{95}Zr	200
^{95}Nb	2 600
^{106}Ru	840
^{110m}Ag	2 900
^{131}I	1 200
^{134}Cs	57
^{137}Cs	83
^{144}Ce	310

In accordance with the requirements specified in ДГН 6.6.6-6.5.001-98 [25], in order to maintain the achieved level of radiation safety the reference levels are established for radiation-nuclear facility, the settlement and environment based on the information about the radiological situation for certain premises of the facility, CA, OZ and other facilities to plan protective measures and on-line radiological situation monitoring. The reference levels are established by the administration of radiation-nuclear facility with mandatory endorsement with the State Regulatory Authority.

In addition to the NPP current reference levels of gas-aerosol releases and radioactive water discharges into environment, the operating organization, in order to identify the causes of non-controlled increase of NPP release and discharge values, establishes administrative and technological levels which are basically research levels. Exceeding of administrative and technological levels is not categorized as a violation of codes and standards effective at NPP, and does not require reporting to the State Regulatory Authority. Maintaining the administrative and technological levels contributes to the optimization of technological processes, development of organizational and technical measures aimed at reduction of levels of NPP gas-aerosol releases and water discharges into the environment, as well as preventing the plant from achieving the established reference levels of radioactive releases and discharges.

Regulation and control of the public exposure (Category C) is carried out based on the calculations of annual effective and equivalent exposure doses of critical groups. The dose limit quota of population exposure is set for the corresponding radiation-nuclear facilities. Based on the dose limit quota the permissible releases and permissible discharges are established for each facility. The dose limit quota for releases and discharges for NPP are given in Table 1.8.

Table 1.8. Dose limit quotas used to establish permissible discharge and permissible release.

Radiation-nuclear facility	Releases: quota DL_E for all ways of dose formation		Discharges: quota DL_E for critical type of water use		Total quota DL_E for air and water ways of dose formation	
	%	μSv	%	μSv	%	μSv
NPP, NHPP, NHP	4	40	1	10	8	80

The limits of radionuclides intake through inhalation (ID^{inhal}) (Intake Dose) and digestion (ID^{ingest}), as well as the limits of radionuclide concentration in the air (CD^{inhal}) (Concentration Dose) and drinking water (CD^{ingest}) are established for the public (Category C). Numerical values of the permissible levels in case of impact of single exposure type, single radionuclide and single exposure type under corresponding reference exposure conditions are given in Table 1.9.

Table 1.9. Permissible levels of radionuclides intake through inhalation and digestion and concentration in the air and water for Category C.

Radionuclide	ID^{inhal}, Bq/year	ID^{ingest}, Bq/year	CD^{inhal}, Bq/m^3	CD^{ingest}, Bq/m^3
^{54}Mn	$4×10^4$	$2×10^5$	20	$8×10^5$
^{58}Co	$3×10^4$	$3×10^4$	10	$6×10^5$
^{60}Co	$3×10^3$	$1×10^5$	1	$8×10^4$
^{90}Sr	$6×10^2$	$4×10^3$	0.2	$1×10^4$
^{110}Ag	$5×10^3$	$4×10^4$	2	$2×10^5$
^{131}I	$8×10^3$	$6×10^3$	4	$2×10^4$
^{134}Cs	$3×10^3$	$4×10^4$	1	$7×10^4$
^{137}Cs	$2×10^3$	$5×10^4$	0.8	$1×10^5$
^{3}H	$2×10^5$	$8×10^6$	100	$3×10^7$

During the period from 2004 to 2017 permissible release and permissible discharge at SS Rivne NPP was regulated in accordance with the documents establishing the limits of releases and discharges (DR_i and DD_i) (design release, design discharge) of the main dose forming radionuclides under normal operation. The norms of permissible release and discharge at SS Rivne NPP were revised 2 times during the specified period.

At present the release (DR_i) limits of main dose forming radionuclides under normal operation have been established at SS «Rivne NPP" and agreed with the Ministry of Health of Ukraine (February 23, 2012). The values are given in Table 1.6.

The permissible release/discharge reflects the requirements to NPP operation in terms of radiation protection of the public under the conditions of local natural ecological system. DR_i and DD_i values do not depend on the number of power units in operation. Exceeding of the permissible release/discharge under normal NPP is not allowed.

In accordance with the "Permissible radioactive water discharge of SS Rivne NPP (Radiation and Hygiene Regulation of Group 1) 132-2011-КУ-ЦРБ" the limits of discharge DD_i (the permissible boundary amount of radioactive substances the discharge of which into the environment is acceptable with water discharges of SS "Rivne NPP") of main dose forming radionuclides under normal operation have been currently established and agreed with the Ministry of Health of Ukraine (February 23, 2012). The values are given in Table 1.7. The permissible discharge reflects the requirements to NPP operation in terms of radiation protection of the public under the conditions of local natural ecological system. DD_i value does not depend on the number of power units in operation.

Exceeding of the permissible discharge under NPP normal operation is not allowed.

In accordance with the requirements [25] the reference levels of gas-aerosol releases and radioactive liquid discharges are established for SS "Rivne NPP".

The reference level values of SS Rivne NPP gas-aerosol releases and water discharges, agreed upon with the Deputy Minister of the Ministry of Health of Ukraine, dated May 13, 2013, are given in Table 1.10 and Table 1.11.

Table 1.10. Reference levels of gas-aerosol releases

Radionuclide group	Reference level, MBq/day
Long-lived radionuclide mixture	9.0
Inert radioactive gases	8.7×10^5
Iodine radionuclides	40
Radionuclides	Reference level, MBq/month
^{60}Co	35
^{134}Cs	48
^{137}Cs	42
^{3}H	5.2×10^5

Table 1.11. Reference levels of radioactive liquid discharges

Radionuclides	Reference level, MBq/year
^{3}H	$5{,}6\times10^6$
^{60}Co	18
^{90}Sr	64
^{134}Cs	20
^{137}Cs	240
^{144}Ce	110

1.4.2 Sanitary protection zone

The sanitary protection zone is established around a radiation-nuclear facility. The criterion for establishing the sanitary protection zone is the limits of the annual intake of radioactive substances through the respiratory and digestive organs and the limits for external exposure doses of the personnel and the public, as well as the permissible concentration of radioactive substances in the atmosphere and water.

The size of the sanitary protection zone is determined taking into account the radiological assessments in the NPP location area during its long-term operation.

The sanitary protection zone performs important functions regarding radiation protection of the public from the effects of nuclear installation both under normal operation and under conditions of radiation accidents. The sanitary protection zone is a territory around nuclear installation and facilities for radiation waste management where the exposure level under normal operation may exceed dose limit quota for the public.

The size of the sanitary protection zone is determined so that under normal operation, abnormal operation and decommissioning of NPP the dose limit quota for the public does not exceed the values established in par 5.5.4 НРБУ-97 [25], which are 80 μSv/year for releases into the atmosphere and 40 μSv/year for liquid discharges, beyond its borders. The quota value is approximately ten times less than the dose received by the public from natural sources.

The design and construction of SS Rivne NPP power units was carried out in compliance with regulatory documents effective at the time of design. Initially the sanitary protection zone was established with 3 km radius.

However, in the future, considering the fact that the area size shall be refined taking into account the wind rose of the dominant directions, the calculations were carried out and upon the agreement with the USSR Chief Sanitary Doctor V.D. Turovsky (letter No. 32-014/324, dated August 1984) the size of the sanitary protection zone for SS Rivne NPP was established with 2.5 km radius.

In compliance with the calculations of emergency exposure doses of the public under the maximum design basis accident, made by Kurchatov Institute of Atomic Energy for power units 1-3 and All-Russian Research Institute for Nuclear Power Plant Operation for power unit 4 in 1989, the size of the sanitary protection zone with 2.5 km radius was confirmed.

According to these calculations the thyroid dose of children under DBA at a distance of 2.5 km did not exceed 6.5 rem for VVER-440 and 1 rem for VVER-1000, where the permissible value is 30 rem.

The SPZis one of the most effective tools for initial protection of the public under the conditions of radiation accidents by means of dispersion and dilution of radioactive releases. Besides, the SPZprovides additional time to alert the population and to take urgent countermeasures (for example, evacuation or iodine prophylaxis).

The size of the SPZis established so that during DBA the exposure doses to the public at the boundary and beyond the SPZdo not exceed the criteria for introducing countermeasures, in accordance with par 7.38 НРБУ-97 [24].

In compliance with НРБУ-97 [24] put into force on January 01, 1998, the size of the SPZis limited to the territory where the level of exposure under normal operation may exceed the dose limit quota for Category C (all the public) individuals exposed to radiation.

It was calculated that even under DBA and continuous living on the border of the SPZ (2.5 km from affected power unit) during 70 years the estimated exposure dose from power unit releases is about 3 mSv.

At present the public does not live within the CA, and there are no enterprises, structures etc. that are not related to NPP. Only buildings and structures of the subsidiary farms and NPP service facilities are located within the CA.

The radiation monitoring is carried out in the CA.

The legal status for establishing and functioning of the NPP sanitary protection zone is regulated by the Law of Ukraine “On the Use of Nuclear Energy and Radiation Protection” [20] and the Law of Ukraine “On Lands for Energy Facilities and the Legal Regime of Special Areas for Energy Facilities” [159].

In accordance with Article 45 of the Law of Ukraine “On the Use of Nuclear Energy and Radiation Protection” [20], a special regime is established at the locations of nuclear installations and facilities for radioactive waste management:

- in the locations of nuclear installation or facilities for radioactive waste management the sanitary protection zone and observation zone are established;

- it is prohibited to live in the sanitary protection zone, the restrictions for production activity not related to the nuclear installation or facilities for radioactive waste management are established, and radiation monitoring is carried out;

- in the SPZit is prohibited to locate residential and public buildings, children’s and medical and health institutions, and industrial enterprises, public catering facilities, auxiliary and other structures not related with the operation of nuclear installation or a facility for radioactive waste management;

- use of the lands and water bodies located in the SPZfor agricultural purposes is possible only with the permission of the regulatory body for nuclear and radiation safety in coordination with the operating organization, under condition of mandatory radiological control of the manufactured products.

Pursuant to the requirements of Article 25 of the Law of Ukraine “On Lands for Energy Facilities and the Legal Regime of Special Areas for Energy Facilities” [159], observation of the established limits in the use of lands within the special territories is the responsibility of all owners and users of the land plots, local executive authorities and local governments, enterprises operating energy facilities.

State Nuclear Regulatory Inspectorate of Ukraine by the Order No. 8, dated January 16, 2012 approved the “Procedure for issuing permits for the use of lands and water bodies located in the sanitary protection zone of a nuclear installation, a facility for radioactive waste management, a uranium facility” НП 306.4.181-2012. The Procedure is approved in order to ensure the effectiveness of the state regulation in the field of the use of nuclear energy.

The permission for the use of lands and water bodies located in the SPZof a nuclear installation, a facility for radioactive waste management, a uranium facility is issued to legal entities or individuals-entrepreneurs intended to use lands, water bodies located in the SPZof a nuclear installation to accommodate industrial enterprises, catering, auxiliary and other structures related to the activity of the nuclear installation. Economic activity without permission is prohibited. Payment for the permission is not charged.

To obtain the permit a legal or natural entity who has an intention to use lands, water bodies, located in the SPZof the nuclear installation submits an application to SNRIU for issuing a permit in the established form and documents according to the established list.

The procedure for the approval by the operating organization is determined by the “Provision on the Procedure for Approval by the Operating Organization of the Intention to Use Lands and Water Bodies of the Sanitary protection zones of NPP of SE “NNEGC “Energoatom” for National Economic Purposes” ПЛ-Д.0.28.597-13.

The SS Rivne NPP SPZis a geometric combination of four circles of 2.5 km radius around each power unit (Figure 1). The observation zone is a circle of 30 km radius with a center at the location of NPP.

Within the boundaries of SPZand OZ the radiation is monitored within the "Radiation Monitoring Regulation", approved by the State Chief Sanitary Doctor of the facility and the State Nuclear Regulatory Inspectorate of Ukraine. In accordance with the Regulation about 2500 environmental samples are taken and measured during each calendar year.

1.4.3 Observation zone

The observation zone comprises territory which is likely to be effected by radioactive releases and discharges from radiation-nuclear facility (NPP) and where the monitoring is carried out.

In accordance with [26] under normal operation of the facility, as a rule, the OZ shall be 3-4 times bigger than the SPZ, however no restrictions on using the territory near the OZ are established.

Currently the observation zone for SS Rivne NPP is established with the radius of 30 km [25, 45].

The radiation monitoring in the OZ is performed in compliance with the "Regulation on the Radiation Monitoring of Rivne NPP" 132-1-Р-ЦРБ [46], approved by the First Vice-President – Technical Director of SE "NNEGC "Energoatom", dated February 02, 2016, endorsed by a letter of SNRIU No. 15-28/7070, dated October 25, 2016, coordinated by the Head of Varash Interdistrict Department of the State Institution "Rivne Regional Laboratory Center of the Sate Sanitary and Epidemiological Service of Ukraine", dated July 08, 2016, and the Director General of SS "Rivne NPP", dated July 05, 2016.

In addition to laboratory monitoring of Rivne NPP radiation impact on the environment and the public, the continuous monitoring has been carried out since April 2007 using the Automated Radiation Monitoring System.

Within the boundaries of the SPZ and OZ 13 monitoring points of the Automated Radiation Monitoring System has been installed.

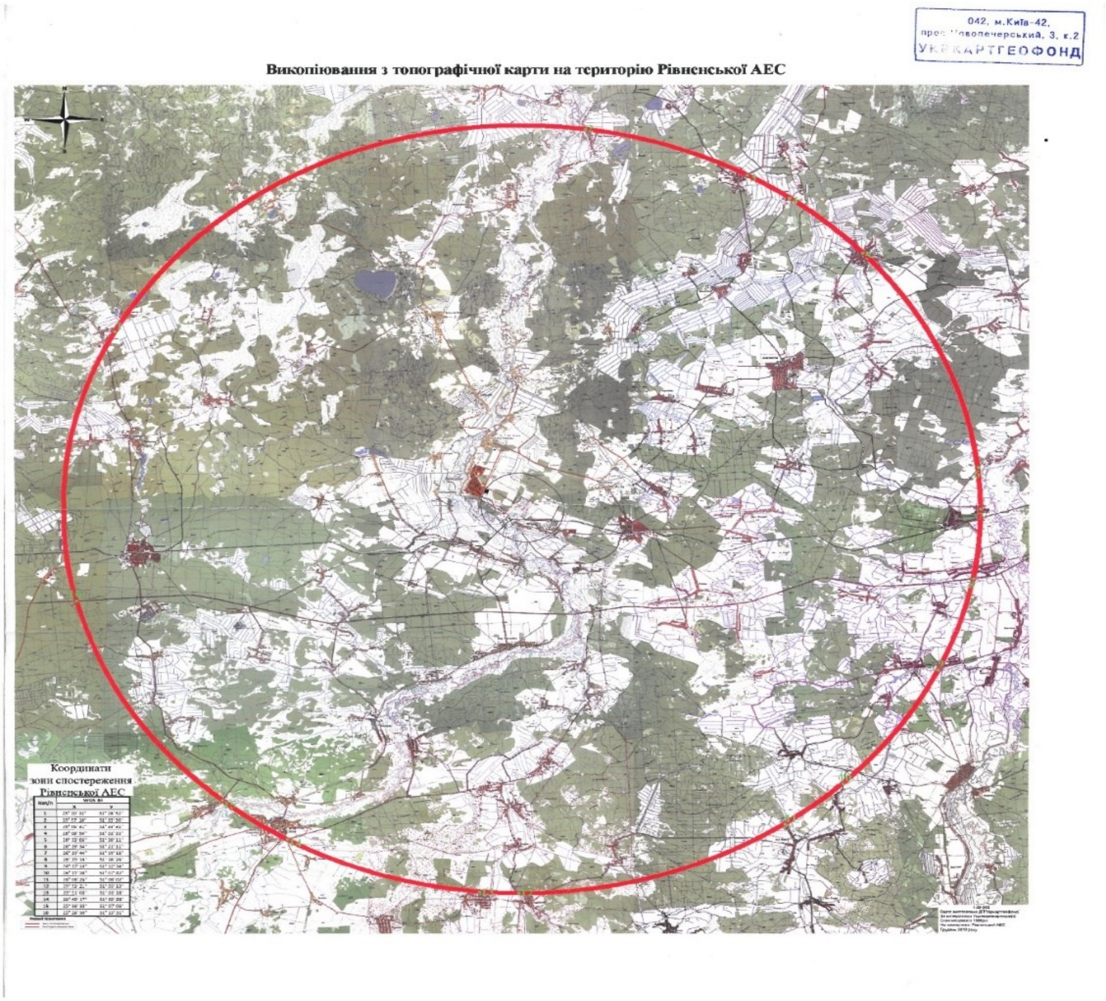


Figure 1.2. The observation zone of SS Rivne NPP

1.4.4 Water use

SS Rivne NPP comprising 4 power units (two VVER-440 and VVER-1000) obtained an approval for increasing the maximum water intake from the Styr river up to 2.32 m^3 per second (Ministry of Land Reclamation and Water Management of Ukraine No. 21/5-547, dated October 25, 1983, minutes of the meeting with Deputy Chairman of the Council of Ministers of Ukraine, dated September 07,1989, by the letter of the State Committee of Nature Protection No. 8-4-6-291, dated July 12, 1990).

Water use at SS Rivne NPP [46] is carried out in accordance with the permit for special water use УКР № 1/Рвн, dated August 06, 2015 (valid till August 06, 2020).

The limit of water intake from the river is 73,164 thousand m^3/year (267.840 thousand m^3/day), from subsurface horizons is 3,386 thousand m^3/year (9,277.0 m^3/day).

Water is supplied from the Styr river to SS Rivne NPP for feeding closed-circuit systems and other technical needs.

Domestic-drinking water is supplied from water intake of the village of Ostriv, deposit "Rafalivske-1". The water intake includes 9 artesian wells.

The industrial-rain waste water from the NPP site is discharged to the Styr river by means of free-flow collector through one outlet as clean within the tolerance range water.

1.4.5 City-planning and fire protection constraints

Due to the fact that the development of SS Rivne NPP industrial complex is envisaged through the reconstruction and modernization of the existing production units which functionally fit into the existing NPP infrastructure solely within its territory, city planning restrictions are not considered.

Fire safety is provided through the fulfillment of legislative requirements of laws and regulations [27-34] during the operation and reconstruction period, as well as the construction of new facilities of SS Rivne NPP industrial complex, namely due to the existing controlled gaps between buildings and structures, fire extinguishing systems, road construction etc.

Fire protection aspects reflect all aspects of fire safety:

– purpose and functions of a fire safety system;

– fire protection decisions on the master plan;

– fire safety classification of building and structures;

– space-planning solutions, fire barriers, fire protection of engineering structures and main provisions for the selection of fire extinguishing materials;

– evacuation routes and exits, access routes and ensuring safety of engineering units;

– measures on fire protection of technological processes;

– measures on fire protection of electrical installations;

– measures on fire protection of ventilation systems;

– fire protection systems: fire protection water supply, fire alarm, fire extinguishing, smoke protection, fire alarm and evacuation control, lightning protection and grounding;

– primary fire extinguishing equipment.

1.5 Information on EIA executor and the list of subcontractors

The Customer is Separate Subdivision "Rivne NPP" of the State Enterprise "National Nuclear Energy Generating Company "Energoatom" (Ukraine, Rivne region, town of Varash, 34403).

The Executor is Limited Liability Company "NT-Engineering" (Ukraine, Kyiv oblast, Kyiv, 6-b Staronavodnytska street, office 272).

The Co-Executor of EIA is Scientific Research Institution "Ukrainian Research Institute for Environmental Problems" (61166, Ukraine, Kharkiv, 6 Bakulin street).

1.6 The list and brief analysis of previous approvals and expert reviews including public expertise

The Act of site selection for Rivne NPP construction at the Rafalivsky point near Rafalivka station of Kyiv-Kovel railway, agreed by all interested Ministers and Agencies, was approved by the Resolution of the Central Committee of the Communist Party of Ukraine and the Council of Ministers of Ukrainian SSR No. 492, dated September 24, 1958.

NPP site is situated in Volodymyretsky district of Rivne region on the right bank of the Styr river.

The distance from Rivne NPP site to Kyiv is 322 km, to the state border of the Republic of Belarus is 60 km, to the Republic of Poland is 133 km, and to other far-abroad countries is 150 km.

Feasibility Study of the first line of NPP construction was approved by the decision of the Scientific and Technical Council of the Ministry of Energy of the USSR No. 35, dated June 05, 1968, technical design was approved by the Resolution of the Council of Ministers of the USSR No. 2394-P, dated November 11, 1973, and updated design was approved by the Order of the Ministry of Energy of the USSR No. 279ПС, dated December 27, 1984. The first line of NPP includes two power units with VVER-440 and one power unit with VVER-1000.

The construction of SS Rivne NPP has been carried out since 1974. Power unit 1 was commissioned in 1980, power unit 2 – in 1981, and power unit 3 – in 1986.

Kyiv department of the "Atomenergoproekt" Institute performed Feasibility Analysis for the reconstruction of Rivne NPP power units 1 and 2. The feasibility analysis includes measures to improve reliability and safety level, taking into account operating experience of similar power units.

The list of consolidated measure to improve reliability and safety of operating power units and those under constructions at the plants with VVER was agreed by the USSR State Committee for the Supervision of State Work in the Nuclear Power Industry, dated July 03, 1987, and approved by the Ministry of Atomic Energy of the USSR and the Ministry of Medium Machine Building of the USSR by the decisions MBTC-84 and MBTC-87, dated July 02, 1987, and Interdepartmental Coordination Group.

The Feasibility Analysis was reviewed and approved by the Main Scientific and Technical Directorate of the Ministry of Energy of the USSR (Conclusion No. 5-23-3/20-20, dated September 08, 1989). The measures provided for in the Feasibility Analysis were implemented at the operating power units 1 and 2.

The Feasibility Study for NPP expansion (the second line of construction) to 3000 MW and NPP power uprate up to 4880 MW was developed by the Ural branch of the "Teploelektroproekt" Institute, reviewed and approved by the Scientific and Technical Council and the Examination Department for Projects and Budget Estimates of the Ministry of Energy of the USSR (minutes No. 95, dated September 11, 1979), reviewed by the Main Directorate of State Expertise Review of the State Building Committee of the USSR (No. АБ-4974-20/4, dated September 29, 1980), approved by the Order of the Ministry of Energy of the USSR No. 155ПС, dated November 03, 1980.

When developing the Feasibility Study for NPP power uprate up of 4880 MW the Act of the construction site selection was issued and then approved by the Ministry of Energy of the USSR on June 26, 1981.

The Feasibility Study and the Act of site selection provided for the creation of an off-channel reservoir for the needs of NPP service water supply.

Based on the approved Feasibility Study the development of NPP expansion project began.

However, during the development of the NPP expansion project the detailed study of the engineering and geological conditions of the territory of the planned construction showed that specified territory was characterized by the occurrence of suffusion-karst processes.

Due to the revealed adverse soil conditions the issue regarding the NPP expansion was reviewed by:

- the Commission established by the Order of the Council of Ministers of the USSR No. 508p, dated March 21, 1983;
- the joint Scientific and Technical Council of the State Building Committee of the USSR and the Ministry of Energy of the USSR (minutes No. 1, dated April 11, 1983);
- the Interdepartmental Technical Council on NPP issues (decision No. ЭН-2108, dated August 23, 1983).

In response to the decision of the Commission, established by the Order of the Council of Ministers of the USSR, to refuse the construction of power units 5 and 6 due to the fact that it was impossible to create an off-channel reservoir at the karsted territory (par 2.1 of the Minutes, dated March 22, 1983), the Ministry of Energy of the USSR by the Order No. Ш-14913, dated November 17, 1983, suspended the development of the project to expand Rivne NPP to three power units of 1000 MW each.

In accordance with the decision of the mentioned Commission and the requirements of the USSR State Planning Committee No. 22-1608, dated November 01, 1983, the Kyiv branch of the "Atomteploelectroproekt" Institute elaborated the "Main design solutions of Rivne NPP design (the second line) if expanded to one power unit of 1000 MW", which was considered as substantiation materials for construction of power unit 4.

As a result of the performed work the substantiation materials "Main design solutions of Rivne NPP design (the second line) if expanded to one power unit of 1000 MW" were elaborated and reviewed by the Scientific and Technical Council and the Examination Department for Projects and Budget Estimates of the Ministry of Energy of the USSR (minutes No. 93/Э-197, dated December 18, 1984), agreed by: the USSR State Nuclear Safety Inspectorate (letter No. 5-526, dated March 29, 1985), State Committee on Hydrometeorology and Environmental Control of the USSR (letter No. 22-634, dated February 12, 1985) and approved by the Order of the Ministry of Energy of the USSR, dated June 17, 1985.

Based on the "Main Design Solutions" the project on expansion of the Rivne NPP second line (power unit 4) was implemented, which was approved by the Order of the Ministry of Energy of the USSR No. 166ПС-ДСП, dated June 25, 1986.

The construction of the second line of NPP started in 1986. However, due to the insufficient funding, 1990 moratorium on the construction of nuclear power units in Ukraine, the construction of the fourth power unit took a sufficient period of time.

By the Decree of the Verkhovna Rada of Ukraine No. 3538-XII of October 21, 1993 "On some measures to provide the national economy with electricity", the 1990 moratorium on the construction of nuclear power plants in Ukraine was lifted. After that, the Ukrainian Government confirmed its intentions to complete the construction of Khmelnitsky NPP power unit 2 and Rivne NPP power unit 4, and perform their modernization to improve safety and reliability in order to ensure compliance with the new national standards and international practice.

On December 20, 1995 the Ukrainian Government and the G-7 countries signed a Memorandum of Understanding providing loans to finance the project, the implementation of which will compensate the decrease in electricity production in case of Chernobyl NPP decommissioning.

Taking into account the general state of energy development in Ukraine, the necessity to commission new power capacities and economic feasibility, the Cabinet of Ministers of Ukraine adopted Resolution No. 1323, dated November 28, 1997, "On financial support of the construction of Khmelnytsky NPP unit 2 and Rivne NPP unit 4".

Specified documents are the basis to continue the construction of Rivne NPP unit 4.

At all phases of Rivne NPP construction the corresponding approvals and expert reviews were carried out, during which the special attention was paid to the environmental issues:

- the Act of site selection for NPP expansion up to the boundary capacity, dated December 02, 1977, contained the proposal to take measures to exclude the possibility of flooding the surrounding territory with an off-channel reservoir, including the city of Kuznetsovsk (now Varash) and the cotton plant planned for construction;

- when reviewing the Feasibility Study of Rivne NPP expansion, the Rivne region Executive Committee (minutes, dated January 27, 1988) added a statement regarding the expansion of the sewage treatment plants for the full development of Kuznetsovsk and provide for the maximum reduction of additional arable lands during the construction of power units 5 and 6;

- during the development of the project on NPP expansion to the boundary capacity the detailed study of engineering and geological and hydrogeological conditions of the territory planned for construction was carried out. The results of this study showed that specified territory is characterized by the occurrence of suffusion-karst processes due to which it was found impossible to create a cooling reservoir both near the NPP and at an economically acceptable distance from it. Under the terms, agreed by the Ministry of Water Management of the Ukrainian SSR (No. 21/5-547, dated October 25, 1983), the expansion of Rivne NPP to more than three power units of the first line is possible to only one power unit 4 of 1000 MW with water intake from the Styr river in the amount of 0.32 m^3/s (in addition to the previously agreed water intake of 2 m^3/s) for irretrievable water consumption and for the reconstruction of the Khrennikovske reservoir;

- the substantiation materials for NPP expansion to one power unit presented six options to found the main building, taking into account physical and mechanical properties of soils, it was recommended to use bored piles with a diameter of 1.2 m and a length of about 34 m resting on basalt rocks. For other buildings and structures the foundation is to be made of continuous plates and tapes;

- in order to stabilize the bearing capacity of sandy soils the attention was paid to the necessity of taking radical measures to prevent the site flooding (replacement of the open hydraulic channels with closed pipes, heavy-duty waterproofing of the spray cooling ponds, cooling towers and vent chambers, pump stations, asphalting of the territories near the cooling towers etc.), the cretaceous layer under main buildings and structures without pile foundation shall be cemented;

In order to protect the environment the following recommendations were incorporated in the design specification for NPP expansion to one power unit:

a) to reduce the contamination of the Styr river with waste water from the second line of NPP the following design solutions shall be taken:

- industrial oily water waste shall be transferred to the wastewater treatment plants of the first line of NPP;

- rain water runoff after local treatment shall be used in the service water supply system;

- radioactive sewage discharges shall be treated at the special water purification plants and returned to the technological cycle;

- liquid radioactive wastes shall be treated at the solidification plant to ensure safe transportation and storage at the regional storage facility;

б) to reduce possible radioactive contamination of air and environment the following measures shall be envisaged:

- ventilation air removed from the controlled access area premises shall be cleaned, if necessary, using aerosol and iodine filters;
- swept-off gas from process equipment is subject to purification;
- ventilation air removed from the controlled access area premises shall be removed into atmosphere through the vent stacks.

During the expert review of the project of NPP expansion to one power unit the “Atomteploelektroproekt” Institute (Decision No. 28, dated May 28, 1984), the Scientific and Technical Council and the Examination Department for Projects and Budget Estimates (minutes No. 93/9-197, dated December 18, 1984) provided the following recommendations:

а) to refuse the construction of drainage channel under the reactor compartment, to provide for crushed stone filtering layer 0.5-0.6 m thick of bed drainage type;

б) to improve turbine compartment ventilation system to ensure normal air parameters;

в) to provide necessary personal protection equipment for maintenance personnel to prevent adverse impact of ionizing radiation of gases and aerosols, and necessary tooling and equipment to prevent radioactive contamination propagation during maintenance;

г) to provide necessary tooling for metal decontamination during maintenance.

After lifting of moratorium on the construction of power units in Ukraine, the international organizations performed the following:

- Environmental Impact Assessment (EIA) of the completion of SS Rivne NPP unit 4 construction (Muschel);
- analysis of options for the development of electric power industry of Ukraine under the cost minimization scheme (Stone and Webster);
- final safety assessment report to solve a loan issue (Ryskaudyt).

Below is a brief description of the research findings.

In accordance with the European Bank for Reconstruction and Development (EBRD) task, the European Commission in association with Consulting Company Muschel performed the “Environmental Impact Assessment of the project of the completion of Rivne NPP unit 4 construction”.

The report contains an assessment of the NPP operating part impact on the environment and radiological situation, as well as the impact occurring during future completion of unit 4 construction. As a result of the performed work the following conclusions were made:

- the NPP impact on the environment, taking into account the expansion, under normal operation will be very insignificant, the impact resulted from design basis and beyond design basis accidents will also be unremarkable;
- impacts related to discharges to water systems will be insignificant compared with the regulatory levels applicable to the public;
- to improve radiation monitoring within the NPP 30 km zone paying special attention to the accounting of releases and adverse impact of low-energy β-radiation sources, such as ^{3}H and ^{14}C;
- to perform necessary analysis of changes in the amount of heat released into the environment and the time, and take into account its effect on the dispersion and precipitation of substances in the form of aerosols during formation of clouds and fogs;
- it is necessary to develop national long-term program of radioactive waste management;

In accordance with the EBRD task, in 1998 Stone and Webster (USA) reviewed 27 main scenarios of the development of electric power industry of Ukraine under the cost minimization scheme taking into account the completion of Khmelnytsky NPP unit 2 and Rivne NPP unit 4 construction and came to the following conclusions:

- The completion of two power units construction in 2000 with a high probability corresponds to the goal and programs of development of energy industry in Ukraine under the cost minimization scheme;
- The considered options to refuse the construction of two power units are characterized by higher costs compared with the options to complete power units construction according to the schedule providing for cost minimization. Medium economic risk in case of refusal the construction is USD 322 million;
- The decision regarding the completion of Khmelnytsky NPP unit 2 and Rivne NPP unit 4 construction in 2000 is characterized by the greatest economic advantages compared with other options;
- Among 27 considered scenarios, 15 showed that if the construction of two power units is completed in 2002, there will be either no economic risk or it will be negligible.

Within the implementation of technical support program for SIC countries Ryskaudyt, acting as a consultant to the Consortium of European Technical Safety Organizations, performed the expert review of the Modernization program for VVER-1000 KhNPP-2 and RNPP-4 and related to it “industry” and “operational” programs.

Upon the results the “Final Safety Assessment Report for the Loan Issue” was issued. This report contained the conclusions that if all the recommendations provided by Ryskaudyt were fulfilled and all proposed and recommended measures were taken:

- NPP design, administration and operation would comply with all the fundamental principles specified in IAEA documents;
- Each level of multilevel protection system would be significantly improved;
- Modernized NPP could be compared with the European standards and acceptable operating experience in terms of safety level from both design and operational point of view;
- Proposed measures specified in the Program together with those of Ryskaudyt are considered complete and sufficient to eliminated internationally acknowledged safety deficiencies of similar NPP;
- The schedule of measure implementation is acceptable in terms of safety assurance;
- During the implementation of the Modernization program and elimination weaknesses, revealed in the expert review process, the NPP safety level would be achieved as at the European NPP of the corresponding generation.

However, the mentioned documents including economic expert reviews and assessments of power unit 4 impact on the environment do not fully comply with the requirements of ДБН А.2.2-1-2003 [16] in terms of structure and content, and cannot be used as a basis for the “Statement on Ecological Consequences of NPP Construction and Operation”. The Statement is a legal document regarding the nature of ecological consequences and guarantees of implementing the measures on environmental safety assurance for the whole period of NPP operation, and one of the main documents based on which the Regulatory Authorities grant the operating license.

In connection to this, the Customer, SE “NNEGC “Energoatom”, made a decision to develop EIA. To implement the decision the Customer represented by SS Rivne NPP prepared Technical Requirements for rendering the service: “Environmental Impact Assessment of SS Rivne NPP 083-01-ТВ-СОНС (ТВ) approved by Chief Engineer – First Deputy Director General of SS “Rivne NPP”, dated February 06, 2018 (Appendix A)

1.6.1 Ukrainian Legislation

SS Rivne NPP gas been in operation since 1980.

Free access to the information regarding the environmental state, participation of the public and public associations in the public hearings, participation of the public in the environmental expert review is guaranteed by the Constitution of Ukraine (Articles 2, 34 and 35) and a number of Ukrainian laws:

- "On the Information" (Articles: 2, 5, 6, 9, 10, 25, 31, 33 i 44) [35];
- "On the print media in Ukraine" (Articles 2, 34 i 35) [36];
- "On the Use of Nuclear Energy and Radiation Safety" (Articles: 3, 5, 6, 8, 10, 11, 20, 24, 37, 47 i 81) [19];
- "On the Environmental Protection" (Articles: 3, 9, 10, 11, 15, 19, 21, 25 i 30) [17];
- "On Radioactive Waste Management" (Articles 8, 22 i 29) [37], and
- "On the City Government" [38];
- "On the Public Association" [39];
- "On the Property" [40];
- "On the entrepreneurship" [41];
- "On Appeal of Citizens" [42];
- "On State Secrets" [43], and the law of Ukraine "On Ratification of the Convention on Access to Information, Participation of the Public in Decision-making and Access to Justice in Environmental Matters" No. 832-14, dated July 06, 1999 [44].

In order to involve the public and public associations to participate in the review of the issues related to the use of nuclear energy, the local administration and local government may organize the public hearings regarding critical design review related to location, construction, decommissioning of nuclear installations and facilities for radioactive waste management.

During public hearings both the materials provided by the Customer and the results of the public and state expert reviews are discussed.

The participation of the public in the environmental impact assessment can be carried out by making statements in the mass media, providing written comments, proposals and recommendations, including the public representatives to the expert commissions, groups on the environmental impact assessment. Preparation of the environmental impact assessment conclusions and decision making regarding further implementation (usage, application, operation etc.) of the facility under environmental impact assessment is carried out with consideration of the public opinion.

Thus the local public's attitude can be formed in the process of environmental impact assessment and during the public hearings of the materials of EIA "SS Rivne NPP Environmental Impact Assessment".

1.7 Information on the attityde of the public and other stakeholders to the planned activity and related problems that need to be addressed

Quick provision of the information to the public on the events at SS Rivne NPP and formation of positive attitude to nuclear energy is carried out by the Department of the Information and Public Relations. In accordance with Article 10 and 11 of the law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" [19] this task is carried out by the press-center, public relations department, editors and radio and television broadcasting, and by the local newspaper "Energia", included into the management structure.

Information Center of SS Rivne NPP is located at:
5 Nezalezhnocti Square, Varash, 34400, Rivne region,
e-mail:informsentr@mail.ua, official site of SS "Rivne NPP": www.rnpp.rv.ua.
Tel.: 2-14-43, 2-11-96, Facebook page: rnpp.polissia.

Pursuant to the law of Ukraine [20] the citizens have the right to receive complete and true information about the nuclear facilities activity.

Information Center operates in four main areas:

- Excursion activities;
- Exhibition activities;
- Work with the public of SS Rivne NPP observation zone;
- Educational activity.

The main goal of power plant policy in the area of public relations is maintaining stable and positive public opinion at SS Rivne NPP location, i.e. the conditions contributing to successful production activity of the enterprise.

Figure 1.3. Excursion and educational activity provided by SS Rivne NPP Information and Public Relations Department among the teenagers.

The information on the current activity and events at SS Rivne NPP is provided to the public by means of [48-51]:

- Daily e-mailing of information messages on the current operation of SS Rivne NPP units to 24 addresses in 2014, 26 addresses in 2015, 22 addresses in 2016 and 2017;
- E-mailing of event press-releases to the central and regional information agencies to 70 addresses in 2014, 2015, 2016 and 2017;

- Publishing of press-releases and messages in the news line of the official site of SS "Rivne NPP".
- Telephone-autoinformer.

Upon the results of events at SS Rivne NPP - conferences, meetings, reviews - the press-releases are distributed to the media and the press service of SE "NNEGC "Energoatom". 156 press-releases were issued in 2014, 410 – in 2015, 461 – in 2016, 480 – in 2017.

Since 2005 the official site of SS Rivne NPP has been functioning. Collecting and updating of the information is carried out by the press-center employees. SS Rivne NPP Facebook page was created in 2015 and has been functioning since. The news line is continuously updated.

Pursuant to the law of Ukraine "On the Use of Nuclear Energy and Radiation Safety", according to which the citizens have the right to receive complete and true information on the nuclear facilities activity, the telephone-autoinformer is constantly on. (tel.: (03636) 64-8-64). It gives the opportunity to get the information on the current state of SS Rivne NPP units which are under operation, environmental and radiation situation in the observation zone. Telephone answering system is aimed at forming the openness in the relations with the public living at the adjacent to NPP area.

Figure 1.4. Work with the public from the observation zone of SS "Rivne NPP"

Twice a week the press in Rivne, Volyn and Lviv oblast is monitored which provides the opportunity to track the need in information, prepared by the Department of Information and Public Relations, and the quality its of perception. The result of the monitoring is the collection of publications about SS Rivne NPP activity.

Since 2016 in order to demonstrate the high level of national NPP safety and reliability, the press-tour of regional media has been held at SS "Rivne NPP".

Figure 1.5. Co-operation with public organizations

Regional mass media published 1199 articles about SS Rivne NPP in 2014, 160 articles – in 2015, 1905 articles – in 2016, 1688 articles – in 2017, that shows the interest in the events at SS “Rivne NPP”. The main topic of the articles is the reliability of power units operation, radiation safety, measures on modernization and reconstruction aimed at power unit safety improvement, social partnership, interrelation with local government, development of infrastructure of the adjacent to SS Rivne NPP areas.

In order to demonstrate the high level of safety and reliability of national nuclear power plants, the press-tours of regional media were held at Rivne NPP in 2014 and 2015. The representatives of regional and local TV companies, information agencies, print and electronic media, public organizations of Volyn and Rivne region participated in those press-tours. In 2014 together with the Association “Ukrainian Nuclear Forum” within the European week of stable energy the press-tour on the topic “Nuclear Energy and its Impact on Climate Moderation” was held for the representatives of the central media, and in 2015 the 4th SE “NNEGC “Energoatom” Summer School and excursion to the production site were held for the participants of the Spring Nuclear School.

In 2014 the workshops for teachers of Fundamentals of Health and Safety from district and regional schools were held on the basis of the Information Center; as well as a meeting with teachers and students of Lesya Ukrainka Eastern European National University and Ternopil Ivan Puluj National Technical University. In the occasion of the 10th anniversary of SS Rivne NPP unit 4 commissioning the photo contest and photo exhibition were held.

The following excursions are organized for the public and guests of the town:

- To the Information Center “Polissia”;
- To the Training Center with demonstration of full scope simulators, radiation protection room;

- To the Automated Radiation Monitoring System complex;
- Observation bus tours around the plant.

In 2015 on the basis of the information Center the following measures were taken:

1. Meeting with the participants of the pedagogical conference.
2. Regional seminar of representatives of the state sanitary phyto inspection.
3. Seminar of representatives of regional energy companies of Ukraine.
4. Photo exhibition – SS “Rivno NPP” for the Antiterrorist Operation.
5. Exhibition of paintings by I. Herchanivska from the “Bird” series.
6. Exhibition of drawings “Bible stories through the eyes of children”.
7. Visit of teachers-ecologists of the city of Lutsk.
8. Informative excursion for the participants of the “Spirographs” theater troupe in the city of Lviv.
9. Study tour for students of the Spring Nuclear School.
10. Acquaintance with the work of WANO - MC Information Center.
11. Excursion to SS Rivne NPP of a group of students of Lesya Ukrainka Eastern European National University.
12. A visit of pupils of physical and mathematical classes of Lutsk secondary school No.9 to SS Rivne NPP facilities.
13. Vocational-oriented meeting with the pupils of schools located in 30 km observation zone (Sukhovolia village, Volodymyretsky district).
14. Organization of the exhibition of paintings by a local artist “I bow to my native land”.
15. Meet-the-artist event with employees of Kuznetsovsk music school
16. A series of excursions for pupils of junior classes on the topic “Worthy descendants of Cossack glory”.
17. Meeting on the occasion of the international day of museums with representatives of the Museum of Volyn Icon (Lutsk).
18. Study tour to SS Rivne NPP for directors of Lutsk educational institutions within the framework of cooperation of city councils.
19. Introductory tour for children from Volnovakha, Donetsk oblast.
20. Grand opening of the Summer Nuclear School with the participation of the plant management.
21. Organizing and conducting of a study tour to SS Rivne NPP facilities for children from multi-member families in Kuznetsovsk.
22. Work with primary school under the program “Fun holidays” of the Palace of Culture of SS “Rivne NPP”.
23. Work with representatives of the Ukrainian-Polish center “Lodz-Kostyukhnovka” delegation.
24. Excursion for youth public organization from Zhytomyr.
25. Organization of a sightseeing tour for representatives of the prosecutor's office of Ukraine and Security Service of Ukraine.
26. Study tour for dentists.
27. Work with students of the Kuznetsovskiy vocational school as part of an introductory course in nuclear power engineering.
28. Excursion for representatives of Lodz (Poland) and Lutsk Catholic Church.
29. Assisting in the organization of educational and methodological meetings of Heads of military units for protection of nuclear power plants in Ukraine.
30. Conducting a virtual study tour for children from the Center of Children and Youth Art.

31. Study tour to SS Rivne NPP facilities for the representatives of Polish cities within power unit 3 lifetime extension.
32. Organizing and conducting of the excursion for the participants of the regional seminar of Rivne teachers of natural sciences.
33. Conducting a meet-the-artist event with the public organization "Golden Age" of Manevychi settlement.
34. An introductory meeting with the pupils of the fine arts group on the topic “My homeland is my land”.
35. Introductory tour for representatives of the Volyn tourist club.
36. A series of excursions for pupils of social clubs on the topic “Rivne NPP - the energy giant of Polissia”.
37. Study tour for the administration and teachers of secondary school №1.
38. Acquaintance with the environmental activities of the SS Rivne NPP in the framework of a meeting with representatives of the Sarny Pedagogical College on the basis of the Automated Radiation Monitoring System laboratory.
39. Summing up and rewarding the participants of the contest “With Hope - to Victory”.
40. Meeting with the representatives of the Volodymyrechchina public organization “Pagin”.
41. Providing individual consultations to the participants of the “Kurchatov readings”.
42. Topic tour for the members of Evangelical Christian Baptist choir.
43. Information support of the All-Ukrainian seminar of representatives of the Treasury of Ukraine.
44. Information support for the participants of the paramilitary security forces staff meeting.
45. Study tour for editors of printed municipal mass media of Rivne region.
46. Organization of public hearings within the implementation of the Complex (Consolidated) safety Upgrade Program.
47. Visits to the 30 km zone: Sarnensky district Verbche village, Volodymyrets settlement, Kolky settlement, Manevytsky district, Volyn region.
48. Organization and holding of a meeting on the Day of Energy Worker of high school students with a veteran of the SS Rivne NPP Mr.Kisly A.Z.
49. Placement of a photo exhibition of Aleksey Valygin, an employee of the SS “Rivne NPP”.
50. Participation in the round table meeting of the city library.
51. Vocational-oriented visits to the educational institutions of the city.

The following contests were held:
1. Scientific report contents – 22 participants.
2. Brain-ring among employees of SS Rivne NPP – 23 participants.
3. Contest of children's drawings “No-war” – 80 works.
4. Competition of children's drawings “With Hope to Victory” – 72 works.
5. Small Kurchatov readings – 40 people.
6. Brain-ring among high school students of the observation zone – 63 people.

In 2016 on the basis of the Information Center the following events were held:
1. Meeting with participants of the Antiterrorist Operation and representatives of the volunteer movement of pupils from the town schools.
2. Round table with deputies of the City Council.

3. Presentation of the book of V. Sukhonosenko, the SS Rivne NPP veteran.
4. Participation in the meeting of the city organization of Chernobyl victims.
5. Organizational work on carrying out a practical workshop with teachers of Fundamentals of Health and Safety from Kuznetsovsk, Sarnensky and Kostopilsky districts.
6. The round table of the youth union of SS “Rivne NPP”.
7. Study tour for representatives of the Christian Baptist church.
8. Study tour for representatives of the Ministry of Health of Ukraine and medical unit 3.
9. The opening of the All-Ukrainian exhibition of children's drawings “With Hope to Victory” with the participation of members of the youth social service, Center of Children and Youth Art, students of the gymnasium.
10. Study tour for students of the faculty of "Nuclear Energy" of the Odessa Polytechnic.
11. A visit of directors of the regional electric grids of Ukraine to SS “Rivne NPP”.
12. Meeting of Afghan events veterans with high school students of the town on the occasion of the withdrawal of troops from the Republic of Afghanistan.
13. Creating a memorial place of S. Tarasyuk, the deceased soldier of Antiterrorist Operation.
14. The opening of the All-Ukrainian exhibition of children's drawings “With Hope to Victory” with the participation of members of the youth social service, Center of Children and Youth Art, students of the gymnasium.
15. Meeting of generations of the chemical department workers.
16. Visits to the 30 km observation zone of SS “Rivne NPP”.
17. Workshop with the teachers of of Fundamentals of Health and Safety from Kuznetsovsk, Sarnensky, Kostopilsky districts.
18. Introductory tour for representatives of dispatching services.
19. Introductory tour for representatives of the Polish Voivodeship
20. Excursion for representatives of the Rivne financial inspection.
21. Round table for representatives of the Radekhivsky district of Lviv oblast.
22. Visits to the 30 km observation zone of SS “Rivne NPP”.
23. A series of topical excursions “RNPP for Antiterrorist Operation” for students of the town.
24. Excursion for teachers of physics of Rokytnivsky district.
25. Excursion for pupils of Dubrovytsky secondary school №1.
26. Excursion for the participants of the regional seminar of the Heads of out-of-school educational establishments.
27. Excursion for teachers of the seminar on the Fundamentals of health in Sarnensky, Kostopilsky districts and Kuznetsovsk.
28. Excursion for representatives of the Republic of Poland.
29. Providing information materials on SS Rivne NPP to the French scientists.
30. Opening of the exhibition on the occasion of the 30th anniversary of the Chernobyl accident.
31. A series of topical excursions for schoolchildren "Lessons of Chernobyl".
32. Participation in the teleconference between Lutsk and Chernigov dedicated to the Chernobyl events.

33. Opening of consulting centers on the extension of RNPP unit 3 lifetime in the observation zone.
34. Visits in the 30 km observation zone of Volodymyretsky district of Rivne region and Manevytsky district of Volyn region.
35. Seminar of Chemistry and Physics Teachers of Rivne region on the basis of the Information Center.
36. Introductory tour for students and teachers of Lesya Ukrainka Eastern European National University.
37. Round table with the participants of the personnel reserve program of SE “NNEGC “Energoatom”.
38. Awarding of winners and laureates of the drawing contest.
39. Participants of the regional seminar of librarians, introductory tour.
40. Visits in the 30 km observation zone of Volodymyretsky district of Rivne region and Manevytsky district of Volyn region.
41. Participation in the festival “Amber Way”.
42. Photo flash mob devoted to the “Vyshyvanka Day”.
43. Meeting with the public to discuss the regular environmental assessment of the C(C)SUP.
44. Cooperation with representatives of the Scientific Center of Radiation Medicine of the Academy of Medical Sciences of Ukraine.
45. Excursion for representatives of Poland.
46. Deputy Day at SS Rivne NPP for representatives of the Volodymyretsky District Council.
47. Meeting with representatives of SE “NNEGC “Energoatom” in the framework of power unit 3 lifetime extension.
48. The 3rd annual bike ride Kuznetsovsk – Bile Ozero.
49. Seminar of the Regional Scientific Library.
50. Introductory tours for representatives of the fire service of Ukraine, citizens of the Republic of Poland
51. Excursion in English for the participants of the English-speaking camp of the Volodymyretsky Collegium.
52. Acquaintance with the work of the SS Rivne NPP of students of educational institutions of Poland
53. Providing information about SS Rivne NPP operation to the students of Polish educational establishments.
54. Organizing and conducting of the contest of Scientific reports.
55. Visits to 30 km observation zone of Volodymyretsky district of Rivne region and Manevytsky district of Volyn region. (St. Chortoryisk)
56. Excursions of the Heads of Mannevychyna who visited SS Rivne NPP to obtain information about the technology of sludge formation.
57. Visit of representatives of the Volodymyrets district council within the EC ecoproject
58. Organizing and conducting an introductory tour to the facilities of SS Rivne NPP for children from large families in Kuznetsovsk.
59. Work with children of SS Rivne NPP employees in the framework of the program “Happy holidays”.

60. Work with representatives of the delegation of the Ukrainian-Polish center “Lodz-Kostyukhnivka”.
61. Excursion for youth public organization from Zhytomyr.
62. Visits to 30 km observation zone of Volodymyretsky district of Rivne region and Manevytsky district of Volyn region. (village of Antonivka, Volodymyretsky district).
63. Excursion for representatives of the Chamber of Accounts
64. Conducting a meeting of Capital Construction Management employees with veterans on the occasion of Construction Worker’s Day
65. Organization of a sightseeing tour for representatives of the prosecutor's office of Ukraine and the Security Service of Ukraine.
66. Excursion for the representatives of the camp “Harcerstvo Polske”.
67. Meeting with delegations of Volodymyretsky and Manevytsky districts in the framework of the program for the use of ameliorants from SS Rivne NPP in the development of the agricultural district.
68. Meeting with representatives of FOLKMUZIKL with the participation of People's Artist of Ukraine Oksana Pekun.
69. Study tour with the dentists of the town.
70. Study tour for youth clubs in the town.
71. Meeting of representatives of the delegation of Manevychchyna, Poland, Lithuania in the framework of the Independence Day celebration.
72. Placement of the photo exhibition on the occasion of the Independence Day “With Ukraine in the heart”.
73. Conducting a patriotic flashmob “Smile, Ukraine!”
74. Introduction of the quiz “Do you know RNPP?”
75. Excursion for employees of the Kiev tram depot.
76. Work with students of Kuznetsovsk vocational school as part of an introductory course.
77. Excursions for representatives of the Catholic Church of Lodz (Poland) and Lutsk.
78. Assisting in the organization of educational and methodological meetings of Heads of military units of Ukrainian NPP protection.
79. Conducting a virtual study tour for children of the local history group of the Center of Children and Youth Art.
80. Introductory tour to the facilities of the SS Rivne NPP for representatives of Voluv (Poland) as part of the City Day.
81. Organizing and conducting excursions for the participants of the regional natural sciences workshop of teachers of Rivne.
82. Information support of representatives of the Commission for Standardization of SE “NNEGC “Energoatom”.
83. Study tour for pupils and teachers of Lutsk gymnasium.
84. Round table of students of the city with representatives of the Ministry of Emergency Situations of Ukraine.
85. An individual excursion for the 30 thousandth visitor of the Information Center - student of vocational school Andrei Mark.

86. Providing answers to information requests in consultation centers and distribution of copies of the "Energoforum" among the population of the observation zone.
87. Visits to 30 km survelliance zone of Volodymyretsky district of Rivne region and Manevytsky district of Volyn region (village of Lisove and Huta-Lisivska).
88. Introductory tour for participants of the professional skill contest.
89. Information for representatives of the Herder Institute, Marburg.
90. Excursion for pupils of Polytska secondary school.
91. Introductory tour for students of Volodymyretsky higher vocational school.
92. Refitting of the photo exhibition devoted to Antiterrorist Operation.
93. Meeting with the teachers of the Kolkovsky higher vocational school of Volyn region.
94. Participation in the International Energy Forum.
95. Meeting of the town youth council with Pavlo Pavlyshyn, Director General of the SS “Rivne NPP”.
96. All-Ukrainian seminar with representatives of the insurance company “Oranta”.
97. Joint participation in the environmental program “Discover Ukraine”.
98. Introductory tour for students of the Kolkivsky higher vocational school of Manevytsky district.
99. Within the framework of the Green Planet project, an environmental action “Collect waste paper - save the tree” is being carried out in the urban facilities of SS “Rivne NPP”.
100. Organizing and conducting the contest Small Kurchatov readings.
101. Organizing and conducting brain-ring on the occasion of the Day of EnergyWorker.
102. Participation in the All-Ukrainian essay competition “Nuclear Energy and Society”.
103. Introductory tour for representatives of local authorities, teachers, and residents of the village of Khynochi, Volodymyretsky district, Rivne region.
104. Conducting "internships" for senior pupils at the production positions of SS Rivne NPP and excursions for representatives of the youth council of the town.
105. Organizing and providing the pupils of the Chudelsk special boarding school with gifts for St. Nicholas Day.

The following events were held in 2017 on the basis of the Information center:

1. Meeting of the Director General of SS Rivne NPP with the youth of the town.
2. Christmas movie for the creative youth of the town.
3. Organization and holding a meeting for employees of local electrical grids of the town.
4. Dialogue between Kuznetsovsk vocational school and Kolkivskaya vocational technical school of Volyn region and a visit to SS “Rivne NPP”.
5. Visit-response to the village of Manevychi Volyn region of the club "Orchid" to the public association “Golden Age”.
6. Meeting of Afghanistan combat veterans with high school students on the occasion of the withdrawal of troops.
7. Introductory tour for representatives of Rivneoblenergo.
8. Summing up the results of the All-Ukrainian drawing contest among students “The peaceful atom unites Ukraine”.

9. Participation in conducting a chemistry lesson for high school students of the town at the SS “Rivne NPP”.
10. Meeting of students with the Head of the personnel training department, Ms. O. Sinitsa on the topic “The role of women in nuclear energy”.
11. A series of introductory tours for participants of practical training of SE “NNEGC “Energoatom”.
12. Summing up the contest of sketches for the design of the facades of SS Rivne NPP buildings.
13. Topical tour “Peaceful Atom” for schoolchildren of settlement Volodymyrets.
14. Excursion to SS Rivne NPP site for children organized and conducted by the Information and Public Relations Department.
15. A cycle of excursions for students of teenage clubs of the town on the topic: “The role of the SS “Rivne NPP ”in the development of the region”.
16. A visit of representatives of the Sarnensky Collegium of SS “Rivne NPP ”.
17. The meeting of employees of the Information and Public Relations Department with representatives of Lutsk sports clubs.
18. Providing information about SS Rivne NPP operation to delegation from Poland.
19. Introductory tour for pupils of Lutsk boarding school.
20. Visit of Rivneoblenergo representatives to SS Rivne NPP site.
21. Overview courses for representatives of SE “NNEGC “Energoatom”.
22. Visit ofrepresentatives of Lutsk Gymnasium to the facilities of SS “Rivne NPP”.
23. Meeting of students of vocational schools, students of the town and the observation zone of the SS Rivne NPP with students of the KPI (a series of lectures).
24. Introductory tour for representatives of the KVN (Club of the Funny and Inventive People) teams of the State Enterprise “NNEGC “Energoatom” and meeting with the management of the SS Rivne NPP headed by the Director General.
25. A series of excursions on the topic “The social policy of the SS Rivne NPP and its role in the development of the region”:
26. 03.05 - directors of educational establishments of Zarechniansky district;
27. 05.05 - delegation of the fabulist club (Poland);
28. 11.05 - representatives of Dovgovilska secondary school of Volodymyretsky district;
29. 12.05 – students of Lesya Ukrainka Eastern European National University (Lutsk);
30. 12.05 – directors of educational establishments of Volodymyretsky district;
31. 16.05 – representatives of Volodymyretsky Collegium;
32. 17.05 – representatives of Rokytnivska secondary school;
33. Providing the consulting support in organization and conducting meetings of representatives of public with Ms. S. Boltovska, Doctor of Historical Science (Herder Institute, Germany);
34. Topical tour “Night at the Museum”.
35. Organization of the exhibition of vyshyvanka “Love and know your native land” on the occasion of the Day of Vyshyvanka.
36. Organizational assistance in carrying out a brain-ring for young people of SS “Rivne NPP”.
37. Overview courses for representatives of SE “NNEGC “Energoatom”.
38. Briefing on the implementation of the C(C)SUP measures for media representatives.

39. A series of topical tours “Our energy is our future”:
40. 01.06. – pupils of Zabolotska secondary school;
41. 01.06. – representatives of Polish Kharcers;
42. 07.06. – pupils of Dubrovytska secondary school;
43. 09. 06. – students of the Cultural Center of Rivne.
44. Public hearing in assessment of C(C)SUP.
45. Providing information about SS Rivne NPP operation to the representatives of “Gas Postach” of Lokachiv, Volyn region.
46. Conducting a practical training for representatives of the external communications department of the SE “NNEGC “Energoatom” and visiting the Ukraine-Polish center in Kostiukhnivka village, Manevytsky district.
47. Study tour for the participants of the Summer English camp of the town.
48. Providing information about SS Rivne NPP operation to the participants of the Polish-Ukrainian business forum.
49. Meeting with the students of the club “Brigantina”.
50. Introduction of the SS Rivne NPP facilities to the representatives of the Ministry of Emergency Situations of the town.
51. Introductory tour for representatives of vocational schools in Rivne region.
52. Overview courses for representatives of SE “NNEGC “Energoatom”.
53. A visit of SS Rivne NPP by representatives of the Ukraine-Polish friendship center of Kostiukhnivka village.
54. During the first half of the year, employees of the IC visited populated areas of the SS Rivne NPP observation zone.
55. Introductory tour for 1977 graduates of Rafalivka boarding school.
56. Introduction to the history of the plant and the town of Varash of the participants of the bike ride of the Lyubomylsky district of Volyn.
57. Study tour for representatives of the Museum of Icons of the city of Lutsk.
58. Introductory tour for Polish Kharcers organization.
59. Attending the exhibition of the Second Ukrainian World War, located in the information center, by the Service for children, family and youth.
60. Excursion for participants of the workshop on the basis of the dental center “Dentist”.
61. Excursion for representatives of the agricultural company “Haiberi”, Volyn.
62. Providing information about SS Rivne NPP operation to the representatives of the regional animators workshop.
63. Providing information about SS “Rivne NPP”operation to the representatives of the English-language camp in Voronky village.
64. Organization of measures for preparation the Ethno-defile of vyshyvanka.
65. Provision of methodological recommendations and information and image materials for school teachers before the beginning of the school year.
66. Participation in the organization and conducting of the Day of Knowledge for students of town schools.
67. Work on historical materials for the representative of the Herder Institute (Magdeburg) Ms. Svetlana Boltovska.
68. The cycle of museum and walking tours dedicated to the Town Day.
69. Introductory tours for vocational school students - introduction to the profession.

70. Meeting of workers of Information and Public Relations Department with representatives of the tennis tournament, providing information about SS Rivne NPP operation.
71. Round table with a local historian Mr. N. Kobyliansky and the presentation of the new book “The Station “Los”.
72. Overview courses for representatives of SE “NNEGC “Energoatom”, work on the SS Rivne NPP site.
73. Organizational events for the participants of the “Nuclear School”, excursions.
74. Ceremonial opening of the “Nuclear School” by P. Ya. Pavlyshyn, Director General of SS “Rivne NPP”.
75. Organization and holding of the Day of the Deputy for the deputies of the Manevytsky District Council.
76. Organization and conduct of classes in the “Nuclear School”.
77. Excursion for employees of the Ministry of Emergency Situations of Rivne.
78. Organization and holding of the Day of the Deputy for deputies of the Volodymyretsky District Council.
79. Providing information about SS Rivne NPP operation to activists of the local history group of the Center of Children and Youth Art.
80. Presentation of the exhibition, dedicated to the anniversary of the Antiterrorist Operation “Heroes do not die”.
81. The lesson of courage, the meeting of the participants of the Antiterrorist Operation with the senior pupils undergoing preconscription military training.
82. Organization and holding of a workshop for schoolchildren of Lviv Educational Complex “School of Engineering – Lviv Economic Lyceum”.
83. Introduction of the Information Center and town of Varash to the WANO representatives.
84. Carrying out an optional course on physics at school No. 5, devoted to the anniversary of power unit No. 4 commissioning and unit No. 3 lifetime extension.
85. The cycle of object lessons on the extension of power unit 3 lifetime.
86. A trip to the Energy Forum “Fuel and Energy Complex of Ukraine - Present and Future”.
87. Work with Rivne archive.
88. Work with the youth organization “Plast”.
89. Introductory tour for representatives of the State Treasury.
90. Nuclear school - visiting outdoor switchgear-750.
91. Introductory tour for the trade union activists of SS “Rivne NPP”.
92. Working with archival data in the framework of a visit of Ms. Veronica Wendland, German professor at the Herder Institute.
93. Providing information about SS Rivne NPP operation to the senior students of Volodymyretsky Collegium.
94. The event dedicated to the Day of Dignity and Freedom.
95. Public Hearings regarding C(C)SUP.
96. Providing information about the IC for representatives of Lvivenergo.
97. Providing information about IC work to the guests from SS “Zaporizhzhya NPP”.

98. Visits together with Deputy Director General for Personnel of SS Rivne NPP observation zone – Nuclear School of SS Rivne NPP for senior high school students from the OZ.
99. Excursion for Volodymyretsky Collegium.
100. Cycle of excursions for pupils of town schools.
101. Participation in the celebration of the 25th anniversary of the Department for Modernization.
102. Organization and conduct of the Small Kurchatov Readings.
103. Introductory tour for the power equipment maintenance subdivision.
104. Organizing and holding the brain-ring.
105. Providing information about SS Rivne NPP operation to students of the Chornyzhska Secondary School, the Delegation of the Belarusians.
106. Introductory tour for employees of the paramilitary security service of SS "Rivne NPP".
107. Providing information about SS Rivne NPP operation to the pupils-museologists of st. Rafalivka.
108. Work with students in schools - lessons in the memory of Chernobyl.
109. Providing information about SS Rivne NPP operation to the students of amateur art school №3.
110. Providing information about SS Rivne NPP operation to the students of Polovlivska secondary school.
111. As part of the press tour - Providing information about SS Rivne NPP operation for journalists from Volyn, Rivne, local media, and the celebration of the opening of Radioactive waste treatment complex.
112. Visit of pupils of school №5 to SS Rivne NPP site.
113. Presenting to orphans and children in difficult life circumstances gifts for the New Year. A trip to the Chudelsk boarding school for presenting gifts.

In 2014 421 excursions were conducted for 2719 people, in 2015 the excursions were conducted for 5368 visitors, including 184 excursions for 2499 pupils. In 2016 588 excursions were conducted for 5722 visitors including 283 excursions for 3009 pupils. In 2017 730 excursions were conducted for 7428 visitors including 304 excursions for 3801 pupils.

The Information Center took the prominent position among the cultural and entertainment establishments of the town and region. Visits to the Information center are included in the list of places to visit during the excursions to the Western Ukraine.

Given that the main succession pool of our enterprise is the young people from the town and adjacent areas, Rivne NPP pays much attention to vocational-oriented education. In this connection, during 2014 the following was held:

- competition among schoolchildren of Kuznetsovsk for the best picture on the topic of "SS "Rovno NPP". Welfare. Homeland ", which was attended by 147 students; The best works of the competition finalists took part in the final part of the competition in Kiev and received prizes.
- competition among schoolchildren of Kuznetsovsk for the best drawing on the topic "NO-war", which was attended by 60 students;
- brain-ring and Small Kurchatov Readings on the topic "Nuclear energy and society" among schoolchildren of SS Rivne NPP 30-kilometer observation zone.
- Stage II of the All-Ukrainian essay competition on nuclear energy topics.

The employees of the department held meetings with the representatives of local government and pthe ublic of the observation zone. In 2014 the excursions for deputies of Lviv town council and Lviv teachers were initiated.

A tradition of conducting the contests among students extended to the SS Rivne NPP observation zone. The results of performed work shows strong interest of youth living in the adjacent territories in topics related to nuclear energy.

Information materials are disseminated among SS Rivne NPP personnel, town, district, regional organizations and institutions, educational establishments.

In 2017 the contests for students from the observation zone settlements were conducted: essays and brain-rings on the topic “Nuclear Energy and the World”, drawings on the topic “The peaceful atom unites Ukraine”. Also in 2017 a competition was held for the best creative work - a sketch of the color design of the auxiliary building facade of SS “Rovno NPP” on the topic “NPP: building the future together!”.

The department employees meet with the public of the observation zone, students of higher educational establishments.

The enterprise personnel gets information through the plant media – radio broadcasts and newspaper, and through the electronic means – an electronic screen, a plasma panel at check point 1, as well as information boards at check points 1, 2, Production and Laboratory building.

The newspaper “Energia” is published weekly in a printing form with an average circulation of 2000 copies and in an electronic form on SS Rivne NPP website. The information content of the newspaper is constantly improved. Hourly radio broadcasts go on air twice a week (Tuesday and Friday). The editors of television and radio broadcasting, in addition to their own programs, create programs “Pulse of RNPP”, which are broadcast on the regional television in Rivne and Lutsk. During 2014 16 and 78 such programs were created and transmitted to mentioned channels. During 2015 16 and 24 such programs were created and transmitted to the mentioned channels. During 2016 21 and 24 such programs were created and transmitted to the mentioned channels. During 2017 – 24 programs.

The television programs of the editorial staff were regularly transmitted to the Press Service of SE “NNEGC “Energoatom” to be placed on national channels. Continuous attention is paid to SS Rivne NPP safe operation, preparation and conducting outages, financial and economic state of the plant, coverage of international reviews, particularly IAEA and WANO missions.

Particular attention is focused on forming the personnel’s commitment to the safety culture principles. Issues of industrial safety, labor discipline, health protection and rest of NPP workers, their social protection were raised. Specific attention has been paid to the usage of funds provided to compensate the risk of the public living within the plant observation zone.

In 2014, the advertising campaign continued to improve the image of the nuclear power industry by placing advertising information on the big boards in Rivne, Sarny and the village of Volodymyrets.

The information on the electronic board is updated daily (check point 1).

The presentations dedicated to public and professional holidays, information about meetings, visits of colleagues, messages from the trade union committee, results of photographic materials on the history of the Rivne NPP, and mass cultural events are demonstrated on the plasma panel.

The Information and Public Relation Department personnel participate in the events conducted at SS Rivne NPP or under the assistance of SS Rivne NPP to cover them in the mass media.

In order to present the plant the department employees participated in the exhibition “Energy Forum of Fuel and Energy Complex of Ukraine: Present and Future».

The Information and Public Relation department specialists as a part of information support brigade participated in the plant emergency response drill. During a year the personnel provided the preparation and printing of booklets for Emergency Preparedness and Response Department, photo album devoted to the 10^{th} anniversary of power unit 4 commissioning, updating of Walk of Fame and Wall of Fame, the personnel of the RTR editors office produced videos devoted to the anniversaries of departments and subdivisions. The Information and Public Relations department comprehensively assisted SS Rivne NPP in organization and conducting “Come in vyshyvanka” event devoted to the Constitution Day of Ukraine and covered it in the media.

During 2017 the personnel updated Walk of Fame and Wall of Fame, the personnel of the RTR editors office produced videos devoted to the anniversaries of departments and subdivisions. The Information and Public Relations department together with social facilities administration organized and conducted patriotic flashmob “Chain of Unity” before the Day of Unity of Ukraine and for the Constitution Day of Ukraine – ethnic defile of vyshyvanka.

Within the limits of the available financing, subscriptions of periodicals for 2015-2018 were carried out for departments and subdivisions of the plant.

2. PHYSICAL AND GEOGRAPHIC FEATURES OF SS RIVNE NPP LOCATION AREA

2.1 Physical and Geographic conditions

SS Rivne NPP is located in town of Varash (former Kuznetsovsk) so that (Figure 2.1) the impact of production activity of nuclear power plant extends to two oblasts of Ukraine – Rivne and Volyn.

Thirty kilometers zone of Rivne NPP is located within the physical and geographic zone of mixed forests, in the region of Volyn Polissia. This region has a number of physical and geographic features which differ it from other regions of Ukrainian Polissia.

In the geomorphological structure of the territory the alluvial plains, extended hilly-moraine, moraine-outwash relief forms have a significant proportion, denudation forms on the Cretaceous base and karst forms are common [52].

The surface of the researched territory is flat slightly wavy lowland, inclined to the north. Compartmentalization of the territory is small. Heights range within 160-200 meters.

The climate within the physical and geographic region of Volyn Polissia is less continental, longer frost-free period and the amount of precipitation. Moisture coefficient of this territory is more 2.4 [53].

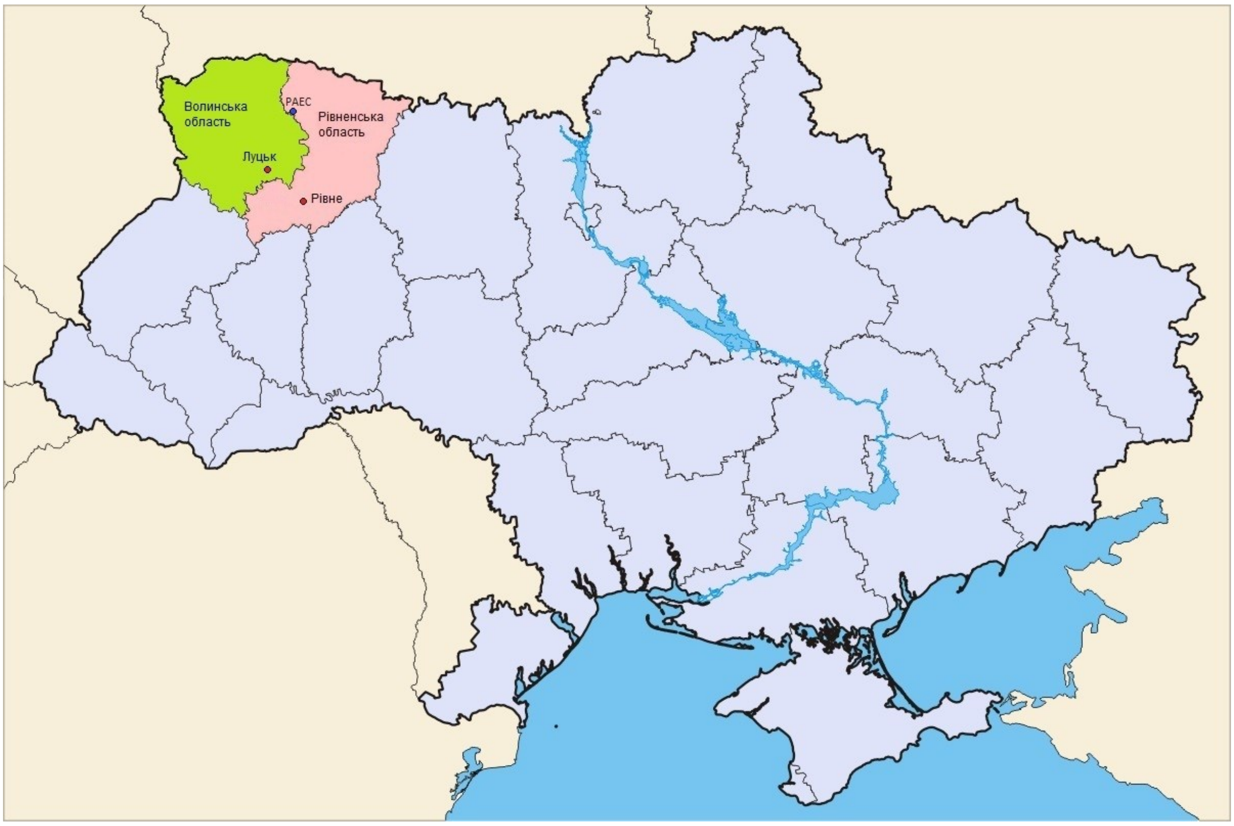


Figure 2.1. Location of Rivne nuclear power plant.

All the researched area is crossed by the river Styr – from the South-West to the North. The river system is very dense (tributaries of Styr and Horyn). The researched territory has many lakes, the biggest one is the lake Bile. The territory is quite marshy. Marshes and swampy lands occupy more than 15% of the territory.

30-kilometers zone of SS Rivne NPP is characterized by significant amount of forests. The forests and bushes occupy about 40% of the territory. Among forests, large areas are occupied by pine-oak and oak-hornbeam forests [52].

Based on the data on landscape study twelve physical and geographic regions have been identified within the researched territory.

The Biloozersky physical geographic region is situated on the north-west of the researched territory. In Geomorphological terms, the area is the second terrace above the floodplain of the river Pripyat which imposed terraces of the river Styr and smaller rivers flowing into the river Pripyat. Within the region, the dominant are the alluvial plains (floodplain terraces) of various levels composed of sands. The surface is compounded by moraine hills (kams), formed by sandy sediments with stony sands with soddy-podzolic soils. Soil surface of this territory is characterized by soddy slightly- and medium-podzolic sandy non-gley and gley soils, and soddy podzolic sandy soils under fresh, wet and damp forests. Also, peat bog soils and peatlands of various thickness are widespread, among which there are raised and transitional, as well as meadow-bog soils under black alder forests and sedge-marshgrass meadows.

Nyzhnostyrsky physical geographic region is the area of distribution of modern alluvial plains (floodplains of the Styr river) of high and medium levels, as well as low wetlands of the floodplain, composed of loamy and sandy alluvium with turfy and meadow silt sandy, sandy and loamy, meadow swamp sandy and light loamy soils under the herb bunchgrass and the sedge wetgrass meadows, mostly reclaimed.

Komarovsky physical geographic region is a terrace lowland of the river Styr with the lowland of its tributary Okonka which in its lower course creates the common terrace with the river Styr. The dominating are relatively high and low ancient alluvial plains, sometimes turning into marshy, among which the dunes can be found. The territory of the region is composed mainly of sands with sod-podzolic and soddy podzolized, non-gley and gley sandy soils under fresh, wet and dump forests.

Verkhniostrysky physical geographic region is the area of modern alluvial plains of the Styr river floodplain of medium and low levels, composed of loamy and sandy alluvium with turfy and meadow silt sandy, sandy and loamy soils, meadow swamp, swamp and peat bog sandy and slightly loamy soils under the herb bunchgrass and the sedge wetgrass meadows, mostly reclaimed.

Telchinsky physical geographic region spreads from the center of researched area to its south border. The region is mostly covered with ancient alluvial plains (floodplain terraces) of different levels, composed mainly of sands with soddy-podzolic non-gley and gley, and soddy podzolized sandy soils under fresh, wet and dump forests. Fragmentarily there are ancient alluvial plains, composed of loamy sediments. They are characterized by the richest turf and sod carbonate silty sandy and sandy soils, occupied by agrocenoses. The subordinate position is occupied by areas of low marshy terraces and floodplains of small rivers and streams with meadow bog, peat bog soils and peatlands of different thickness under black alder forests and sedge marshgrass meadows. The region is characterized by significant spread of swampy and dry depressions including those of karst nature.

Polytsky physical geographic region occupies the south-east of 30-kilometer zone of SS "Rivne NPP". Within this region there are landscapes of low inter-river plains, flat and hilly, partially marshy. They are composed of water-glacial sands with sod-podzolic, mainly silt sandy and sandy soils, that are characterized by considerable fertility and therefore are mostly plowed. The region is also characterized by the presence of inter-river plains composed of sands, underlain by water-glacial and lake loamy sediments, with sod-podzolic sandy and sandy soils of varying degrees of gleying, which are different by rich environmental conditions (nemorose). Here, as well as in the previous region, there is a significant spread of depressions with peat-gley soils and peatlands under the wetgrass-marshgrass vegetation and black alder forests.

2.1.1 Rivne region

Rivne region is situated in the north-western Ukraine. Its area is 20,051 km^2, which is 3.1% of the total area of Ukraine [54].

The territory is comprised of 16 administrative regions and four towns of regional subordination: Rivne, Dubno, Varash (former Kuznetsovsk), Ostrog.

In total there are 1027 settlements in the region, among which 11 towns, 16 urban-type settlements, 1000 rural settlements. As of January 01, 2016 the population of the region was 1161.8 thousands of people.

Figure 2.2. Rivne region.

The climate is moderately continental: mild winters with frequent thaws, warm summers, average annual precipitation is 600-700 mm. Winter comes at the end of November, and a steady snow cover is formed in the last days of December - the first ten days of January. The summer that comes at the end of May lasts until September. This is a period of high air and soil temperatures, precipitation, and crop ripening. Clear, cool early autumn weather is set in early September. In the Geomorphological terms, the region is divided into three parts: Polissia, Volyn Lesove Plateau and Small Polissia, located in the south, between the towns of Radyvyliv and Ostrog, where the spurs of the Podilsk highland are wedged with heights of more than 300 m above sea level. The location of Rivne region on the boundary of the Eastern European platform and the Carpathian geosynclinal region led to a turbulent and ambiguous course of geological history reflected in the heterogeneity of the tectonic structure and the formation of a rather complex set of geological sediments in most of it.

The territory of the region is located within two large platform structures - the Ukrainian Shield and the Volyn-Podilsk Plate, and only a small area on the north-eastern outskirts of Rivne lies within the Pripyat Trough. The mineral resource base of the region consists of the minerals of the fuel and energy sector (peat), precious stone (amber), basalt raw materials for the production of mineral wool and fiber, raw materials for the production of building materials (cement raw materials, glass, construction chalk, building stone, etc.), fresh and mineral groundwater.

Hydrologically, Rivne region is located in the area of three artesian basins of groundwater: Volyn-Podilsk, Pripyat and Ukrainian basin of fractured waters. The undiscovered groundwater resources of the region are estimated at 1314.9 million m^3/year. Approved groundwater reserves are 195.8 billion m^3/year. Rivne region as well as other oblasts of the western and northern region of Ukraine is rich in surface waters. The region has 171 rivers with a length of over 10 km, there are also 150 lakes, 12 reservoirs, and 1,688 ponds. The rivers of the region belong to the Prypiat basin and are fed mainly by melted snow waters and, to a lesser extent, by groundwater and precipitations. The largest of them are Styr with the tributary Ikva, Stvyga with the tributary Lva, Horyn and its tributary Sluch. The main direction of the flow from south to north is due to the general decline in the area from the Volyn Lesove Plateau to the Polissia Lowland. The largest among the lakes are Nobel (4.99 km^2) and Bile (4.53 km^2). There are also a significant number of lakes in the floodplains of the Goryn, Styr, and Veselukha rivers. The lakes are used for recreation, fishing.

Marshes are widespread throughout the region, most of them are lowland, less common - transitional and upland. It should be noted that the marshiness is very uneven and ranges from 40% in the north to 2-3% in the south. Soil cover is heterogeneous. The most common are sod-podzolic, podzolic, sod, peat and peat bog soils. The sod-podzolic soils are characteristic for Polissia. The south of Polissia is represented by sod and peat bog soils. Light gray soils and podzolized chernozem formed in the forests of the Volyn Plateau, are almost all plowed. The flora of the region has more than 1.6 thousand species of higher plants. The vegetation is mainly forests and other wooded areas. In Polissia the pine and pine-oak forests are most common, in the Volyn Lesove Plateau there are mostly deciduous forests, and in Small Polissya there are oak-pine forests with more grass than in Polissia. The fauna is typical for the forest zone and is widely represented by mammals, birds, reptiles, amphibians, cyclostomes and fish. The Polissia zone is characterized by a large variety of fauna, among which there are rare in modern Ukraine representatives of vertebrates (elk, lynx, wood grouse, black grouse, hazel grouse, etc.).

In the forest-steppe zone of the region, the number of hares, foxes, mouse-like rodents and steenbrases is growing, but the species composition of the forest fauna is much poorer than in the forests of Polissia (more often there are only squirrels, martens, somewhat less wolves, wild boars, etc.). At the same time, there are some vertebrate species that are spread throughout the region, not having certain regional ranges. Among such representatives of avifauna are waterfowl, marsh and meadow birds (ducks, waders, quails, etc.).

2.1.2 Volyn region

Volyn region is situated in the north-western part of Ukraine and borders on the Republic of Poland in the west, the Republic of Bilorus in the north, Rivne region in the east, and Lviv oblast in the south [55 - 60].

The area of Volyn region is 20.1 thousand square kilometers or 3.3% of the total area of Ukraine.

Figure 2.3. Volyn region.

The region occupies the western part of the East European plain and is situated in the west of plain spaces of two natural-geographic zones of Ukraine-Polissia and Forest-steppe. Its major part (almost three-thirds of total area) is located in the Western Polissia lowland, the smaller part is located in the forest-steppe zone on the Volyn Lesove Plateau. The territory of the region is crossed by a part of the Main European Divide, which divides the river basins of the Black and Baltic Seas.

Volyn region is characterized by a relatively warm temperate continental climate with a sufficient amount of heat and moisture.

Volyn is rich in rivers and lakes. Its rivers belong to the Prypiat basin and partially to the Western Bug. The density of the hydrographic inland fresh water system here is two times greater than the average in Ukraine. It is composed by the rivers Prypiat, Styr, Stokhid, Turia, Vyzhivka, the tributaries of the Western Bug and others.

There are 137 rivers and 268 lakes in the region. The largest and most picturesque lakes are Svitiaz, Pulemetske, Turske, Lucemir, Peremumut, Orikhove, Volianske, Bile, Liubiaz.

2.2 Geomorphological conditions

The process of relief formation of the 30-kilometer SS Rivne NPP zone was influenced by both endogenous and exogenous factors of relief formation. If the internal forces of the Earth determine the main structural features of the surface (elevation, decline, etc.), the external factors (water, wind, glaciers, etc.) designed the sculpture of the modern relief - they formed valleys, hills, lake and marsh hollows.

SS Rivne NPP 30-kilometer zone is situated within the Russian platform to the west and north-west from Ukrainian Crystalline Shield. This part of the platform does not have commonly recognized geotectonic name. In the scientific literature it is called Galytsko-Volyn Depression, Volyn-Podil Plate, Volyn-Podil Shelf, slope of the Ukrainian Crystalline Shield. According to the geomorphological zoning, the entire researched area belongs to the subregion of Volyn Polissia, which occupies the south-western part of Odesa oblast of the Polissia accumulative lowland.

The Pre-Cambrian crystalline basement lies at different depths, but is not exposed anywhere within the zone of research. The contour lines of the crystalline basement surfaces have a sublatitudinal direction and rise to the north [61]. Only in the extreme south and in the south-eastern part of the 30-km zone of SS Rivne NPP the basement depth exceeds 500 m. The crystalline basement is compounded by stepped faults of the north-west strike [61]. Igneous rocks poured over these faults are mainly represented by basalts (the Riphean sediments). Rivne basalts are exposed or lie close to the surface to the north of Rivne near the villages of Berestovtsi, Zlazne, Stepanska Guta, Mutvytsa, Polytsi, Suhovoli. They are open at a depth of 10 meters by the well in the floodplain of the river Styr. They lie in separate small arrays and form 4-7-sided prisms in the form of pillars with a visible height of 15-20 meters [61]. At the mine site it can be seen that on the domed basalt surface there are “bombs” of 14-15 cm in diameter. The upper part of the basalts has traces of weathering. Rivne basalts have important geomorphological values. The area of development of basalts is generally elevated, in some places the basalts form gentle dome-shaped elevations in the form of hills with a diameter of several hundred meters and a relative height of 20-25 m. A sedimentary of Paleozoic, Mesozoic, and Cenozoic age lies on the uneven surface of the crystalline basement.

Paleozoic rocks of sedimentary (marine) origin lie in a monoclinical manner within the Polissia Lowland on the crystalline basement. The farther west of the crystalline shield, the more young Paleozoic sediments lie beneath the Cretaceous, and the ancient are deepen.

Cretaceous sediments are represented by a relatively uniform layer of chalk and flint marl, less often - of sandstone layer. The thickness of the Cretaceous sediments increases from east to west and reaches 20 m in Sarny and 80 m in Manevychi. The Cretaceous sediments are predominantly horizontal, but in some cases violations are observed. In the Cretaceous sediments karst relief forms were developed. Cretaceous deposits play an important role in the geomorphological structure of the researched 30-km zone. They are almost continuously distributed here, lying above the local basis of erosion, in most of the territory they serve as bedrock for anthropogenic deposits and in many places define the modern relief. Only in the northern part of the researched area the Cretaceous sediments are covered by Paleogene sands and clays of Kiev and Kharkiv age [61].

Anthropogenic deposits, which have a relatively small thickness, are characterized by a wide development of alluvial deposits and a large proportion of the glacier complex, represented by sandy material with boulders. Clay moraine is very rare, there are almost no forest deposits [62].

The low thickness of anthropogenic deposits indicates a predominantly positive direction of the latest tectonic movements.

Thus, the main geomorphological features of the 30-kilometer zone of SS Rivne NPP are: a significant proportion of alluvial plains in the surface structure, the extensive development of hilly-moraine relief, the presence of denudation relief forms on the Cretaceous foundation and the development of karst relief forms.

In geomorphological zoning within the sub-region of Volyn Polissia, the Upper-Prypiatska accumulative (alluvial-moraine) lowland, Volyn (Lyuboml-Stolynsk) moraine strand, Sarny accumulative lowland and Kostopilsk denudation plain are distinguished. All these geomorphological areas are represented within the 30-kilometer zone of SS “Rivne NPP”.

Verkhnioprypiat accumulative lowland is an integral part of the Pripyat lowland, which is a lower part of the Polissia lowland. From the south, Verkhnioprypiat lowland is bounded by the Volyn moraine ridge along the line Karasin-Serkhiv-Bilska Volya-Zelene.

The surface of the region is a flat plain with separate hills of sands and moraine outliers. Prevailing absolute heights are 150-170 m. Pre-Quaternary sediments do not break the surface almost anywhere in the area. They are represented by tertiary sands and clays or chalk deposits. The thickness of anthropogenic deposits reaches 25-30 m. The main role among them is played by alluvial deposits of the river Styr and its numerous tributaries. The dominant forms and types of modern relief here are marshy floodplains, floodplain terraces, dune formations.

Volyn moraine ridge. The absolute height of the highest areas reaches 200-220 m. Therefore, from the north, the ridge clearly stands out in relief against the background of the Verkhnioprypiat lowland, reaching a relative height of 30-35 m, and in some places the difference between the elevations of moraine hills and the bottom of river valleys is 50-60 m. The southern border of the moraine ridge passes near Sofianivka-Chartoryisk-Zholkin.

The ridge is especially clearly distinguished in the relief in the area from Manevychi to Dubrovytsia, where it is bounded by the lowland Styr-Slovechna. The area is not a ridge in the full sense of the word. It consists of separate hills, small ridges, ramparts, lows between them. The river valleys, cutting through the ridge, divided it into separate sections. The largest among them within the 30-kilometer zone of Rivne NPP are Manevitsky – in-between the rivers Stokhid-Styr, Volodymyretsky – in-between the rivers Styr-Horyn.

The basis of the moraine ridge is uneven, elevated surface of the Cretaceous sediments, and in some areas - Paleogene sediments, preserved from the spill in the form of islands.

The most extensive in the area are moraine hills, small moraine ridges. Between the hills and ridges there are low areas, which are of the moraine-outwash plain origin. In the lower areas there are lakes and swamps. However, the swampiness of this area of the 30-kilometer zone is significantly less than the previous one. In addition to glacial and water-glacial landforms in this area, there are a denudation relief forms of Cretaceous rocks, and aeolian and karst landforms.

An important role in the relief is played by river valleys, which have their own morphological features within the zone. As a rule, river valleys, breaking through the moraine ridges, become narrow and have high slopes. It is especially well-marked in the valley of the river Styr in the area from the Old Chartoryisk to the Old Rafalivka, where it crosses the moraine ridge.

The Sarny accumulative lowland is a flat lowland with dominant elevations of 150-180 m above sea level.

The bedrock is sharply exposed here, and the main role in the structure of the surface belongs to anthropogenic sediments of alluvial and water-glacial origin. They lie on Paleogene sands and clays, and in places of deeper washout on the Cretaceous base. Unlike the previous region, there is almost no moraine in the Sarnensk accumulative lowland and there are no glacial relief forms. The thickness of anthropogenic deposits almost everywhere exceeds 20-25 meters. The geomorphological features of the area are determined primarily by the fact that it occupies part of the Styr-Slovechna lowland [62]. Its morphology is compounded by modern valleys of the rivers Styr, Horyn, crossing the lowland. The floodplains of these rivers are wide and reach 2- 5 km. The presence of sands contributes to the development of eolian relief forms. They are represented by sand ridges, ramparts, valleys. In some areas, the sands are broken and intertwined.

The Kostopil denudation plain occupies a small part of the zone in the extreme south of the 30-kilometer zone of SS Rivne NPP with absolute altitudes 155-220 m above sea level. In this area, except for the Cretaceous sediments, basalts, shales and sandstones of Riphean and Cambrian are located in some places above the local basis of erosion. Among anthropogenic deposits, water-glacial and alluvial deposits are most common.

The territory on which the SS “Rivne NPP» site is located, is the elevated surface of the Cretaceous sediments which forms a pedestal for glacial deposits (Volyn moraine ridge). Layered sands with pebbles and gravel are part of the geological structure of this territory, covered on the surface with sand with boulders.

2.3 Flora and fauna, reserve areas

2.3.1 Flora

The territory of the 30-kilometer zone of SS Rivne NPP is located in Volyn Polissia, which is the south-western edge of the mixed forest zone. The flora of the researched area is characterized by typical features of the Polissia nature - the predominance of marshes, meadows and forests of boreal species, vegetation is a well-marked boreal complex with a predominance of pine and mixed forests and mesotrophic marshes.

The natural vegetation of the researched area is still largely preserved. Plowing ranges from 10% in the northern and eastern parts, 25-30% in the western and increases to 50-55% in the central part. The forests are dominant in the vegetation cover. The average forest coverage is 40-50%. The swampiness decreases from the north (20%) to the south (0.5-4%). From east to west, this pattern is not observed. The meadows are distributed relatively evenly and are concentrated both in the floodplains of the rivers and on land. There is extended water vegetation and voids in the sands. Due to the unsuitable arable land, the proportion of commensal vegetation has now increased.

The main feature of the forests of the 30-kilometer zone of Rivne NPP is their edaphic specificity, due to the predominance of fluvioglacial and moraine sandy sediments of light mechanical composition among the Quaternary rocks. The pine forests are dominant on such sediments. The distribution of leaf forests - primarily oak and hornbeam - is very limited. The limiting factors are not climatic conditions favorable for their germination, but soil poverty. Therefore, areas of leaf forests are found fragmentarily in combination with pine and oak-pine forests in the central and southern parts of the territory and are located on moraine hills. Due to the poor drainage of most of the territory, alder forests are widespread. Spruce forests are found in the northern part of the territory. Relatively small areas are occupied by pine forest derivatives - birch forests. After logging, as a rule, pine cultures are created, which prevail everywhere among young and middle-aged plantations.

According to the nature, the pine forests (Pineta sylvestris) of the research area belong to the subtaiga pine forests [63] of broadleaf-pine forests, to which the research area also belongs. The composition of the flora of pine forests combines boreal, nemorose species and species that grow in the Forest-Steppe. Boreal species dominate in the grass-shrub layer or are found here plentifully.

The major role in the cenoses of pine forests is played by mosses, often forming the ground layer. They are represented by real and sphagnum mosses.

Pine forests are represented by all types - from lichen and sphagnum to complex broadleaf-pine, enriched with nemorose species. In the research area, which is a lowland plain, cut by moraine hills and sandy ridges, pine mono-dominant forests occupy a prominent place in the vegetation cover. Different types of them occupy all elements of the mesorelief, except for depressions which are occupied mostly by eutrophic or mesotrophic swamps.

The largest areas are occupied by green-moss and myrtillus and green-moss pine forests. The rest of the community of pure pine forests is less common or is found fragmentarily.

Oak-pine forests (Querceto roboris - Pineta sylvestris) are found throughout the research area, but are most common in the central and southern parts. Characteristic features of oak-pine forests are the presence of a two-layered stand, the underwood layer, as well as the relative species diversity of the grassy-shrub layer, which combines boreal and nemorose species. They occupy the foot of the slopes and flat areas.

The woody layer of oak-pine forests is formed by pine (sublayer I) and oak (sublayer II). In addition to these two species, drooping birch, aspen trees are found in the stand, and alder trees are found in the lower lands.

Underwood is distinguished only in intact forests. It is usually formed by hazel, in lowlands by buckthorn.

The grass-shrub layer of these forests is usually well developed, it is richer and more diverse than in the cenoses of mono-dominant pine forests. Boreal species usually dominate - blueberry, bracken, wood sorrel. The most common here are oak-pine blueberry forests, less common are bracken-blueberry and wood sorrel forests.

In addition to the described main pine forests associations, there are others, less common, such as pine lichen forests, molinia, sphagnum, heather, cowberry, oak-pine green moss forests, lily of the valley and rare for Polesie and Ukraine pine and oak-pine juniper forests, spruce - pine forests, pine-baulchik forests.

Oak forests (Querceta roboris) are spread in small tracts on the territory of the 30-kilometer zone of SS Rivne NPP among the pine and oak-pine forests. Oak forests are located on the upper parts of the relief, occupying areas with sufficient drainage soils and, at the same time, the richest sod-podzolic sandy-loamy soils.

The main areas of oak forests are concentrated in the southern and central parts, where carbonate rocks or basalts come close to the surface. On these grants the oak is highly competitive and forms a clean, high-performance tree stand. Together with the oak the hornbeam often co-dominates, there are also single birche, aspen, pine, linden trees.

The underwood is formed by a hazelnut with a little of buckthorn. Herbage is formed by nemorose and boreal species.

Among oak forests, associations of acidophilic ecological-genetic link predominate [64], which are formed on poor and very acidic soils. These are the hazelnut-blueberry, hazelnut-dithering-grass, hazelnut-bead ruby, blueberry-buckthorn and buckthorn-dithering-grass oak forests.

Neutrophilic oak forests grow on medium-rich acidic and slightly acidic soils, and are represented by hazel-hairy sedge, hazel-star, hazel-snytevy oak forests.

Hornbeams grow in the most drained conditions for oak formation. In the herbage widely local nemorose species dominate which belong to the shade-loving complex. Boreal species are often found, but do not play a significant role.

Black alder forests (Alneta glutinosae) are found throughout the territory and are located in depressions of watersheds and river valleys, most often in the inland areas of floodplains. They grow on soils varying from sod-podzolic-gley to silty-gley. In the relief, alder forests are located below pine and oak-pine forests. The floodplain alder forests are fed by flowing waters, and the lowlands alder forests by weakly flowing and still waters. Such environmental conditions are optimal for alder trees growth. Their tree stand is highly productive, formed by alder trees mixed with aspen, fluffy birch, oak, ash trees. The underwood is more often buckthorn, sometimes raspberry. Herbage is formed by forest, hydrophilic, marsh, meadow-marsh species.

Depending on the species dominating in the herbage, the alder forests have a typical spatial distribution in the 30-km zone.

In the northern part, sedge and fern alder forests are most common. They belong to the alder forest of medium flowing water feed. Changing water regime and rich mineral nutrition contribute to good growth of the stand and development of the poor herbage.

In the southern part the tall grasses alder forests are most widespread. They belong to the alder forests of strong flowing water feed, they are characterized by high soil fertility, fast spring runoff of water, lowering of the level of groundwater in summer. The most common are nettle alder forest, meadowsweet alder forest. Their stand is characterized by high productivity, the underwood is open. Meadow-bog species are represented in a little differentiated herbage. Moss cover is not expressed.

In the northern part of the research area there are small islands of spruce forests (Piceeta abietis). Their characteristic features are high density of crowns, and, as a result of this, strong shading, loose soil structure, the absence of a distinct layer of underwood and insufficiently developed grassy-shrub layer, which is dominated by evergreen species, reproducing mainly vegetative, and a well-developed moss cover.

Spruce forests of this territory (as well as throughout Polissia) occupy a kind of ecological niche at the border of the formations of the three main forest-forming species of Polissia - pine, oak and alder trees. Therefore, these species are the components of the tree layer of the majority of spruce phytocenoses. A characteristic feature of spruce forests is that they are formed in specific edaphic conditions - mainly on fairly wet soils in river valleys, lowland and transitional swamps. Spruce appears as a component of pine, oak and alder forests on sufficiently large areas in different edaphic conditions.

In phytocenotic terms, spruce forests are represented by superior associations such as oxalis spruce and blueberry spruce forests.

Drooping birch forests (Betuleta pendulae) are found throughout the research area, but they do not occupy large areas. Most of the birch forests are young and meddle age plantations. Birch forests with monodominant stands are rare. Most often in the stand formed by birch trees, a significant part is taken by pine trees, in more humid ecotops by pubescent birch, alder trees.

In the course of time, birch forests are gradually replaced by pine trees, at the time when they come into the ripening categories, the change of species has already been completed.

The grassy-shrub cover of birch forests is diverse in species composition. Its structure includes forest species, but meadow and edge species often also penetrate these light forests. Forming on the areas of pine forests, birch forests often "inherit" their grass-shrub layer. Sometimes the role of dominants of this layer belongs to species assektator of pine outforests, primarily grasses, which managed to seize dominance in the changed conditions.

In the phytocenotic relation, birch forests are represented by the blueberry, molinia, bracken and dithering-grass associations.

White birch forests (Betuleta pubescentis) are found in separate areas, mainly in strips along the edges of swamps and in small flat depressions among pine forests. They represent a kind of Ecotone between the marshy pine forests and forest sphagnum and lightly-forested swamps. The tree stand of these humid forests contain a significant admixture of pine, drooping birch, alder and aspen trees. White birch forests are represented by two groups of associations - white birch-polytric moss and white birch-sphagnum. The first is formed at the junction with pine and drooping birch forests. The aspect in these forests is formed by polytric moss.

Communities of the second group are the transition from swampy forests to sphagnum bogs. Marsh species dominate in their grass-shrub layer, the number of forest species is extremely small. Moss covers form sphagnum mosses.

Marshes are a characteristic element of the landscape of the area. They form large hydrological complexes with the surrounding forests. They are represented by eutrophic and mesotrophic types.

In the zone of research, eutrophic marshes are located in unfavourable areas as valleys of river basins, depressions. Their largest areas are concentrated in the floodplain of the river Styr, in its northern and southern parts. Among the eutrophic marshes, the grassy bogs are dominant: sedge, to a lesser extent reed, mannagrass, and sedge root. Grassy-moss (sedge-hypnum) marshes occupy small areas.

The most common are sedge cenoses, formed in conditions of significant moisture of rich floodplain and diluvial waters. The largest areas are occupied by cenoses with a predominance of Carex acute. Among the high-grass swamps, cenoses of reed sweet grass prevail.

Grass-moss, mainly sedge-hypnum, swamps are found everywhere, but do not occupy large areas. They are formed in conditions of stagnant moisture and a significant layer of peat. The degree of watering of grass-moss communities is lower, and the conditions of mineral nutrition are worse, therefore, the moss layer is always well developed. In the herbage of these marshes, sedges play a major role, the dominants are bottle sedge and tussock sedge.

Forest eutrophic swamps are found rarely in the northern part of the researched territory and are represented by alder swamps. Reed and hydrophilic forbs predominate in the herbage.

The presence of poor sandy soils in the soil cover, as well as the geomorphological features of the territory - the formation of bogs in closed drainage basins - explain the wide distribution of sphagnum mesotrophic communities in the vegetation cover. Mesotrophic bogs are represented by groups of lightly-forested sphagnum and grass-sphagnum bogs formations. Lightly-forested marshes are formed along the periphery of large marsh massifs under the conditions of less moisture. They are usually surrounded by swampy forests around the periphery, and in the direction to the center of the massifs they are changed into open sphagnum transitional swamps. Lightly-forested cenoses are found on highly moistened swamps with deep peat deposits and have an open layer of bushy pine trees, there are clumps of grey willow. The grass-shrub layer is developed to varying degrees, the floral core is composed of marsh and forest-marsh species with a predominance of slender sedge. The number of forest species is small. Sphagnums predominate in a rather dense and monotonous moss cover.

Forestless grass-sphagnum communities are common in large swamp areas. They predominate in open water-flooded hollow marshes, which are often difficult to pass. These swamps are represented almost exclusively by slender sedge-sphagnum formations. Grain-sphagnum communities such as reedgrass and reed-sphagnum occupy much less area.

Meadow vegetation of the research area is represented by floodplain and continental meadows. Floodplain meadows are found mainly in the floodplains of the river Styr and its tributaries, especially in the middle of the most elevated part, where the river cuts through the outwash. Here real and swampy meadows dominate, less part is taken by peaty meadows.

Real meadows are located on medium-high relief elements and are formed on fresh and moist sod and meadow soils. They are presented both by tall grass and small grass real meadows. In the communities of tall grass meadows, meadow fescue and creeping bent grass prevail; in the communities of small grass meadows, colonial bent grass, red fescue, and meadow bluegrass prevail. These communities have a rich floristic composition.

Marshy meadows are formed in areas with excessive constant moisture on marsh silt-gley soils, located in pre-terrace or central parts. Herbage is formed mainly by reed canary grass and marsh bent grass.

Peaty meadows are formed in areas with stagnant moisture with peaty and peaty-gley soils. Tufted hair grass is dominant.

Continental meadows appeared at the mixed forests area on different elements of the relief and soils. They are represented by upland and lowland meadows. Land meadows are dominant in the occupied area. They are located at water dividers, in hills and slopes, as well as in dry lowlands and are represented by real and rough meadows.

These meadows are located mainly on the slopes of water-dividing ridges, flat areas. There are mostly soddy sandy loam soils podzolized to varying degrees [65]. The colonial bent grass formation is dominant in these meadows. Smaller areas are occupied by the communities of red fescue and velvet grass formations.

Lowland meadows are better represented in the conditions of hilly-ridge shaped relief among the bedrocks of dense and water-resistant formations with a high level of groundwater. Lowland meadows are characterized by constant moisture, the predominancy of sod-gley soils and signs of bogging. Among the lowland meadows there are mostly peaty meadows, there are also small areas of rough meadows. Among the peaty meadows, hair grass meadows prevail, but they do not occupy large areas. They are located mainly in flat depressions, where water stays for a long time. The groundwater of these depressions usually fall gradually, resulting in the gleying of the soil to a considerable depth.

The lowland rough meadows, characterized by acidic and poor soils, are found mainly in conjunction with peaty meadows. The lowland rough meadows are represented only by the formation of mat grass communities.

The presence of lakes, cut-off lakes, main meliorative canals contributed to the formation of aquatic vegetation. Among bank and aquatic vegetation the reed mace, reed, club-rush communities are dominant. On the water surface there are white-water lilies, snow-white-water-lilies, brandy-bottles, squill communities. Aquatic immersed communities are represented by pondgrass.

At the location of pine forests, due to the lack of nutrients in sod-podzolic soils, grassy and less often shrub voids are formed. Among grassy voids, the most common are communities with grey hair-grass, less often thyme, communities of Polissia fescue grass and mat grass. Heather voids dominate among shrub communities.

Anthropogenic changes in the vegetation cover of the research territory in modern conditions are vectorized in the direction of expanding the areas of pine monocultures at the location of mixed forest communities. Due to overgrazing meadows undergo significant transformation. The floodplain forest area has been reduced. Due to the neglect of arable lands, the proportion of segetal and ruderal vegetation increases.

In natural plant communities, there are 486 plant species. The dominant are Angiosperm species, which account for more than 95, that is fully consistent with the data for the flora of the Ukrainian Polissia.

The flora of the research area belongs to the migration type, formed due to the floras of the humid, arid and arctoalpine groups. Leading positions in the flora are taken by boreal species. Among them there are mainly species with the Holarctic and Eurasian types of habitats. Boreal elements form the types of meadows, swamps and softwood forests. The boreal flora is dominant due to edaphic conditions. Depending on environmental factors, mesophytes and mesotrophes predominate. A characteristic feature of Polissia is the presence of nemorose elements, which are inferior to the boreal, but play a significant role mainly in deciduous oak and hornbeam forests. Of particular interest is the presence of the southern elements in the pine forests: the fragrant daphne, low skorzonera, clover lupine, Micheli sedges etc. The flora of dry open sandy deposits, along with the boreal elements, is formed by psammophytic: false-cornflower jurinea, sheep's bit, Lithuanian silene, Ukrainian goat's-beard etc.

The brioflora of the research area is characterized as nemorose-boreal one with a significant predominance of the boreal element, that corresponds to its location in the zone of mixed forests. Brioflora of forest formations is the richest and diverse. This is explained by the presence of a number of ecotopes that are favorable for the development of bryophytes, namely: forest soil, the bark of living trees, rotten wood.

Thus, the flora of the 30-kilometer zone of SS Rivne NPP is an interesting object, both from the floristic and phytocenotic points of view. The vegetation cover has a strongly marked boreal complex, in which pine forests and transitional bogs predominate, having on the one hand a significant number of wetland forests, on the other hand, dry pine forests. The Cenofond is characterized by the presence of a number of rare communities at the national and regional levels. In the flora of swamps, meadows, coniferous forests, boreal species dominate, the poor ecotopes of which has created favorable opportunities for their growth. In sozological respect, flora is distinguished by the presence of a large group of Red Book species, glacial relics, and border-areal species.

2.3.2 Fauna

Zoogeographic zoning [66] gives the following systematic position of the 30-km zone of SS "Rivne NPP":

1.Boreal European-Siberian subregion;

1.2. Eastern European District, mixed leaf forest and forest-steppe area;

1.2.a. Section of Eastern European mixed forest and forest-steppe;

1.2.a.a. Subsection Western or Volyn Polissia [66].

According to S.I. Medvedev [67] the zone of SS Rivne NPP should be attributed to the Right-Bank Polissia zone of broad-leaved and mixed forests.

The fauna of the research region is represented by complexes typical for Polissia [68]. According to literary data, more than 60 species of mammals and about 200 species of birds live here.

In entomological terms the Central European forest fauna is well represented here, there are species which range is limited by the Dnieper from the east (Cychrus attenuatus F., Carabus intricatus L., C. arvensis Hrbst., Corymbites purpureus Poda, Phausis splendidula L., Hoplia graminicola F., H. hungarica Burm., Anisoplia villosa Goeze, Amphimallon ruficornis F.).

Within the 30-kilometer zone of SS “Rivne NPP”, 6 main types of the entomocomplexes are allocated. Among them, 5-terrestrial (forest, bush, meadows, marsh, man-made) and 1 water. Forest entomocomplexes are among the most common and valuable in the 30-km zone of SS “Rivne NPP”.

The basis of forest entomocomplexes are insect species consortively associated with the main forest species - pine, birch, oak, alder trees etc. The forests in the surveyed area occupy a large area, but they are secondary (planted or covered with coppice) and are often very poor in entomological terms. This is especially relevant to monocultural plantings of pine. The pests are well presented here – pine tussock moth (Lymantriidae), pine moth (Dendrolimus pini L.), pine looper moth (Bupalus piniarius L.), as well as pine sawfly (Diprion pini L. and Neodiprion sertifer Geoffr), short-nosed weevil (Brachyderes incanus L.), pine weevil (Brachonyx pineti F.). Among stock insects there are larger and smaller pith borers (Blastophagus piniperda L. and B. minor Hart.), bark beetles (Ipinae), grey borer (Acanthocinus aedilis L.) and other borers (Cerambicidae). In the fresh pine stumps and logs a large pine weevil lives (Hylobius abietis L). On the edges, especially in young pine plantings, there was a large amount of grape katydid (Ephippiger ephippiger F.), and a weevil (Rhinoncus castor F) was quite common in the glades.

At the same time, insect-entomophages in pine monoculture stands have a relatively poor species composition. Several species of braconids (Braconidae), ichneumonids (Ichneumonidae) and chalcides (Chalcidoidea) are noted here. The xylophagous-dorictins (Doryctinae) parasites were more common among braconid. Higher diversity of insects species is distinguished in forest entomocomplexes of mixed tree stands. The consortium of petiolate oak (Quercus robur L.) is the richest in species composition. In the ecological and environmental aspects the oak is the most valuable species of the country. Among leaf-eating insects there are several species of leafworms (the filbert leafroller - Archips rosana L., palearctic leafroller - A. xylosteana L., great brown twist - A. podana Sc., Etc.) can be found on oaks in the 30-kilometer area of SS “Rivne NPP”. A number of species of moths (brindled beauty - Lycia hirtaria Cl., winter moth - Operophthera brumata L., clumsy oak moth - Ennomos quarcinaria Hufn., etc.), various moths (green owlet moth - Dichonia aprilina L., gray-brown oak moth - Dryabota protea Bkh. etc.).

Lackey (Malacosoma neustria L.) and some species of tussock moth (Lymantriidae) are also common. Tischeria moths are found on oak among leaf-eating insects. Oak bark pests, especially jewel beetles (Buprestidae) and borers (Cerambicidae) are also numerous. The numerous species on young oaks and other deciduous trees were weevils Strophosoma capitatum Deg.. In the litter, weevils – strawberry root weevil (Otiorhynchus ovatus L.) and black weevil (O. tristis Scop.) are common.

A green grasshopper - Tettigonia viridissima L. - was singularly found, and on the edges and glades the dark bush-cricket Pholidoptera cinerea L. and wood cockroach Ectobius sylvestris Poda were typical.

Among insect-entomophages, braconids from Dolichogenidea, Apanteles, Aleiodes, Meteorus etc. were found on oak trees. Also, ichneumon and chalcid flies (both primary parasites and hyperparasites) were revealed. Parasitic tahina flies were also found along the edges.

Meadow biotopes, as well as ruderal vegetation, are the richest in species of insects such as orthopteroid insects (Orthoptera) and beetles (Coleoptera: Carabidae, Curculionidae). Marshes and floodplain areas are often the habitat of northern (boreal) elements of the entomofauna, while meadow and anthropogenic ento-complexes include southern (steppe and forest-steppe) insect species (Aiolopus thalassinus F.).

In the surveyed area, 18 species of insects listed in the watch lists of the Red Book of Ukraine and the European Red List were identified. Among them, 7 species for the Rivne region are not listed in the Red Book of Ukraine.

In the 30-kilometer zone of SS Rivne NPP 11 species of amphibians are identified. The most common is the lake frog (Rana ridibunda), which inhabits most aquatic and near-water biotopes. Pond frog (Rana lessonae) is much less common. Common species are the gray frog (Bufo bufo), the brown frog (Rana temporaria), the garlic toad (Pelobates fuscus). In meadows, swamps and other near-water biotopes, the moor frog (Rana arvalis) is quite common. The red-bellied toad (Bombina bombina), green tree frog (Hyla arborea), spotted newts (Triturus vulgaris) and crested newts (Triturus cristatus) are less common.

The reptile fauna of the 30-kilometer zone of SS Rivne NPP is represented by 7 species. An ordinary marsh turtle that lives in a number of studied by us water bodies and around them, the sand lizard (Lacerta agilis), which prefers dry and sunny areas, inhabits sparse forests, groves, small woods, hillsides and gullies, brushwoods. Among the snakes, ringed snake (Natrix natrix) is found almost everywhere, it lives along the banks of rivers, lakes, in floodplain meadows, in reed thickets, in forest swamps and other sites. Less common are the viviparous lizard (Lacerta vivipara) and the blindworm (Anguis fragilis). Occasionally, the common northern viper (Vipera berus), and listed in the Red Book of Ukraine the smooth snake (Coronella austriaca) are found on the forest edges and in the brushwoods.

The most numerous group of vertebrates of the 30-kilometer zone of SS Rivne NPP are birds. As part of the ornithofauna of the region, 11 species were identified which are listed in the Red Book of Ukraine. In total, we have registered 190 species of birds, including 65 species nesting in the 30-kilometer zone of SS “Rivne NPP”, although according to literary information 120 species of birds constantly nest in this region [69].

A number of bird species visit the research area irregularly or are migratory [69, 70].

The most numerous and often found are the forest birds: chaffinch (Fringilla coelebs), tree pipit (Anthus trireialis), great tit (Parus major), blackcap (Sylreia atricapilla), yellow hammer (Emberiza citrinella), treecreeper (Certhia familiaris), grosbeak (Coccothraustes coccotraustes), white-collared flycatcher (Ficedula albicollis), greater spotted woodpecker (Dendrocopos major), wood warbler (Phylloscopus sibilatrix), buzzard (Buteo buteo), raven (Corvus corax), jay bird (Garrulus grandarius), siskin (Spinus spinus), robin (Eritacus rubecula) etc. Goshawk (Accipiter gentiles), dorhawk (Caprimuldus europaeus), golden oriole (Oriolus oriolus), wood pigeon (Columba palumbus), cuckoo (Cuculus c anorus), crested tit (Parus cristatus), scarlet finch (Carpodacus erythrinus) etc. Hazel grouse (Tetrastes bonasia) is less common and the least common is black grouse (Lyrurus tetrix) [70]. Red kite (Milvus milvus) has been found twice and peregrine falcon (Falco peregrinus) has been found just once, those are the most rare birds in the region [69, 71].

Among the birds of the wetland and meadow complexes the following have been identified: the gray heron (Ardea cinerea), the moorhen (Gallinula chloropus), the coot (Fulica atra), the mute swan (Cygnus olor), the mallard duck (Anas platyrhynchos), marsh harrier (Circus aeruginosus), yellow wagtail (Motacilla flava), black-headed gull (Larus ridibundus), black tern (Chlidonias niger), kingfisher (Alcedo atthis). Along the rivers and lakes (open meadow areas, bush thickets of floodplains, etc.) the common are: yellow hammer (Emberiza citrinella), whinchat (Saxicola rubetra), thrush nightingale (Luscinia luscinia), marsh warbler (Acrocephalus palustris), great reed warbler (Acrocephalus arundinaceus), blue-throated robin (Cyanosilv ia svecica), river warbler (Locustella fluviatilis) etc. The less common are: corn crake (Krex krex), night-heron (Nycticorax nicticorax), great-crested grebe (Podiceps cristatus). Even less common are black stork (Ciconia nigra) and grey crane (Grus grus), and sometimes species nesting in the area [69- 71]. Rather common, but not numerous species of waders are: woodcock (Scolopax rusticola), snipe (Gallinago gallinago), double snipe (Gallinago media), sandpiper (Tringa ochropus).

For open biotopes (fields, voids, pastures, areas along forest belts, etc.) the background species are: sky lark (Alauda arvensis), crested lark (Galerida cristata), wheatear (Oenahthe oenanthe). The common species, such as hoopoe (Upopa epops), kestrel (Cerchneis tinnunculus), greenfinch (Chloris chloris), quail (Coturnix coturnix) etc. are less often found. In areas adjacent to wet meadows, natural reservoirs corn crake (Krex krex), more often lapwing (Vanellus vanellus) are sometimes found. Species living in sparse tree-shrub vegetation, interspersed with open biotopes are: yellow hammer (Emberiza citrinella), goldfinch (Carduelis carduelis), linnet (Cannabina canabina), red-backed shrike (Lanius collurio), towny pipit (Anthus campestris) etc., which is consistent with data specified in the literature [69, 72- 74].

The mammalian fauna of the studied region probably includes about 50 species [72]. We identified 46 species of mammals. The species composition is determined primarily by the considerable forest cover of the territory and the relative small population. 6 species listed in the Red Book of Ukraine can be found on the territory of the zone, they are: otter (Lutra lutra), steppe polecat (Mustela eversmanni), badger (Meles meles), water shrew (Neomis anomalis); extremely rare: garden dormice (Eliomys guercinus) [75] and barbastelle (Barbastella barbastella) (found in one specimen).

Among the Rodentia rodent group, the following were identified: the root vole (Microtus oeconomus), the bank vole (Clethrionomys glareolus), the pine vole (Microtus subterraneus), the field vole (Microtus arvalis), the muskrat (Ondatra zibethica), beaver (Gastor fiber), brown rat (Rattus norvegicus), red squirrel (Sciurus vulgaris).

There are 4 species among the dormouse family: fat dormouse (Myoxus glis), hazel dormouse (Muscardinus avellanarius), forest dormouse (Dryomus nitedula) and garden dormouse (Eliomys guercinus).

The mouse family is represented by: in the region by house mouse (Mus musculгs), field mouse (Apodemus agrarius), forest mouse (Sylvaemus sylvaticus), harvest mouse (Micromys minutus), yellow-necked mouse (Sylvaemus tauricus), birch mouse (Sicista betulina).

Representatives of the Insectivora, registered in the region: hedgehog (Erinaceus europaeus), shrewmouse (Sorex araneus), lesser shrew (Sorex minutus), mole (Talpa europaea). Less common are the lesser white-toothed shrew (Crocidura suarecolens) and the bicolored white-toothed shrew (Crocidura leucodon) much less frequently: water shrew (Neomys fodiens), southern water shrew (Neomys anomalus).

Common representatives of the Chiroptera in this region are: forest pipistrelle (Vespertilio nathusii), noctule bat (Nyctalus noctula), pipistrelles (Vespertilio pipistrellus). According to literary data, the fauna of bats is represented by at least 10 species of bats [73, 77].

The most common and relatively mass representative of the Carnivora is the fox (Vulpes vulpes). There is a relatively small number of a raccoon dog (Nyctereutes procyonoides), which lives in tangles along rivers etc. We also registered otter (Lutra lutra), rock marten (Martes foina), pine marten (Martes martes), weasel (Mustela nivalis), stoat (Mustela erminea), European polecat (Mustela putorius), steppe polecat (Mustela eversmanni). It is rare, but there is a wolf (Canis lupus). According to the survey, lynx is found extremely rare (Felix lynx) [71, 76].

Brown hare (Lepus europaeus) is widely spread [77].

The hoofed are represented in the region by species common for Polissia - elk (Alces alces), roe deer (Capreolus capreolus) and wild boar (Sus scrofa).

2.3.3 Register of objects of nature reserve fund

According to the data of the departments of environmental protection in the Volyn and Rivne region, there are 48 objects of nature reserve fund (including the natural reserve "Bile Ozero") in the 30-kilometer area of SS Rivne NPP the area of which is more than 12 thousand hectares. These are mainly reserves of national importance, located within Manevytsky district of Volyn region and Volodymyretsky district of Rivne region.

Among the objects of the nature reserve fund (Table 2.1), botanical and forest reserves predominate (23 and 7 objects, respectively), which is a place of life for rare and not widely-spread species. In addition, on the territory of the 30-km zone there are 4 hydrological, 5 general zoological, 4 ornithological reserves, two complex and one swamp reserve. In 2000, the reserve "Bile Ozero" was established.

To the west of SS Rivne NPP in the immediate vicinity of the plant in the floodplain of the river Holubytsia (a tributary of the river Styr) there are Kolodiisky and Kostiukhnivsky botanic resreves with the total area of 17.0 hectares. Besides, Vovchytsky botanic reserve (10.0 hectares), "Chorna Dolyna" ornithological reserve (16.0 hectares), Manevytsky forest reserve (16.0 hectares), Dubyna (70.1 hectares), Berezovy Gai (10.5 hectares), Manevytsky general zoological reserve (138.0 hectares), and Lake Hlybotske hydrological reserve (9.5 hectares) are located in this zone.

To the north west of SS Rivne NPP there are Okonski Dzherela hydrological reserve (0.55 hectares), Okonsky spurce forest botanic reserve (2.6 hectares), and Hradiivska Dubyn forest reserve (7.5 hectares).

To the south of SS Rivne NPP in the floodplain of the river Okonka there are Chartoryisky general zoological reserve (188.0 hectares) and Chartoryisky spruce forest reserve (5.9 hectares). Besides, there are Zarichchia forest reserve (20.0 hectares), Telchsky general zoological reserve (66.7 hectares) and Zhuravichivska forest reserve (2.4 hectares).

To the south-east of SS Rivne NPP there are 7 botanic reserves: Velykoosnytsky (57.2 hectares), Maloosnytsky (9.0 hectares), Telchevsky (33.0 hectares), Osoka (56.5 hectares), Dub Zvychainy (0.3 hectares).

To the north-east of SS Rivne NPP there are several reserves of different designation: botanical Ravine "Vizhar" (36.0 hectares), Khinotsky (2267.0 hectares), Chervonoselsky (1004.0 hectares). In the village of Voronky there is one of the largest botanic reserves Voronkivsky with the area of 2277.0 hectares and Lake Voronky within which the swamp reserve with the area of 23.0 hectares is created. In order to preserve the artificially created stock the park "Antonivka"

(9.7 hectares) in the village of Antonivka, and the complex reserve Volodymyretsky Park (3.0 hectares) in the town settlement of Volodymyrets were created.

To the north of SS Rivne NPP at a considerable distance of the plant there is Ravine Styrske ornithological reserve (273.0 hectares), and to the north-west there are Mulchytsky (3410.0 hectares) and Ozersky (1840.0 hectares) botanic reserves, there are also Likot general zoological reserve (144.0 hectares), Chorny Busel ornithological reserve (32.1 hectares), Karasynsky forest reserve (9.4 hectares).

Thus, within the 30-km zone of SS Rivne NPP the objects of natural reserve fund are unevenly distributed. Most of them are concentrated in the northern (N - 1, NE - 10, NW - 5) and southern (S - 5, SE - 7, SW - 4) directions from SS “Rivne NPP”, 16 objects to each direction, a little less, 9 objects, are located to the west of Rivne NPP. The largest objects of the natural reserve fund are located in the north-east and north-west of the 30-km zone of Rivne NPP, their total area is 11,452.7 hectares. The total area of objects located in the southern directions is 449.7 hectares, to the west of Rivne NPP is 271.1 hectares.

Table 2.1. Nature reserve area register

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insitutions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
1 Lake Voronky	Marshy	23,0 (27,4)	Village of Voronky, Voodymyretsky district	State farm "Zoria"	Decision of the region executive committee №343, dated 22.11.83
2 Velykoosnytsky	Botanic	57,2 (22,1)	Manevychi district, village of Osnytsia, Osnytske forestry, kv. 39, typ. 3, 15-18	Kolkivsky forestry	Decision of the region executive committee № 493, dated 30.12.80
3 Volchytsky	Botanic	10,0 (16,8)	Manevychi district, village of Kostiukhivka, Volchytske forestry, kv. 3 typ. 1	Manevytsky forestry	Decision of the region executive committee № 493, dated 30.12.80
4 Kolodiysky	Botanic	9,5 (12,9)	Manevychi district, village of Kostiukhivka, Volchytske forestry, kv. 8 typ. 3	Manevytsky forestry	Decision of the region executive committee № 493, dated 30.12.80
5 Kostiukhnovsky	Botanic	7,5 (13,1)	Manevychi district, village of Kostiukhivka, Volchytske forestry, kv. 15 typ. 3-5	Manevytsky forestry	Decision of the region executive committee № 493, dated 30.12.80
6 Maloosnytsky	Botanic	9,0 (20,7)	Manevychi district, village of Velyka Osnytsia, Osnytske forestry, kv. 32, typ. 22	Kolkivsky forestry	Decision of the region executive committee № 493, dated 30.12.80

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insituttions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
7 Mnevytsky	Botanic	6,3 (18,3)	Manevychi district, town of Manevychi, Volchytske forestry, kv. 40, typ. 23	Manevytsky forestry	Decision of the region executive committee № 493, dated 30.12.80
8 Osoka	Botanic	56,5 (22,3)	Manevychi district, village of Osnytsia, Osnytske forestry, kv. 40, typ. 1, 12, 14, 16, 21	Kolkivsky forestry	Decision of the region executive committee № 493, dated 30.12.80
9 Telchevsky	Botanic	33,0 (21,2)	Manevychi district, village of Osnytsia, Osnytsky forestry, kv. 39, typ. 3, 15-18	Kolkivsky forestry	Decision of the region executive committee № 493, dated 30.12.80
10 Chartoryisk spurce forest	Botanic	5,9 (11,9)	Manevychi district, village of Staryi Chartoryisk, Chartoryiske forestry, kv. 55, typ. 3, 6	Manevytsky forestry	Decision of the region executive committee №4/3, dated 09.12.98
11 Okonsky spurce forest	Botanic	2,6 (20,0)	Manevychi district, village of Severynivka, Okonske forestry, kv. 3, typ. 20	Manevytsky forestry	Decision of the region executive committee №361-p, dated 20.11.86
12 Oak-1	Botanic	0,01 (20,7)	Manevychi district, village of Velyka Osnytsia, Osnytske forestry, kv. 32	Kolkivsky forestry	Decision of the region executive committee №255, dated 11.07.72
13 Oak-2	Botanic	0,01 (18,8)	Manevychi district, village of Velyka Osnytsia, Osnytske forestry, kv. 25, typ. 23	Kolkivsky forestry	Decision of the region executive committee №255, dated 11.07.72
14 Oak-3	Botanic	0,01 (18,0)	Manevychi district, village of Velyka Osnytsia, Osnytske forestry, kv. 15, typ. 17	Kolkivsky forestry	Decision of the region executive committee №255, dated 11.07.72

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insituttions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
15 Khinotsky	Botanic	2267,0 (27,4)	Khynotske forestry, kv. 1, 2, 4, 5, 9, Stepanhorodske forestry, kv. 30, 33, 34, 37, 38, 41, 42, Khynotske forestry, kv. 3, 6, 7, 8, Stepanhorodske forestry, kv. 27-29, 31, 32, 36, 40, 46		
16 Ozersky	Botanic	1840,0 (28,4)	Ozeretske forestry, kv. 1, 2, 5-7, 10-15, 17-20 Ozeretske forestry, kv. 4, 8, 20, Partysanske forestry, kv. 55-57	Rafalivsky state forestry	Decision of the region executive committee №343, dated 22.11.83
17 Mulchytsky	Botanic	3410,0 (24,6)	Ozeretske forestry, kv. 33-37, 39, 40, 46, 47, 52, Mulchytske forestry, kv. 3, 5, 7, 8, 15-18, 23, 24, 27-32	Rafalivsky state forestry	Decision of the region executive committee №343, dated 22.11.83
18 Krasnoselsky	Botanic	1004,0 (21,2)	Krasnoselsky forestry, kv. 15, 24-27, 40-43	Volodymyretsky state forestry	Decision of the region executive committee №343, dated 22.11.83
19 Voronkovsky	Botanic	2277,0 (29,4)	Voronkovske forestry, kv. 17, 22-26, 28-34, 36-42, 46, 51, 52, state farm “Zoria”, Voronkovske forestry, kv. 18-21, 27, 35, 44-48	Volodymyretsky state forestry, state farm “Zoria”	Decision of the region executive committee №343, dated 22.11.83
20 Ravine “Vizhar”	Botanic	36,0 (18,9)	Collective farm “Druzhba”, village of Dovgovolia	Collective farm “Druzhba”	Decision of the region executive committee №343, dated 22.11.83

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insituttions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
21 Ravine “Lypne”	Botanic	40,0 (21,4)	Collective farm “Urozhai”, village of Lypno	Collective farm “Urozhai”	Decision of the region executive committee №343, dated 22.11.83
22 “Antonivka” Park	Botanic	9,7 (27,3)	Village of Antonivka, Volodymyretsky district	Antonivska village council	Decision of region council №33, dated 28.02.95 г.
23 Ravine “Potky”	Botanic	9,0 (28,3)	State farm “Zoria”, village of Voronky	State farm “Zoria”	Decision of the region executive committee №343, dated 22.11.83
24 Volchytsky	Ornithological	290,0 (17,1)	Manevychi district, village of Volchytsk, Volchytske forestry, kv. 5, typ. 4, kv. 20, 21	Manevytsky state forestry	Resolution of region council № 18-р, dated 03.03.93
25 Zhuravychivska	Botanic	2,4 (29)	Manevychi district, village of Rudnyky, Rudnykovskoe forestry, kv. 33, typ. 2	Kolkivsky state forestry	Decision of region council №17/19, dated 17.03.94
26 Okonski Rodnyky	Hydrological	0,55 (25,7)	Manevychi district, village of Okonsk	Production workshop “Manevytsky”	Decision of region executive committee №255, dated 11.07.72
27 Rudnykovsky	Forest	6,5 (28,2)	Manevychi district, village of Rudnyky, Rudnykovske forestry, kv. 29, typ. 4	Kolkivsky state forestry	Decision of region council №17/19, dated 17.03.94
28 Lake Hlybotske	Hydrological	9,5 (28,9)	Manevychi district, village of Horodok, Horodokske forestry, kv. 13, typ. 46, 47, 51	Horodoksky state forestry	Decision of region executive committee №401, dated 23.11.79

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insituttions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
29 Ravine “Poroda”	Hydrological	36 (21,0)	Volodymyrets district	Volodymyretsky state forestry	Decision of region executive committee, dated 1983
30 Tseptsevytske Dzherelo	Hydrological	1,0 (28,4)	Volodymyrets district	Volodymyretsky state forestry	Decision of region executive committee, dated 1972
31 Volodymyrets Park	Complex	3,0 (19,6)	Town of Volodymyrets, boarding school	Volodymyrets boarding school	Decision of region executive committee №317, dated 20.06.72
32 Hradiivska Dubyn	Forest	7,5 (27,7)	Manevychi district, village of Gradie, Gradiivske forestry, kv. 49, typ. 30	Kolkivsky state forestry	Decision of region council №17/19, dated 17.03.94
33 Dubyna	Forest	70,1 (22,7)	Manevychi district, town of Manevychi, Manevytske forestry, kv. 25, typ. 23, kv. 26, typ. 10, kv. 29, typ. 5, 14, 19, kv. 30, typ. 8, 13	Manevytsky state forestry	Decision of region executive committee № 226, dated 31.10.91
34 Zarichchia	Forest	20,0 (16,6)	Manevychi district, village of Zarichchia, Telkovske forestry, kv. 7, typ. 21	Kolkivsky state forestry	Decision of region council №17/19, dated 17.03.94
35 Karasynsky	Forest	(26,5)	Manevychi district	Manevytsky state forestry	
36 Manevytsky	Forest	16,0 (24,6)	Manevychi district, town of Manevychi, Manevytske forestry, kv. 14, typ. 3	Manevytsky state forestry	Resolution of region executive committee № 361-p, dated 20.11.86

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insituttions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
37 Karasynsky	General zoological	225,0 (29,8)	Manevychi district, village of Zamostie, Karasynske forestry, kv. 40, 41	Manevytsky state forestry	Decision of region executive committee № 226, dated 31.10.91
38 Berezovy Hai	Forest	10,5 (22,9)	Manevychi district, village of Prylisne, Horodokske forestry, kv. 53, typ. 2	Horodoksky state forestry	Decision of region executive committee № 226, dated 31.10.91
39 Teletsky	General zoological	66,7 (18,0)	Manevychi district, village of Kulykovychi, Teletske forestry, kv. 14, typ. 6, 12, 23, 40	Kolkivsky state forestry	Resolution of region council № 18-p, dated 03.03.93
40 Chartoryisky	General zoological	188,0 (9,9)	Manevychi district, village of Chartoryisk, Chartoryiske forestry, kv. 29, 40	Manevytsky state forestry	Decision of region executive committee № 226, dated 31.10.91
41 Lokotie	General zoological	144,0 (25,9)	Manevychi district, village of Serkhiv, Serkhivske forestry, kv. 2	Manevytsky inter-farm forestry	Resolution of region council № 18-p, dated 03.03.93
42 Manevytsky	General zoological	138,0 (28,1)	Manevychi district, town of Manevychi, Manevytske forestry, kv. 2	Manevytsky state forestry	Decision of region executive committee № 226, dated 31.10.91
43 Chorny Busel	Ornithological	32,1 (27,7)	Manevychi district, village of Karasyn, Karasynske forestry, kv. 44, typ. 18, kv. 57, typ. 29, kv. 64, typ. 19	Manevytsky state forestry	Resolution of region council № 18-p, dated 03.03.93

Name	Category	Area, hectare (distance from RNPP, (km)	Reserve area location	Enterprise, organizations, insituttions – landusers responsile for the reserve area	Resolution, decision based on which the reserve area is established
44 Ravine "Styrske"	Ornithological	273,0 (29,0)	State farm "Bilsky" village of V. Telkovychi, state farm "Dibrovsky"	State farm "Bilsky", "Dibrovsky"	Decision of the region executive committee №343, dated 22.11.83
45 Ravine "Romanshchyna"	Ornithological	90,0 (26,3)	Volodymyretsk district	Volodymyretsky state forestry	
46 Chorna Dolyna	Ornithological	419,0 (18,8)	Manevychi district, village of Haluziia, Haluziievske forestry, kv. 48-50	Manevytsky state forestry	Resolution of region council № 18-p, dated 03.03.93
47 Cherensky	Botanic	903,0 (28,7)	Manevychi district, to the north of the village of Karasyn village of Zamostie, Karasynske forestry, kv. 26, typ. 6, kv. 27, typ. 2, kv. 29, typ. 16, kv. 30, typ. 2, 4, kv. 31-33, kv. 37-38	Manevytsky state forestry	Order of the Council of Ministers of Ukraine № 383, dated 03.08.78

3 CHARACTERISTIC OF THE DISTRIBUTION OF ALL NEGATIVE FACTORS WITHIN THE AREA OF PLANNED ACTVITY IMPACT

This section provides information about external hazards (EH) typical for the area of SS Rivne NPP location. The list of EH subject to consideration within this work has been created. EH that have impact on SS Rivne NPP activity can be divided in two groups:

- Natural;
- Man-made.

Hydrometeorological processes and phenomena:

- floods;
- ice phenomena on water sources (ice gorges, ice jams);
- water resources change (extremely low flow, abnormal reduction of water level);
- tornados;
- strong winds;
- precipitations;
- extreme snow falls (heavy snow);
- air temperature;
- ground surface icing;
- lightning;
- water intake facility blocking.

Factors creating the external impact of man-made nature (man-made factors):

- aircraft crash;
- common caused fire;
- explosions at the facilities;
- releases of explosive, flammable, toxic gases and aerosols into the atmosphere;
- breaking of natural and artificial reservoirs.

The list given above is taken as a basis for the environmental impact analysis and may be changed taking into account collected data, towards impacts reduction.

Preliminary exclusion of EH is carried out using simple logical equations allowing to demonstrate without complex calculations and detailed evaluations that external impact is not dangerous for SS Rivne NPP power units and stationary facilities of chemical, fire, and explosion hazard accidents at which can result in contamination and significant adverse impact on the environment and public.

The criteria for EH preliminary exclusion are:

- distance from the source of hazard to SS “Rivne NPP”;
- low frequency of EH;
- non-significance of expected EH contribution to the accidents at SS “Rivne NPP”.

3.1 Natural factors of impact on SS Rivne NPP

Flooding

Spring floods at the river Styr. The impact of the Styr spring floods on SS Rivne NPP is considered in terms of the possibility of flooding of buildings and structures of power units 1, 2, 3, and 4, as well as stationary facilities of chemical, fire and explosion hazard.

For the rivers with water intake area of more than 200 km^2 according to the literature data [78] it is reasonable to consider water level increase related only to spring floods since the water level during the spring floods is significantly higher than during the flooding [79]. Therefore, for the river Styr, the area of the spillway that is 10,400 km^2 to the water intake of SS "Rivne NPP", water rising related to the floods will be considered.

The characteristic of spring floods at the river Styr. The river Styr is the main river flowing through the 30-kilometer zone of SS "Rivne NPP", it crosses the 30-kilometer zone of SS Rivne NPP from the south east to the north west and its length within this area is 113 km (Figure 3.1). the total length of the river is 494 km, the water intake area is 12900 km^2. SS Rivne NPP water intake is situated 326.7 km from the river head and 167.3 km from its estuary, and closes the water intake area which is 10400 km^2.

Annual river level variation within the 30-kilometer zone of SS Rivne NPP s characterized by the high water levels during the spring floods. During summer-autumn and winter periods a short-term insignificant water level increase due to rain showers and winter thaw.

During the flood the water rises to the heist level on the second day after the river uncovering. The peak of the flood lasts one day. Flood ends in mid-May, less often in the first decade of May. The average duration of the spring flood is 70 days, in some years the spring flood lasts up to 130 days (due to rainfalls).

Spring raising of the river Styr levels above the previous horizon usually reaches 2.5-3.0 m. The greatest amplitude of variation of levels 3.74 m [79].

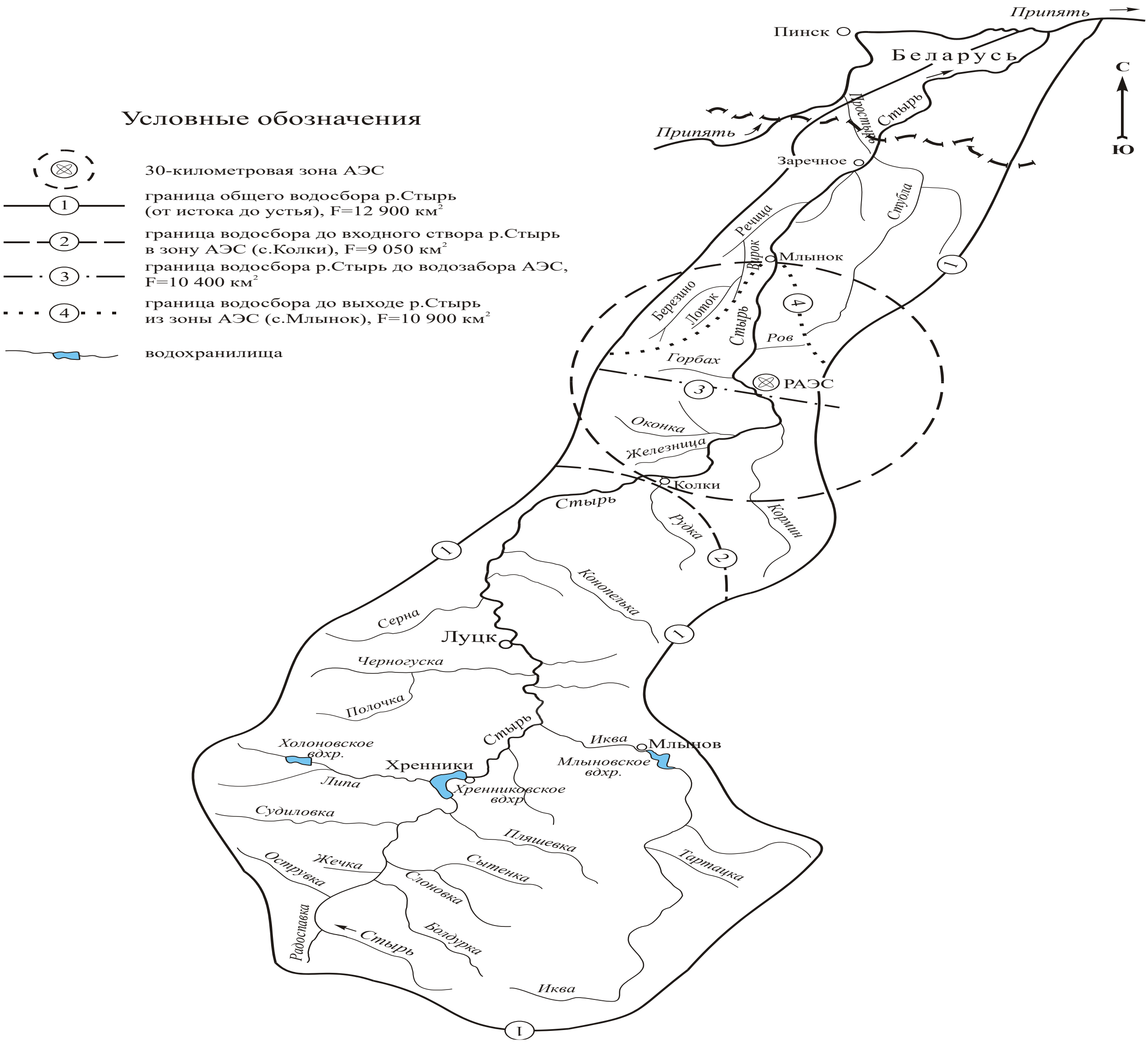


Figure 3.1. Schematic plan of the flood basin of the river Styr

To characterize the levels of water rise in the river Styr the data of long-term studies of hydrometric points located in the area of SS Rivne NPP are used. Estimated flood levels are given in [79, 80].

Table 3.1. Maximum levels of the river Styr at the water intake section of SS "Rivne NPP", m abs.

Parameter	Occurrence probability, %							
	0.001	0.0001	0.00001	0.01	0.1	1	5	10
Elevation, m abs.	166.0	168.8	167.6	165.2	164.4	163.6	163.0	162.8

The highest level of spring flood in the basin of the river Styr within the area observed during the period from 1947 to 1999 took place on April 09, 1956. At the section of SS Rivne NPP water intake this level reached the elevation of 163.20 m. Almost the same level of spring flood was registered in 1979 (absolute elevation 163.00 m). The estimated 0.01% occurrence probability level is 165.20 m.

The estimated 0.01% occurrence probability level is 165.20 m. During the period from 2007 to 2017 mentioned levels have not been exceeded according to the data given in Table 3.2.

Table 3.2. Statistics on maximum level of the river Styr for the period from 2007 to 2017 at the sections of SS Rivne NPP water intake, m abs [81].

Month	Maximum levels of the river Styr, m abs								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
January	159.45	159.56	159.96	160.12	160.67	160.73	159.29	160.57	159.56
February	159.33	160.23	159.92	160.29	160.35	160.89	159.44	160.66	160.01
March	160.19	160.51	159.72	160.62	160.65	160.72	160.16	160.70	159.99
April	160.64	160.20	160.22	160.62	160.54	160.42	159.78	160.97	159.46
May	160.49	159.46	160.23	160.09	160.12	159.92	159.68	160.75	159.52
June	160.49	159.28	160.12	159.69	159.82	159.06	159.67	160.55	159.89
July	159.60	159.65	159.71	159.68	159.57	158.96	159.50	160.16	159.22
August	159.88	158.99	159.67	158.94	159.51	159.38	159.13	159.59	158.76
September	160,09	159.03	159.90	158.77	159.70	159.08	159.13	159.32	158.72
October	159.83	159.01	160.40	159.44	159.74	158.82	159.40	159.33	158.74
November	159.57	159.13	160.40	159.65	159.67	158.83	159.62	159.36	158.80
December	159.31	159.46	160.07	159.58	160.77	159.05	159.70	159.34	159.13

Impact of spring floods on the river Styr on SS "Rivne NPP".

The planning level of the structures of SS Rivne NPP power units is about 188,000 m, the additional water treatment facilities is 192,000 m. The maximum water levels during the floods on the river Styr does not impose a hazard to NPP structures [79, 80], since SS Rivne NPP is raised above the water level of the river Styr to more than 25 m. [82].

Considering this, the impact of flooding on buildings and structures located on the SS Rivne NPP site can be excluded due to the elevation of NPP site above the floodplain of the river Styr.

Floods on the river Styr.

Since the height of the water rise during floods for rivers that have a water intake area of more than 200 km2 is much more than the water rise during floods, it is reasonable, according to [78], to consider the rise of water in the river Styr only associated with floods. According to [79], the maximum flow of floods of 1% occurrence probability is 6 times less than the maximum flow during floods. Consequently, maximum water levels during floods on the river Stir do not impose a hazard to NPP structures and are to be excluded, and are not considered further.

Impact of heavy rains on NPP

The accumulation of water at SS Rivne NPP site can be dangerous if the height of the precipitation over the site objects is exceeded. To ensure protection of the NPP territory from atmospheric precipitation, a system of water drains and an industrial sewage system are provided for at the site. Danger to the structures and components of nuclear power plants can be caused by short-term intensive heavy showers, during which the industrial drainage and the facilities drainage systems are not able to drain the required amount of water. Industrial sewage systems are designed in accordance with general building regulations based on the conditions for receiving and passing drains from rainfall with once a year frequency. Drainage of surface water from SS Rivne NPP site is carried out through the planned surfaces to the trays of roads or ditches reinforced with monolithic reinforced concrete, followed by discharge into the storm sewer [79, 80]. Excess rainwater penetrates the soil [79]. After purification rainwater from SS Rivne NPP site is used to feed the technological cycles of nuclear power plants [83]. The description of the industrial sewage system is provided in [79, 80].

Design standards for the design of water drain systems for buildings and industrial sewage systems are defined by СНиП 2.04.01-85 and 2.04.03-85 [84], in which the design flow of rainwater is determined based on the intensity of rain for 20 minutes (q20). For SS Rivne NPP site this design criterion is 100 liters/s×h or 0.6 mm/min [79].

To determine the intensity of rain, the results of [86] are used. The frequency of rainfall lasting less than an hour on the territory of Rivne region is 0.067. The distribution of precipitation intensity is given in Table 3.3.

Table 3.3. The distribution of precipitation intensity for Rivne region

Precipitation amount, mm	30	40	50	60	70	90	100
Frequency of precipitation amount in case of rainfall, %	38.6	10.6	19.1	4.3	4.3	12.8	2.1
Precipitation intensity during 20 minutes rain	1.1	1.5	1.9	2.3	2.7	3.4	3.8

The graph in Fig. 3.2 based on data from table 3.3. shows the precipitation intensity with a 20 minute rain duration, obtained by way of calculation from the hourly intensity using a reduction coefficient that is given in [80, 81] equal to 2.3 (calculated reduction coefficient 2.2 [87]). The approximating curve is constructed by the least squares method:

$$W(h) = 0{,}268 \times \exp(-1{,}162 \times h)$$

Probability of exceeding the design criteria 100 l/s×h (0,6 mm/min) isW (0.6) = 0.133.

Figure 3.2 shows the probability of exceeding the intensity of rain lasting 20 minutes for SS Rivne NPP site, which shows that the design criteria for this type of impacts may be violated with a frequency of 0.133 1/year. Figure 3.2 also shows data on the strongest rainfall and rain showers in SS Rivne NPP site area, the territory of Ukraine and in various regions of the globe [78]. The given data show that the maximum daily height of precipitation in the Rivne region does not exceed 100 - 110 mm, and in the territory of Ukraine - 183.2 mm with a maximum rain intensity of less than 3 mm/min.

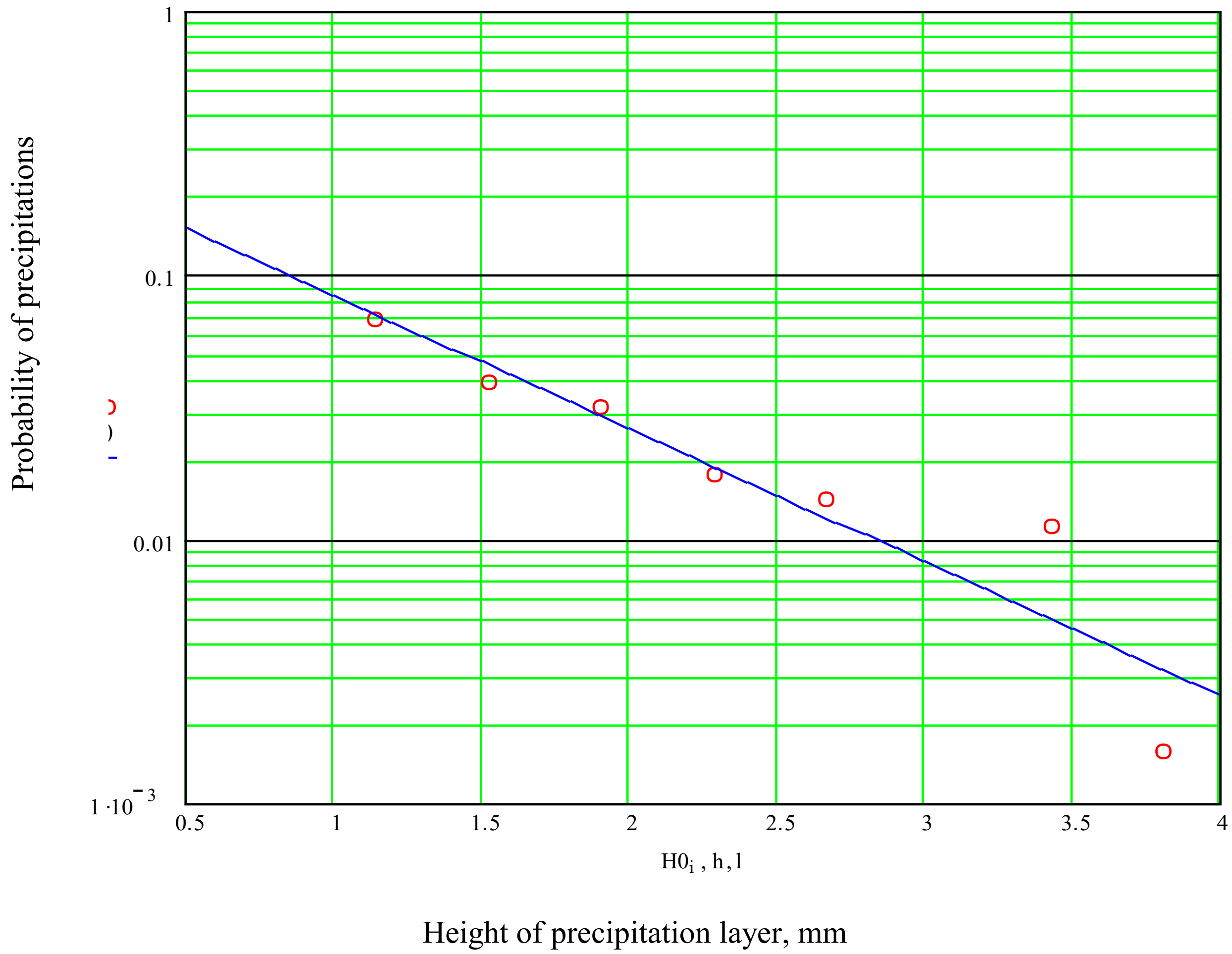


Figure 3.2. Precipitation intensity during 20 minutes rain

Data on the maximum intensity of rain in different parts of the globe, including Ukraine, are presented in Table 3.4. During observations of intense precipitation over the globe, no precipitation was recorded with an intensity exceeding 8.4 mm/min. The daily maximum precipitation in the Rivne region as of June 7–12, 1969 was 100–110 mm. [85]. According to the data of the Manevichi meteorological station (26 km. from SS “Rivne NPP”) in the Rivne region, the extreme daily maximum of 103 mm exceeds the average monthly sum of summer precipitation to about 1.2-1.5 times [79, 80], and 106 mm of precipitation were at the Sarny station on September 11, 1963.

Rain showers are dangerous not only because of a large amount of precipitation, but also because of high intensity. According to observations by the Kovel meteorological station, where there is a rain-recording gauge, the greatest intensity over a 5-minute interval was 2.6 mm/min on August 08, 1958, and the maximum intensity for one hour was 0.7 mm/min on September 05-06, 1992 [79, 80].

Table 3.4. The most heavy showers and rainfalls in different regions of the globe and on the territory of Ukraine

Country, place	Year	Duration of rain, hours, minutes	Height of precipitation layer, mm	Maximum precipitation intensity, mm/min
Ukraine, Mykolaiv	1995	06:46	182.3	2.96
Ukraine, Khrystynivka	1932	04:30	147.0	2.68
USA, Preston	1893	00:05	31.0	6.2
USA, Wisconsin	1881	00:15	57.0	3.8
France, Bordeaux	1883	00:20	87.0	4.35
Nepal, Mangalpur	1964	02:00	139.0	1.2
Austria	1904	00:45	194.0	4.3
USA, Virginia	1906	00:30	252.0	8.4
India, Calcutta	1935	03:00	300.0	1.7
USA, Missouri	1947	01:00	305.0	5.1

Calculated flood levels are approximated by the expression:

$$w(h) = \exp(-(ah + b))$$

$$b = -462.401$$

$$a = 2.855$$

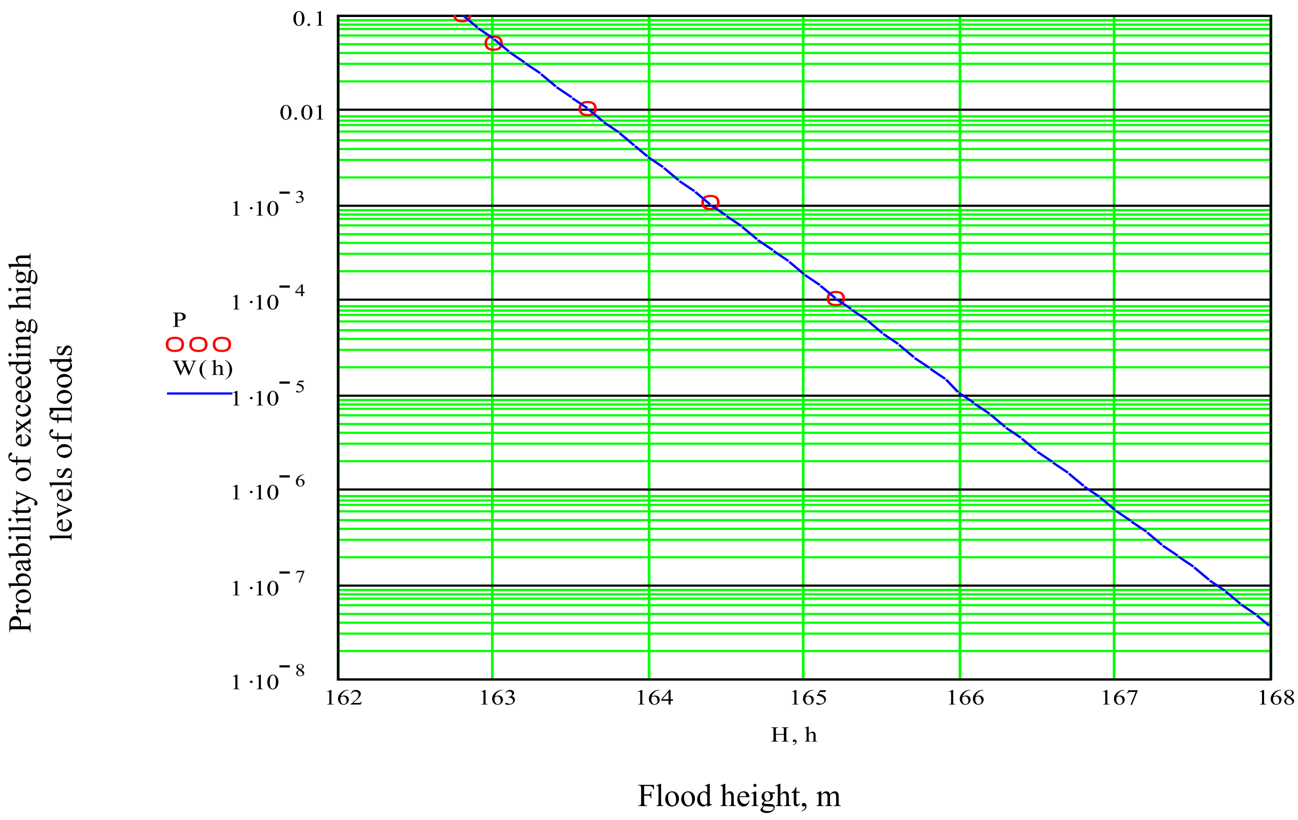


Figure 3.5. Probability of exceeding high levels of floods on the river Styr

According to reports on the results of meteorological observations in SS Rivne NPP region over the past (including 2017) years [87, 88], the amount of precipitation did not exceed the maximum previously recorded value. In addition, the given data do not affect the results of elimination, since the external effect of precipitation consciously has a much lower occurrence frequency than other EH, and cannot lead to more serious consequences.

The effect of rainfall largely depends on the movement of cyclones and anticyclones, the seasonal characteristics of which are shown in Figure 3.6 and Figure 3.7.

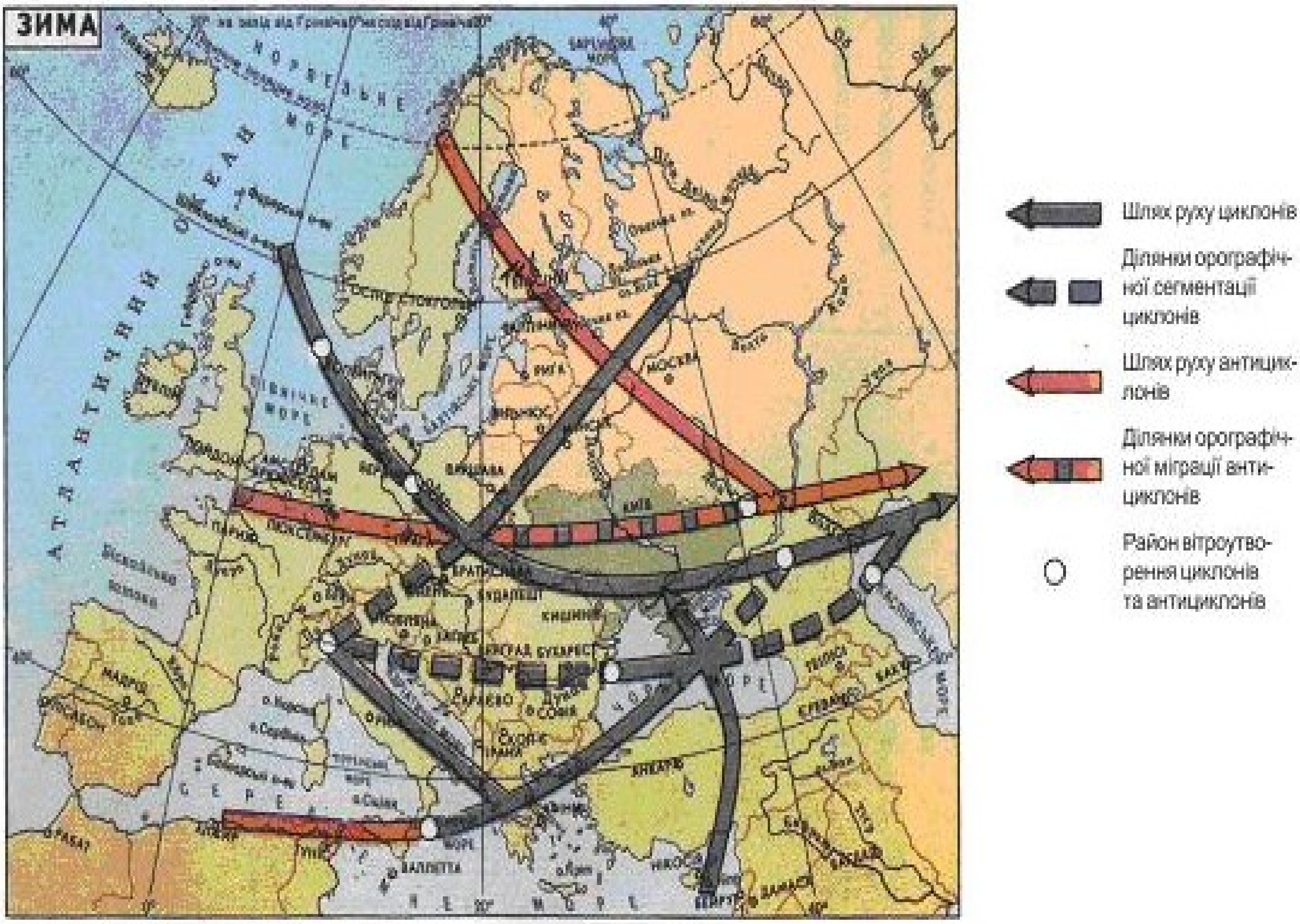


Figure 3.6. Main routes of cyclones and anticyclones in winter

If the rain intensity exceeds the design criteria, it is possible that the normal power supply equipment of the power unit may fail due to rainwater leakage through the roofs and openings (for example, the transport gate) of the turbine hall building, deaerator compartment and electrical equipment stacks. These leakages can occur when the water level exceeds the design level, resulting from the impossibility drain the necessary amount of water from the roofs of buildings and the NPP site. Leakages may result in possible malfunctions of normal power supply system equipment etc.

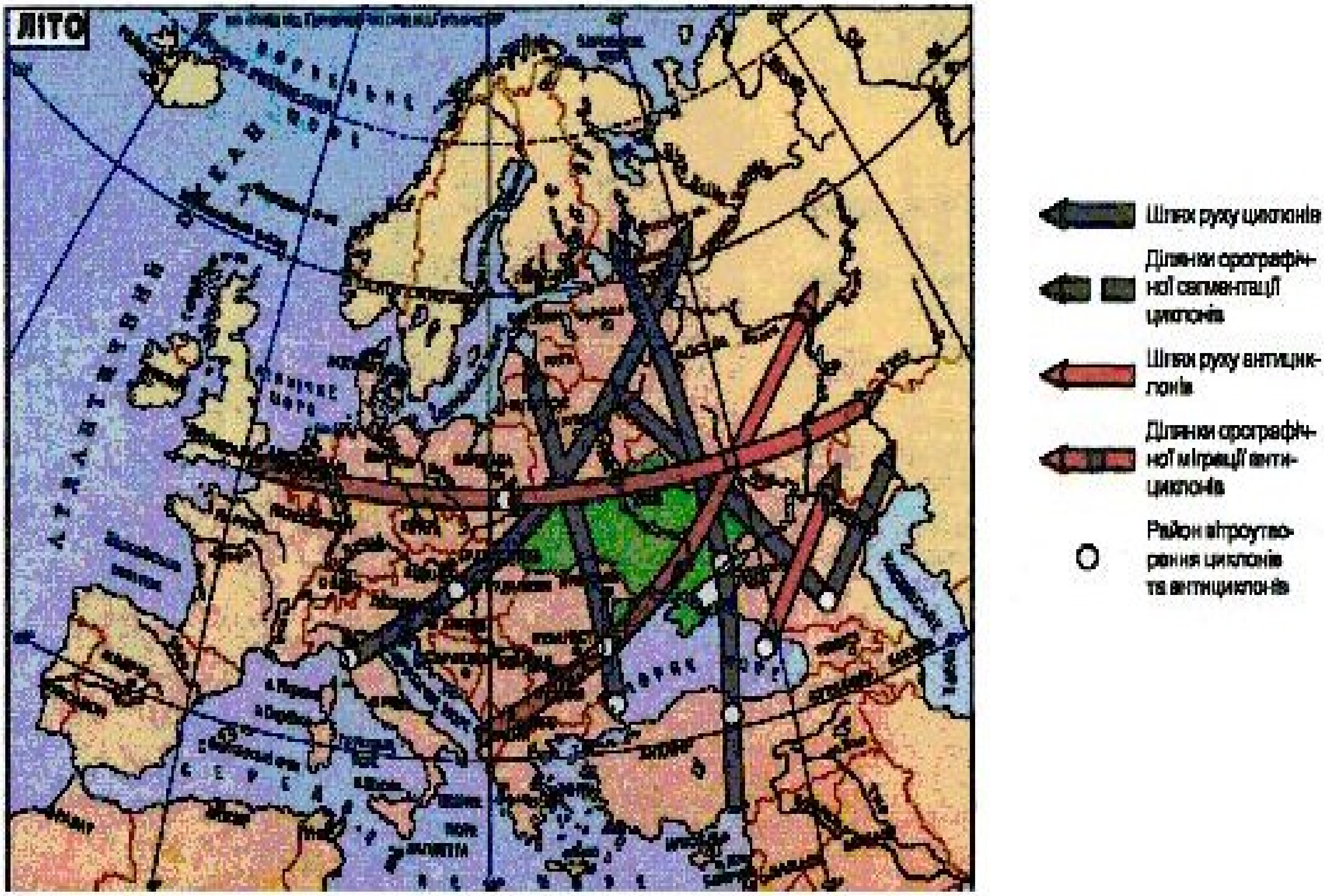


Figure 3.7. Main routes of cyclones and anticyclones in summer

If the rain intensity exceeds the design criteria, it is possible that the normal power supply equipment of the power unit may fail due to rainwater leakage through the roofs and openings (for example, the transport gate) of the turbine hall building, deaerator compartment and electrical equipment stacks. These leakages can occur when the water level exceeds the design level, resulting from the impossibility drain the necessary amount of water from the roofs of buildings and the NPP site. Leakages may result in possible malfunctions of normal power supply system equipment etc.

When determining in [82] the frequencies of emergency events based on the processing of statistics of actually recorded events during the operation of power units, various initiators were taken into account, including cases in which the initiating events of emergency situations were triggered by external factors. Thus, the influence of heavy showers on NPPs is excluded from further consideration.

Ice phenomena on the river Styr (ice gorges, ice jams).

Data regarding ice phenomena on the river Styr.

With the transition of air temperature in the autumn-winter period to negative indicators, the first ice formations appear on the river Styr (slush, grease, broken ice). This usually happens in early December, and in some years in November or at the end of December. The ice thickness during the winter varies due to frequent thaws. In some years, the thaws are so long that the winter breakup on the rivers takes place. By the end of winter, the ice thickness on the shallows reaches 0.2–0.3 m, on the stretches of the river - up to 0.4 m. During the most severe winters, the ice thickness reaches 0.50–0.60 m. The average duration of the period with ice phenomena is about 100 days.

Freezing together at the river banks, these formations first become ice ledges, and then complete ice coverage. First, the ice covers stretch areas, bays and coastal shallow water. On the rapids, the formation of ice may be delayed by one to two weeks. The presence of open water areas in wintertime creates favorable conditions for slush ice run, ice jam phenomena and the formation of intrawater ice. Ice jams are usually observed at the bridges, as well as on steep bends of the river course and in shallow water areas. The accumulation of slush, freezing up with the bottom, contributes to the formation of ice jam. These phenomena can partially or completely block the flow of the river and cause a sharp increase (or decrease) in the levels above (below) the ice jam.

Spring breakup of the river Styr usually occurs in mid-March, less often in early February (as in 1946) or in early April (as in 1956). There are also years when the freeze-up on the river is very short, ice melts in place and does not form ice drift. During the ice drift the major mass of ice passes the course, but there is a possibility of carrying the ice to the floodplain when the high level of the flood is accompanied by ice drift. During the period of spring ice drift, ice gorges are observed in steep bends of the course and at the bridges. Ice gorge lasts not more than a day. The rise of levels resulted from ice gorge or ice jam phenomena usually does not exceed 0.3–0.4 m and is significantly less than the rise of water caused by spring floods. At the water intake section of SS “Rivne NPP”, such phenomena can be observed below the water intake near the town of Varash [79, 80]. The duration of the spring ice drift is on average 6 days. The longest ice drift was in 1958, it lasted 40 days (with such a duration, the drift is not intensive).

The impact of ice gorges and ice jams on facilities of “Rivne NPP”.

The auxiliary water pumping station is located on the right bank of the river Styr at the elevation of 165,000 m. The length of the underwater channel from the mouth to the water intake openings of the plant is 370 m, while the water comes to the water intake by gravity. Mechanical damage to the pumping station from ice gorges and ice jams is impossible, since the auxiliary water pumping station is located at a considerable distance from the course of the river Styr [80].

Taking into account the low level of water rise during ice gorge and ice jam compared with the water rise during floods, the impossibility of mechanical damage to the pumping station from ice gorges and ice jams due to the significant distance of the pumping station from the river Styr, it can be concluded that the operation of the auxiliary water pumping station will not be effected by the ice phenomena this effect can be excluded.

Change of water resources, abnormal water level reduction in the river Styr.

The lowest water levels on the rivers of the 30-kilometer zone are usually observed in July and August. Levels of winter low water are higher than summer levels on the river Styr by an average of 20-30 cm. The smallest summer-autumn levels for the period 1947-2017 were observed in October 2011 [79-81, 89]. The lowest level in the SS Rivne NPP intake point in 2011 was 158.63 m abs. Estimated minimum daily water level in the river Styr are given in Table 3.5.

Table 3.5. Minimum daily levels of the river Styr at the section of SS Rivne NPP water intake, m abs

Parameter	Occurrence probability, %					
	50	75	90	95	97	99
Elevations: summer, autumn	159.4	159.1	159.0	158.9	158.8	158.3
	159.7	159.5	159.3	159.2	159.1	159.0

Duration of low levels on the rivers is from several days to one month. Usually it takes place in July-August, sometimes in September. The rivers do not completely dry and freeze over.

For the period from 2007 to 2017 the mentioned levels have not significantly changed compared to those specified in table 3.6.

Table 3.6. Statistical data regarding minimum levels of the river Styr during the period 2007-2017 at the section of SS Rivne NPP water intake, m abs [89].

Month	Minimal levels of the river Styr, m abs								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
January	158.89	159.22	158.96	159.49	159.58	160.35	158.86	159.66	159.03
February	158.91	159.34	159.57	160.03	159.55	160.48	158.96	160.09	159.44
March	158.99	159.97	159.58	160.00	159.73	160.37	159.29	160.46	159.47
April	160.28	159.47	159.46	160.11	160.11	159.93	159.55	160.55	159.09
May	159.48	159.08	160.14	159.39	159.79	159.10	158.68	160.50	158.87
June	159.22	158.76	159.01	159.46	159.55	158.75	158.86	160.16	159.28
July	158.91	158.74	158.87	158.91	159.47	158.72	158.75	159.53	158.77
August	159.34	158.72	159.31	158.76	159.13	158.87	158.61	158.91	158.62
September	159.83	158.75	159.01	158.70	159.19	158.70	158.82	158.89	158.63
October	159.08	158.88	159.90	158.73	159.58	158.63	159.07	159.15	158.64
November	159.09	158.95	160.08	159.43	159.55	158.73	159.28	159.13	158.70
December	159.16	158.95	159.80	159.20	159.46	158.75	158.86	159.17	158.63

Impact of abnormal water reduction in the river Styr on SS Rivne NPP operation.

Water to replenish water losses in the spray cooling ponds, as well as in the circulating water system is supplied from the following sources:

• form the river Styr with preliminary treatment at water purification plant – the main makeup water system;

• from the circulation system of power units 1 and 2 (non-essential head pipeline) –backup makeup water system;

• residual water of water purification plant and purified water of household sewage of conditionally "contaminated" zone after radiation monitoring.

In addition, it is envisaged to operate the cooling system of group A without makeup within 24 hours due to the operation of the available capacity of the spray cooling ponds [79, 80]. The backup source for group A cooling system makeup is also envisaged [79]. When calculating water balance an excess of runoff was found for the river Styr in low-water years during the operation of four power units of SS Rivne NPP [79].

However, under an abnormal decrease of the water level in the river Styr, there is a possibility of termination of makeup water supply to groups A, B spray cooling ponds and to the circulating water system. Pumps in the auxiliary water pump station are designed for the minimum water level in the river Styr 158.80 m [79], which corresponds to the minimum daily water level of 97% of the occurrence probability in the summer. Thus, it is possible to stop the supply of makeup water with a frequency of 0.03 1/year.

Under the abnormal decrease of the water level in the river Styr, groups A and B, as well as circulating water systems can be disabled. The conditional probability of core damage [90], in the event of the failure of these systems, is 9.17E-08. The contribution to the core damage frequency (CDF) of the failures of these systems is 0.03 × 6.84E-08 = 2.05E-09 1/year (or 0.13% of CDF value) and is less than 1% of CDF value calculated for internal initiating events of the accident, since, in accordance with [90], the CDF value for SS Rivne NPP is 1.62E-06.

Based on the above, it can be concluded that an abnormal decrease of the water level in the river Styr does not impose a hazard to the structures and components of NPP, and this effect can be excluded.

Tornadoes

Information on natural meteorological phenomena occurring in the territories bordering SS Rivne NPP site is given on the basis of the data of the Hydrometeorology Committee of Ukraine on especially dangerous weather phenomena [91] and the climate reference book [85].

Tornado is a strong small-scale whirlwind, formed under well-developed cumulonimbus clouds and spreads in the form of a giant dark cloud column, descends in the form of a funnel to the surface of the earth (or sea). Approaching a vortex on the earth's surface, it sometimes draws in and raises water, dust, sand, and often very heavy objects (logs, roofs, etc.) to a great height. Tornado has great destructive power. Normal tornadoes are observed simultaneously with a thunderstorm, heavy rain, sometimes hail.

According to the zoning of tornado-hazardous events, SS Rivne NPP site is located in the tornado-hazardous area [92]. According to the catalog of tornadoes registered on the territory of the USSR from 1945 to 1986 [92] and the data of the Hydrometeorological Committee of Ukraine for the period 1986-1997 [93], directly on the territory of the 30-kilometer zone of SS Rivne NPP the 0 intensity tornado was registered in the village of Manevychi on August 06, 1974.

The closest to SS Rivne NPP were tornadoes of 0 intensity class at the village of Lobachevka, Volyn region (May 20, 1960, 55 km south of SS “Rivne NPP”), in Rivne (August 20, 1973, 80 km south of SS “Rivne NPP”), and tornadoes of 1 intensity class in Kovel (July 14, 1984, 82 km west of SS “Rivne NPP”) and in Kamin-Kashyrsky (June 23, 1997, about 72 km north-west of SS “Rivne NPP”) Volyn region, and in Novograd-Volynsky, Zhytomyr oblast (June 02, 1980, 142 km south of SS “Rivne NPP”). Tornado of 2 intensity class was registered on May 28, 1951, 120 km south-west of the SS Rivne NPP in the territory of the Republic of Belarus.

The probability of a tornado-hazardous phenomenon in a limited area, which is the 30-kilometer zone of SS “Rivne NPP”, according to [92], is usually estimated from the annual probability of passing the calculated tornado and the estimated tornado intensity class. These characteristics in this case are approximately as follows:

- annual probability of a tornado passing through any point of the 30-km zone of SS Rivne NPP is 9.25×10^{-7} reactor/year;

- estimated intensity class of probable tornado is 1.92. The probability of not exceeding the estimated tornado class is 0.90 (in 90 cases out of 100, the calculated intensity class will not be exceeded).

Table 3.7. Tornadoes registered within 200 km radius from SS “Rivne NPP”.

The place where a tornado is registered	Date	Intensity class	Distance from SS Rivne NPP and direction (point)
1 Davyd – Horodok district, Brest oblast	28.05.1951	2	~120 km to NW (territory of the Republic of Belarus)
2 Village of Lobachovka, Volyn region	20.05.1960	0	~ 55 km to SW
3 Village of Obroshyno, Lviv oblast	23.08.1966	0	~ 165 km to SW
4 Rivne	20.08.1973	0	~ 80 km to SSE
5 Manevychi, Volyn region	08.06.1974	0	~ 26 km to W
6Novhorod-Volynsky, Zhytomyr oblast	02.06.1980	1	~ 142 km to SW
7 Kovel, Volyn region	14.07.1984	1	~ 82 km to W
8 Village of Shelvov, Lokachyn district, Volyn region	20.07.1987	0	~ 102 km to SSW
9 Kamen-Kashursky, Volyn region	23.06.1997	1	~ 72 km to NW

Tornadoes are observed throughout Ukraine and cause material damage. Tornado is a strong air circulation, which has the form of a funnel, which descends from a powerful cloud or resembles a dust cloud, rotating and rising from the ground. The tornado exists not for long, moving along with the cloud, particles of moisture, sand, dust and other particles.

In accordance with [94], SS Rivne NPP is located in the tornado-hazardous ID zone. The class of tornado, calculated for this zone on the basis of statistical data on 77 tornadoes, corresponds to the value K = 2.78, and the annual frequency of tornadoes through any point in the region is 1,11E-06 1/year.

In this section, the impact on SS Rivne NPP of tornadoes specific for the ID zone, as those having a higher frequency of passing through the NPP site and a high impact intensity, is conservatively considered.

The result of recalculation of the tornado class for the location of SS Rivne NPP are provided in [95]. As a result of statistical data selection for the territory within a radius of 200 km from SS Rivne NPP with RD-95 [96] and the data of the Hydrometeorological Committee of Ukraine for the period 1986-1997, 9 tornadoes were selected with a maximum intensity class 2 on the Fujita scale. Based on this statistic, the calculated class of tornado intensity was obtained equal to 1.92. Annual probability of tornado passing through any point of SS Rivne NPP is 9,25E-07, which is somewhat lower than the value obtained for ID zone.

Tornado characteristics are given in Appendix D of this research.

Impact of tornado on the buildings and structures of SS “Rivne NPP”.

As a result of a tornado passing through SS Rivne NPP site, the buildings and structures containing safety systems equipment, buildings comprising normal operation systems, and a number of auxiliary buildings and structures may be damaged that can lead to the emergency situation at NPP site, pollution of the environment and negative impact on humans [85].

Detailed description of the building and structures important to safety and engineering structures is given in [97].

In case of tornado at SS Rivne NPP the following components of safety important systems and normal operation systems can be damaged:

- spray cooling ponds of essential service water systems of groups A and B;
- outdoor switchgears and transmission lines;
- ventilation and air conditioning systems with outer air intake.

To assess the stability of the reactor compartment, we used loads typical for tornado of class 3, 4. The results of the calculations did not show the vulnerability of the reactor compartment to tornadoes of class 3, 4 and less.

Since the building of the emergency diesel generator station was designed taking into account the air shock wave (ΔP = 30 kPa), and the stresses in building structures under the loads from the air shock wave exceed the stresses caused by the loads from the tornado (in case of class 3 tornado the load does not exceed 8.1 kPa), the impact caused by a tornado, does not impose a danger to the building of the emergency diesel generator station. Damage of the building structures associated with damage to the frames or glass, which may occur during a tornado, does not lead to the failure of safety systems located in these buildings. Thus, on the basis of the calculations and estimates given in [97], the building of the reactor compartment and the building of the emergency diesel generator station are excluded from further consideration.

In case if tornado passes through the turbine building the damage is possible. Provided in Appendix E the additional evaluation of tornado impact on the buildings and constructions of framed type and systems important to safety located inside these buildings and structures allows to make a conclusion that this impact can be excluded from the further consideration.

In case if tornado passes through pump stations of circulation water systems (this system includes unit pump station and cooling tower relift pumping plant) the malfunction of circulation water system is possible. The conditional probability of core damage under the circulation water system failure is 6.84E-08 [90].

The damage of mentioned buildings, structures and components of the power unit cannot only be caused by the loads resulted from pressure drop and wind pressure in case of tornado at NPP site, but also by possible strikes of flying objects captured by tornado. The possibility of transferring these items depends on their availability in the tornado area, as well as their tightness to the ground and other random events. Table 3.8 shows the names and characteristics of objects that can be lifted into the air during a tornado of a certain class [98].

Table 3.8. Velocity and type of flying object captured by class **k** tornado (tornado class is specified near velocity value)

Flying object	Maximum height of the object in the air, m	Flying object velocity, m/s (under the corresponding tornado class)			
		45 (0,7)	67 (1,7)	89 (2,6)	112 (3,4)
Wooden board	61	27	32	40	45
3-inch tube	30	18	22	29	38

Flying object	Maximum height of the object in the air, m	Flying object velocity, m/s (under the corresponding tornado class)			
		45 (0,7)	67 (1,7)	89 (2,6)	112 (3,4)
Support	9	*	*	*	36
Vehicle	9	*	*	*	11
* Under given velocities the object is not lifted off the ground					

The results given in Table obtained by computer modeling under the following conservative assumptions:

- It is assumed that the flying objects do not rotate;
- The largest object area is assumed to be perpendicular to wind speed;
- The vertical component of wind speed is assumed to be constant with height.

Computer simulation does not take into account the rotation and overturning of the vehicle relative to the vector of tornado motion, as well as the reduction of its speed due to friction in a collision with the ground. The data given in Table 3.8. are significantly conservative. According to the calculation results given in Table 3.8, the vehicle movement begins at a tornado speed of 112 m/s (tornado class 3,4), therefore impacts associated with vehicle strikes on NPP buildings and structures may not be considered.

Other objects that can fly under the tornado (boards, pipes ets.) similar to those presented in Table 3.8. can also not be considered due to their small mass. The contact of these items with enclosing reinforced concrete structures can lead to local chipping and splitting of concrete, however, this will not affect their design functions. When small flying objects (boards, pipes, etc., similar to them) hit the window and door openings, it can be assumed that the latter were destroyed and a further direct impact on the equipment and pipelines located inside the buildings.

In this case, the following damages were considered: (a) single systems equipment of the turbine hall and (b) simultaneous damage of the several systems equipment. The PSA review showed that the consequences of equipment failures in case (a) are already taken into account in the Level 1 PSA for internal initiating events. The consequences of failures in case (b) can be considered similarly to the consequences of the spatial interactions influence (jets, pipeline whip, spraying, etc.), modeled in the framework of the flooding PSA. Considering the frequency of tornadoes 1,11E - 06 and the likelihood of small objects flying into the holes, the frequency of undesirable consequences as a result of such events is insignificant compared to those already modeled.

Thus, the impact of a tornado on the listed buildings and structures can be excluded from further consideration.

Impact of tornadoes on the spray cooling ponds.

The elements of the cooling systems that may be affected by the tornado include the spray cooling ponds of groups A and B. Damage to the spray cooling ponds may occur due to the influence of the tornado on the open reservoir, as a result of which water can be carried out of the pond. As a result of this impact, the water level in the pond may reduce below the permissible level necessary for normal operation of the unit. Cases of tornadoes impact on natural water bodies and their consequences are given in [99].

A description of the spray cooling ponds is given in [79, 80]. The failure of the three spray cooling ponds can lead to an initiating event of the T13 group "Loss of essential service water system”. The conditional probability of core damage due to the failure of the essential service water system is 6,93E-03 [90].

It shall be noted that malfunction of spray cooling ponds operation together with the malfunction of power supply systems operation cannot be excluded from further consideration. Conditional probabilities and consequences of such events shall be considered in the next stages of work.

Impact of tornadoes on the air inlets of ventilation and air conditioning systems.

Air cooling systems may be damaged due to sudden changes in pressure related to tornado occurrence at the NPP site and damage to the air intake of these systems. A description of the air cooling system is given in [100]. Elements of the air intake of air cooling systems are equipped with ultrasonic signaling devices - passive devices with mechanical parts, which, when exposed to long-duration air shock waves with a pressure of 0.3 to 10 kgf / cm², close the USD. Considering the time of the impact of a tornado on the air intake, which is units and fractions of seconds at a tornado speed, this effect can be represented as an impact associated with the impact of a shock wave. Since the magnitude of the pressure drop during the class 3 tornado is 7–8 kPa, it can be stated that tornadoes of lower than 3 class will not cause the damage of the air intake elements of the ventilation systems. Therefore, the impact of a tornado on these elements can be excluded from further consideration.

Impact of tornadoes on the power supply systems.

Tornadoes at the NPP site can result in the loss of power supply. Such systems include the systems of in-house normal and backup power supply. These systems may fail, for example, due to broken wires connecting the power unit to the outdoor switchgear-750 or the second set of stand-by transformers with outdoor switchgear-330, resulted from wind pressure on the wires, insulators and transmission line supports. Breakage of wires can occur in case of intersection of the path of a tornado with a power line.

As shown in [101], at wind speeds of more than 31 m/s (such wind is typical of the 0 class tornado), the in-house power supply systems may fail. The frequency rate of a tornado of this class and higher at any point of the NPP site is 1,11E-06. Breakage of flexible communication lines connecting the power unit to the open switchgear-750 and a flexible communication line connecting the 330 kV switchgear to the second set of stand-by transformers can lead to an initiating event.

According to initiating events grouping in the PSA Level 1, this is initiating event of T1 group “De-energizing of all sections of normal power supply” [82], however, this event cannot be excluded from consideration, since in this case, under the loss of essential service water as a result of tornado over the spray cooling ponds the ability to restore power supply through available systems is completely lost.

Based on the results of the research given in [102] and the results of this work, a range of tornado classes and their basic parameters, the impact of which is dangerous for buildings and structures of SS “Rivne NPP”, have been determined. Using the results of work [97] and a qualitative analysis of possible emergency events, the screenings of NPP buildings, engineering structures and components that are not exposed to danger has been made. The conditional probability of a simultaneous impact of a tornado on the normal power supply and service water systems (spray cooling ponds of essential service water of groups A and B) shall, in accordance with the TOR, be determined at the next stage of work.

Seismic activity

During the complex geological-seismotectonic analysis near SS "Rivne NPP", seven seismotectonic zones of four levels of potential seismic activity were identified: potential zones of possible earthquakes (ZPE) of the 1st and 2nd order and seismotectonic zones of the 1st and 2nd orders. The seismotectonic activity of the latter two is very low. Seismic action from the local potential ZPE is estimated: the project earthquake (PE) - 5 points; maximum estimated earthquake (MEE) - 6 points.

Thus, the seismic hazard for the SS "Rivne NPP" site may represent only the earthquake in the Vranch zone (Romania) and the local potential zones of possible earthquakes. Estimation of seismotectonic potential by a formalized method based on the earthquake catalog of the West-European platform's event allows us to conclude that there are no zones with high seismotectonic potential at the vicinity of the SS "Rivne NPP" site, only several distances with seismotectonics are allocated at a distance of more than 40 km north of the site. the potential of $2.8 < M < 3.9$. Proceeding from the general analysis of seismological and seismotectonic conditions, one can conclude that the PE and MEE are 5 and 6 points, respectively, for moderate soil conditions.

More detailed information is provided in the Report "Conducting the Environmental Impact Assessment of the Rivne NPP site" Book 3 Part 3 "Geological Environment".

Strong winds

The atmospheric air protection from the harmful impact [103, 104] of RNPP releases require accounting of the meteorological and aerologic characteristics of the atmosphere state, which influence directly on the radionuclides spreading. The primary focus should be on those characteristics that worsen the atmosphere self-purification mechanism and contribute into accumulation of impurities in the aerial environment.

Considering the peculiarities of the atmosphere circulation, the winds that prevail in territory of Rivne NPP during a year at the elevations are north-western and western winds. During the summer period, the likelihood of north winds increases, and in winter – south-eastern and southern winds. During the transition seasons, the amount of south-eastern, southern winds increase, and at the height of 100 m the northern winds occur (Attachment F "Wind characteristics in the 30-km area of Rivne NPP").

Repetition and wind speed are determined in layers at the height of up to 100 m, up to 200 m (in most cases, the height of active part spreading of the radionuclide release flare) and up to 500 m (average height of the layer of mixing in the Rivne NPP region).

The average wind speed with the height increasing from 10 m (the level of underlying surface) to 100 m changes from 3.5 m/s to 7.6 m/s; at the height of 200 and 500 m the values of the average wind speed are 7.8 and 8.8 m/s, respectively. In the annual course, the average wind speed tends to increase up to 8-11 m/s during the cold time and it decreases to 7.0-7.3 m/s during the warm period. In this section, the following characteristics are considered as main aerologic characteristics of the ground atmosphere layer:

- wind direction and speed at different heights;
- temperature inversions (ground and elevated);
- repetition of air "stagnation", height of the mixing layer, cloudiness mode, atmosphere resistance.

To determine the characteristics and parameters of wind processes, the data were used from observations of strong winds in the meteorological stations that are closest to the Rivne NPP site, i.e. Lyubeshiv, Manevici, Sarny, Riven, Lutsk, Shepetivka. These stations conduct systematic observations during a long period (more than 50 years), which ensures their credibility.

In relation to the NPP, the meteorological conditions of the northern part of the NPP area are determined by the meteorological station Lyubeshiv, the central and western parts – by the meteorological station Manevichi, the eastern part – by the meteorological station Sarny, the south-eastern and southern part – by the meteorological station Rivne, the south-western part – by the meteorological station Lutsk (Attachment F).

The closest meteorological station to the NPP is Manevichi. This meteorological station is located within the 30-km area of Rivne NPP and is recognized as a reference station for identification of the most calculated climate characteristics. The aerologic characteristics of the climate were obtained using the data from the meteorological station Shepetivka, which is a representative one for the north-western territory of Ukraine. The data from the closest meteorological stations of the RNPP region are presented in Table 3.9.

Table 3.9. Meteorological stations of the Rivne NPP area

Meteorological station	Observation period	Distance from NPP	Height of the site, m abs	Height of the flare, m
Manevichi	1946 - till present	26 km to W	198	15.1
Sarny	1944 - till present	50 km to E	153	11.0
Rivne	1940 - till present	80 km to SSE	230	12.0
Lyubeshiv	1950 - till present	54 km to NW	149	10.6
Shepetivka	1949 - till present	155 km to NW	277	11.0
Rafalivka station	1968 - 1970	9 km to N	170	10.0
Lutsk	1941 - till present	78 km to SW	210	12.0

The extreme wind speed.

Calculation of the maximum wind speed of insignificant repetition for the NPP area is performed using three methods [91], in particular:

- graphical method MGO;
- analytical method MGO;
- Analytical method of Gumbel.

The input data for identification of maximum wind speed insignificant repetition were taken from the materials of three meteorological stations located in the close vicinity to Rivne NPP: Manevichi, Sarny, Lyubeshiv.

The calculated wind speeds used the values defined by the Gumbel method from the meteorological station Manevichi (as the largest among other methods). Besides, the meteorological station Manevichi is representative for the site of Rivne NPP.

The document [37] provides the Gumbel distribution parameters for strong winds registered by the meteorological stations of Ukraine, based on the series of anemo-rhumbometric observations, which cover the period from 1975 to 1993.

The meteorological observations are based on the observations by 16 rhumbs with 10-minute speed averaging and 2-minute wind direction. The Gumbel distribution characteristics from the meteorological station Manevichi is provided in Table 3.10. The station Manevichi is the most representative station for the area of Rivne NPP.

Table 3.10. Maximum calculated wind speed according to the meteorological station Manevichi, determined using the Gumbel method.

Meteorological station	Amount of data	Gumbel distribution parameters		Maximum registered wind speed, m/s	Forecast for N years, m/s			
		α	β		5	25	50	100
Manevichi	2020	0.4071	21.44	25	25.1	29.3	31.0	32.7

Table 3.11 provides data on the strong winds for 1986-2014, as well as the forecast for 100 years, excluding the regions of Carpathian and Crimea [105].

Table 3.11. Number of cases with the wind speed exceeding 25 m/s.

Wind speed, m/s	26-30	31-35	36-40
Number of cases with strong winds	145	27	4
Number of cases with strong winds, %	82.4	15.3	2.3

Table 3.12. Calculated wind pressure.

Probability of wind speed exceedance, 1/year	Wind speed, calculated on the basis of distribution of extreme wind speeds for meteorological station Manevichi, m/s	Wind speed, calculated on the basis of materials [105], m/s	Wind pressure n/m^2, calculated on the basis of distribution of extreme wind speeds for meteorological station Manevichi	Wind pressure n/m^2, calculated on the basis of materials [105]
1.0E-01	27.0	28.0	0.44	0.48
1.0E-02	32.7	34.1	0.65	0.71
1.0E-03	38.4	40.0	0.90	0.98
1.0E-04	44.1	45.9	1.18	1.29
1.0E-05	49.7	51.8	1.51	1.64
1.0E-06	55.4	57.7	1.87	2.03
1.0E-07	61.0	63.8	2.27	2.49

According to [106], the external impact with the frequency below 10^{-7} 1/year was not analyzed. These are the winds with the wind speed not greater than 54 m/s. The winds with the speed greater than 50 m/s are typical for the tropic hurricanes and open sea spaces during storms. In the middle latitudes above the ground surface, the wind speeds exceeding 50 m/s are observed in the upper atmosphere layers in the area of free atmosphere [107]. Taking into account that the Rivne NPP site is located in the region of middle latitudes (51˚ 20 ' N) at the distances exceeding hundreds of kilometers from the costs of the closest seas in the flat land, the upper wind speed can be limited by the value of 50 m/s.

According to the reports on the results of meteorological observations in the region of Rivne NPP for the last few (including 2014) years [86-89, 108-110], the maximum wind speeds did not exceed the maximum values registered before. Besides, the data on the possible wind speeds do not influence the screening results and have the reference character.

During the analysis of the series of observations, all cases with the temperature probing were conditionally divided into two groups: with normal atmosphere stratification, when the air temperature was decreasing with the greater elevation; and the inversive change of the air temperature characterized by its increase with the greater elevation.

Depending on of the height of the lower boundary, the following is differentiated:

- ground inversions, - cases of stratification, when the temperature increases with the height from the ground surface level already;
- increased inversions characterized by abnormal stratification at some height above the underlying surface.

Since the atmosphere ability for purification significantly reduces in the inversion layers, the statistical analysis was performed mainly for the series of probing data related to the layers with reduced turbulence.

Wind impact on the buildings and structures.

Strong winds can cause damage to the buildings and structures, containing safety important systems, as well as the normal operation systems, which in its turn can lead to damage of the safety important system or elements. The detailed description of building structures is provided in [97]. In addition to the buildings, listed in the table, a series of plant elements can be sensitive to the impact of wind loads. Such elements may include:

- ventilation stack of the reactor hall;
- open switchgear and power transmission line.

Description of the ventilation stack and elements of power transmission line [79, 80] is provided below.

Ventilation stack.

The ventilation stack with the top elevation of 100 m leans to the roofing of the reactor building. The stack is metal in the reactor hall and consists of two pipes: the external one with the diameter of 3.0 m, and the internal one with the diameter of 1.6 m. It is located on the roof of the reactor building and leans on the concrete headwall, which is a continuation of the ventilation duct. Half of the pipe is in the reactor building and another half (50 m) appears above the building roof. Two metal bars are connecting the stack and the dome of the reactor building.

Characteristics of the cables of power transmission lines.

The cable of AC 300/39 type is used for connecting the power unit with the open switchgear-750kV. The cable of AC 400/51 type is used for the flexible communication line 330 kV of the second set of standby transformers 6 kV - 4 tr, 5 tr. The technical characteristics of the cables are provided in Attachment E. The biggest length of the span of 750 kV open switchgear line is 297.5 m, with the maximum deflection of 10.76 at the temperature of +20 ºC. The biggest length of the span of 330 kV second set of transformers is 339.0 m, with the maximum deflection of 10.87 [111, 112] at the temperature of +20 ºC.

The design criteria for wind pressure on the Rivne NPP buildings.

To compare the wind pressure with the values foreseen in the design, the loads to the plant buildings and structures that were in place during the design phase are provided [113, 114].

Table 3.13. Design values for buildings and structures that contain safety important systems.

Systems and components	Category according to [115] and [100]	Wind load according to SNiP II-6-74 [114], n/m^2	Pressure at the shock-wave front according to PiN FE – 5.6, kPa
Reactor hall	I	350	30
Standby diesel power plant	I	350	30
General power unit standby diesel power plant	I	350	30
Turbine hall	II	350	30
Auxiliary building	II	350	30
Overpass between the reactor hall and auxiliary building	II	350	30

The RNPP site is located in the wind zone 2 according to [114]. The normative value of the wind pressure for this zone is 35 kgf/m^2. In accordance with the requirements of the present-day normative document [116], the RNPP site is located in the wind zone 3. The normative value of the wind pressure for this zone according to the new norms is 50 kgf/m^2 (500 Pa). This difference between the requirements of the current normative document and the one used at the plant design phase is not critical for the building structures, buildings and installations. The wind loads were defined with the overloading coefficient OC=1.2 (СНiП II-6-74 “Loads and Impacts”) [114] at the RNPP design phase. The values of the wind pressure were calculated using the formula $W_0 = 0.61 \times v^2$, where the speed v is measured in m/s, and the wind pressure in N/m^2. The value of the wind load used during the plant design phase was equal to: 35×1.2 = 42 kgf/m^2. The corresponding wind pressure for this wind speed is 26.2 m/s.

Wind impact on buildings and structures of Rivne NPP.

Comparison of the normative wind pressure with the designed wind pressure brings to the conclusion that the design criteria for the wind pressure for buildings and structures, that contain safety important systems, occur more rarely than the wind loads, thus the buildings can be vulnerable to the strong winds. However, as indicated in [117], this approach for the building structures can appear to be too conservative.

At that, according to [114] the pulsation component of the wind speed is allowed not to be taken into account during calculations of the multistoried buildings located in the areas of A and B types (with the height up to 40 m and correlation of the height to the span of less than 1.5). The highest building at RNPP site is the turbine hall (buildings of categories II and III are analyzed as per ПиНАЕ- 5.6 [113]). According to the geometric characteristics of the turbine hall building (length - 127 m, width - 45 m, height - 39 m) specified in [118], the criteria [114] are met and the pulsation component of the wind speed is not taken into account.

Comparison of the design criteria, using the pressure at the shock wave front, with the values of the wind pressure shows that loading on the standby diesel power station (SDPS) during the blast is 20-30 times greater than the wind load. Thus, the SDPS can be excluded from further analysis.

For the other wire-frame buildings at the plant site, as demonstrated in Attachment E, the extreme wind (in the worst case) can result in the partial break of the glazing.

This strength margin is sufficient for stating that the strong winds do not represent danger to the above mentioned buildings and structures. Due to the impact of strong winds on some buildings (for instance, turbine hall), the frames or glass panels can be damaged, but that will not lead to violation of operation of the safety important systems located in these buildings.

Wind influence on the power supply systems.

Calculation of the wires strength showed that rupture of the wires does not occur at the wind speed less than 120 m/s. Based on this, it can be stated that the wind impact will not lead to breaks/ruptures of the flexible connection lines. However, as shown in [101], with the wind speeds of more than 31 m/s (such wind is peculiar for zero class tornado), the abnormal operation of the essential service water system can occur. Probability of speed exceedance of such wind in the plant area is 1.40E-03.

Breaking of the flexible communication lines that connect the power unit with the open switchgear (OS)-750 kV, and the flexible communication line between OS-330 kV (damage of supports, isolators, etc.) and the second complex of the standby transformers can lead to the initiating event. According to the IEs grouping in the PSA Level 1, this relates to the IEs group T1 “Loss of all normal power busses” [82]. Occurrence of this IE, due to the wind impact, is not associated with the additional failures and can be excluded from further analysis. Thus, the actions that take place at the plant associated with the winds are excluded from further analysis.

Distribution of the wind speeds in the 30-km area of Rivne NPP has the following peculiarities. During a year, the highest annual average wind speeds are observed in the southern part of the area, 4.7-5.0 m/s at the western and north-western wind direction. In the central and western part of the area, including the area of the plant site, the wind speeds reduce to 3.1-3.2 m/s, at that keeping the same direction – western and north-western. Up to the midnight, the wind speed tends to increase to 3.7 m/s (at western winds). The lowest annual average wind speeds (2.1-3.2 m/s) are reported to be everywhere at northern, north-eastern and eastern wind directions.

The peculiar feature of the wind speed distribution in the 30-km area of Rivne NPP is an increase of the annual average wind speed from 2.5 to 4.1 m/s from the north to south (Attachment F). The same regularities are preserved during separate months of the year. In the central, western and eastern parts of the area, the annual average wind speed is within 2.8-3.0 m/s.

As a rule, the high wind speeds are observed at the prevailing wind directions and relate more to the cold period of time.

Repetition of the maximum wind speeds in the given (calculated) grades (14-15, 16-20, 21-25 m/s) for this territory was defined from the number of cases of a certain grade with maximum wind speeds for a multi-year experience at the meteorological stations Lyubeshiv, Manevichi, Sarny, Rivne. The calculation results are provided in the tables of Attachment F.

Based on the conducted studies, it can be stated that the maximum wind speeds occur more often in the given grades in the 30-km area of Rivne NPP at the western and north-western wind directions, more seldom at the south-western direction (at the wind speed ≥ 25 m/s). The extreme wind speed was registered in the southern part of the area and achieved 38 m/s (the meteorological station Rivne) and 40 m/s (the meteorological station Lutsk) at the north-western wind direction. The high wind speeds are observed usually during the cyclonic activity.

The average number of the days in a year with the wind speed, which is equal to or exceeds the given value at this territory, is provided using the data from the meteorological station Sarny and is the following:

≥ 8 m/s - 53 days, ≥ 15 m/s - 3 days, ≥ 20 m/s – 0.2 day.

The days with the wind speed ≥20 m/s are more often observed during the cold period of time, and the days with the wind speed from 8 to 15 m/s in any month of the year.

Atmospheric phenomena: fogs, thunderstorms

Occurrence of the atmospheric phenomena are usually associated with the character of synoptic processes that take place in the analyzed territory. The major impact on the duration and intensity of the most of them is imposed by the physical and geographical peculiarities of the territories.

Fogs is a collection of minute water droplets in the air, which are formed as a results of the dump air cooling. The fog worsens the sanitary and hygienic quality of the atmospheric air, since they contribute into increased air pollution by absorbing different substances. The fogs characteristics on the analyzed territory is presented using the data from the meteorological stations Manevichi, Sarny, Rivne and Lyubeshiv.

Table 3.14. Number of foggy days

Number of days	Month												Period		Year
	01	02	03	04	05	06	07	08	09	10	11	12	10-03	04-09	
Meteorological station Lyubeshiv															
Average	2	3	2	1	1	1	1	1	2	4	4	4	19	7	26
Maximum	9	10	7	7	3	3	6	7	9	14	8	10	-	-	57
Meteorological station Manevichi															
Average	3	2	3	1	1	1	1	1	2	4	4	4	20	7	27
Maximum	6	9	8	3	3	3	3	4	6	9	11	8	-	-	41
Meteorological station Sarny															
Average	3	4	3	2	1	1	1	2	3	4	4	5	23	10	33
Maximum	10	11	8	5	4	4	7	4	10	10	12	12	-	-	55
Meteorological station Rivne															
Average	4	5	4	2	2	2	1	3	3	4	5	6	28	13	41
Maximum	8	12	11	5	6	5	7	6	13	10	16	12	-	-	69
Meteorological station Lutsk															
Average	4	4	4	1	2	2	1	1	3	4	4	5	25	10	35
Maximum	9	11	10	3	5	6	4	7	10	10	11	13	-	-	53

With regard to the fogs distribution in the territory of Rivne NPP, the increase of the amount of fogs is observed from the north to the south (from 26 days in the north and up to 35-41 days in the south). At that, number of foggy days is approximately the same during the warm period of time on the analyzed territory (8-10 days), and the number of foggy days during the cold period of time changes from 19 days in the north to 24-28 days in the south of the area. The biggest number of days with fogs in a year is practically the same in the north, east and south-west of the area, in the south-east of the area – 69 days.

Table 3.15. Duration of fogs

In hours

Meteorological station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Любешів	Average duration												
	9	7	10	3	2	2	2	2	5	14	21	15	92
	Maximum duration												
	31	56	54	9	7	11	8	13	17	44	66	57	193
Маневичі	Average duration												
	14	11	17	3	3	3	3	3	8	16	26	23	130
	Maximum duration												
	55	70	60	16	9	12	12	13	28	52	63	64	185
Рівне	Average duration												
	22	24	25	7	6	4	3	5	12	15	27	33	183
	Maximum duration												
	62	89	107	19	24	13	12	16	70	52	104	76	406

Thick fogs (visibility within 100 m and less).

Thick fogs are observed during the cold period of time. The classification of fogs by their origin does not have a critical significance for the NPP. Regardless of the origin of the formed fog, its presence does not influence spreading of the substances in the subsurface layer of the atmospheric air.

The fogs with the visibility ≤ 100 m in the western part of Ukraine are observed in 7% of cases with the fogs presence. At that, the territories of Rivne and Khmelnitskiy oblasts did not have cases of thick fogs.

Thunderstorm activity.

Thunderstorm activity is defined by the intensity. The intensity of the thunderstorm activity is a quantitative characteristic of the precise district or geographic point, which is the site of Rivne NPP in this case, and defines the following:

- repetition of thunderstorms (according to the data of the meteorological stations, number of days in a year accompanied with thunderstorms);
- duration of thunderstorms (total amount of hours in a year, during which the meteorological station registers the thunderstorm activity);
- specific density of thunder strokes into the ground (expected number of thunder strokes within 1 km^2 of the ground surface for a year).

Monitoring of the meteorological parameters and characteristics of the climate conditions in the area of Rivne NPP is fulfilled with the help of the meteorological station Rivne, located 80 km to the south east from the NPP site, and the meteorological station Sarny, located 50 km to the east from the NPP. The characteristics of the thunderstorm activity are provided in Table 3.16 [119, 120] for these meteorological stations.

Table 3.16. Characteristics of thunderstorms at Rivne NPP site

Meteorological station	Average number of days with thunderstorms for a year	Average duration of thunderstorms, hours	Number of lightning strikes at 1 km^2 surface for a year
Riven	30	62.8	5.5
Sarny	29	63.0	5.5

Influence of the lightning is commonly divided into two main groups: primary impact caused by the straight lightning strike and secondary impact inducted by its discharges or moved by the extended metal communication lines to the object. On one hand, the danger from the straight strike and secondary actions of the lightning for the buildings and installations is defined by the parameters of the lightning strikes. On another hand, by the technological and structural characteristics of the object (presence of explosive or fire hazardous areas, fire resistance ability of the building structures, and types of communication lines arranged, their cabling inside the object, etc.).

The straight lightning strikes cause the following effects onto the object:

- electrical, which are associated with the injury of people or animals by the electric current and occurrence of the overvoltage at the effected elements. The overvoltage is proportional to the amplitude and transconductance of the lightning current, inductivity of the structures and resistance of the earth grounding, which tap the current to the ground. Even with the lightning protective measures in place, the straight lightning strikes with high voltage and transconductance can lead to overvoltage for several megavolts. If no lightning protection is in place, the paths of lightning voltage movement are not controllable and its strike can create a risk of injury by current / electric shock, dangerous voltages of the step and contact, overlapping to other objects;

- thermal, which are associated with the rapid heat generation due to a direct contact of the lightning channel with the area of the object and due to passing of the lightning current through the object. The energy generated in the lightning channel is determined by the lightning discharge, duration of the lightning flash and amplitude of lightning current. In 95% cases of the lightning strikes, this energy (calculated with the resistance of 1 Ohm) exceeds 5.5 J, which is two-three orders greater than the minimum inflammation energy of most gas, steam and dust containing air mixtures used in the industry. Thus, under such conditions the contact with the lightning channel always creates a risk of inflammation (in some cases explosion), the same relates to the cases when the lightning channel melts through the vessel of the explosive external facilities. When the lighting current passes the thin conductors, there is a danger for their melting and breaking;

- mechanical, which are conditioned by the shock wave to be emitted from the lightning channel, and by the electrodynamic forces that effect the conductors and the lighting current. This impact can be the reason, for example, for flattening of the thin metal tubes. The contact with the lightning channel can cause a rapid steam or gas generation in some materials followed by the mechanic break-down, for example, flattening of the wood or formation of cracks in the concrete.

The secondary lightning effects relate to the influence of the electromagnetic field of the near discharges on the object. This field is usually considered as two constituents: the first one is conditioned by movement of the discharges in the leader and lightning channel, and the second one – by the change of the lightning current over time. These constituents are called sometimes the electrostatic and electromagnetic induction.

The electrostatic induction appears in the form of overvoltage, which occurs on the metal structures of the object and depends on the lightning current, distance to the place of the stroke and resistance of the earth grounding. In case of no appropriate earth grounding, the overvoltage can reach hundreds of kilovolts and pose a risk to people and walls between different parts of the object/facility.

The electromagnetic induction relates to formation of the electromotive force in the metal circuits, which is proportional to the transconductance of the lightning current and area covered by the circuit. The extended communication lines in the modern production buildings can form a large area of circuits, where electromotive force can be several tens of kilovolts. In the places of proximity of the extended metal structures, the risk is created for the overlapping and sparks in the break-ups of open circuits with possible dissemination of energy of about tens parts of a joule.

One more type of the dangerous impact of the lightning is high voltage in the communication lines arranged in the object/facility (wires of overhead transmission lines, cables, pipelines). It is about the overvoltage that occurs in the line during straight and close lightning strokes and is disseminated in the form of a wave, which covers the object. The risk is posed due to possible overlapping from the communication to the grounded parts of the object. The underground lines also cause a danger, since they can obtain part of the current flowing in the ground and transmit it to the object.

The lightning stroke cannot be prevented, but it is possible to mitigate its consequences. The problem with prevention of hazardous impact from the lightning stroke is technically resolved through the anti-lightning protection of the buildings, insulations and equipment. At that the protections of objects is ensured by the lightning arrester [120].

To define the frequencies of impact from the lightning strokes to the NPP facilities, the calculation was performed with regard to the frequency of striking these objects by the lightning. For the purpose of calculation, the safety important buildings and installations selected as these analyzed objects, as well as the span of the transmission line, which connects the open installation of transformers (light yard) with the OS-330 kV. The typical support P-330-3 was selected as a support, which is applied for transmission of the electricity with the voltage of 330 kV. The calculation results are presented in Tables 3.17 and 3.18.

Table 3.17. Frequency of damaging the NPP buildings and structures caused by lightning stroke

Building/structure	Length, m	Width, m	Height, m	The frequency of lightning strikes per year
Reactor hall	66.0	66.0	66.55	1.20E-01
Turbine hall with the electrical devices rack and deaerator department	127.0	70.0	44.4	7.30E-02
Standby diesel power station	57.6	28.8	11.4	6.60E-03

Table 3.18. Frequency of damaging the span of power transmission line, connecting the open transformer facility with the open switchgear-330, which is caused by lightning stroke.

Support type	Length of span, (m)	Height of cable carrier on the supports, (m)	Number of straight lightning strikes, 1/year	Number of strikes into the support, 1/ year	Number of strikes into the wire, 1/ year	Number of strikes into the wire, 1/ year
П330-3	250	33	0.33	0.04	0.03	0.26

According to the results presented in the tables, it can be concluded that even with application of lightning arrester (lightning protection), this impact cannot be excluded from further analysis according to the frequency criteria (the impact frequency is less than 10^{-7} 1/year).

Severity of consequences from the lightning strokes depends primarily from the explosion or fire resistance ability of the buildings or installations during thermal impacts of the lightning for these objects. The list of explosion or fire hazardous buildings and installations at the NPP site are presented in the relative sections of the report. It is also demonstrated in these sections that occurrence of the extreme situations at these objects (explosions and fires) do not pose a risk to the Rivne NPP site. Thus, the secondary phenomena associated with the impact from the lightning for these objects can be excluded.

During the lightning stroke, the biggest mechanic force occurs in the parallel conductors with the current. In the work [121] it is shown that the impulse force does not exceed 0.5 - 1 kgf×sec/m at the distance of 0.1 m between the conductors. Such an impulse is equivalent to the average in force hammer stroke and does not pose a threat for the buildings and installations of Rivne NPP. The shock wave, which is spread over from the lightning channel at the distance of 20-50 cm from the channel, has an insignificant pressure at the shock wave front and decreases quickly with the distance. This shock wave represents a threat not for the NPP buildings but for the people who are present by the channel [121]. Thus, the mechanic effects associated with the lightning strokes to the NPP, can be screed out.

Abnormal electrical mode of the controlling plant systems occurred as a result of the direct lightning stroke, electrostatic and electromagnetic induction, as well as associated with the high pressure, can lead to the IE from IE group TZ-1 “Transients leading to reactor trip” or IE group T1 “Loss of all normal power busses” as a result of violation of the electrical mode of the in-house systems. The lightning impact that leads to such violations in the plant operation was registered during operation of Zaporizhzhya NPP Unit 5 [117]. According to the criteria of exclusion accepted in [122], such effects can be excluded from the analysis as the events accounted for in PSA Level 1 for internal initiators. In such a way, effects imposed onto different power supply and controlling systems of Rivne NPP associated with the lightning impact on these systems, can be excluded from further analysis.

Heavy glaze (diameter of ice deposit ≥ 20 mm)

For the analyzed period, the heavy glaze was observed three times in the territory of Rivne region, two times – on the territory of Volynska oblast, once – on the territory of Khmelnitska oblast. The icing duration varies in the wide range, from 15 minutes to 15 days and more. In most cases, the glaze lasts for less than 12 hours, more seldom – about a day.

The especially dangerous ice deposits are characterized by large intensity of ice build-up, from 1.1 to 2 mm/year (in 50% of cases) [123].

It should be noted that the natural meteorological phenomena pose various impacts on the nuclear power plant and its possible negative influence on the environment and people: from additional loads to the plant structures (strong wind, tornadoes, snow storms) to the conditions that cause spreading of substances (mixtures) and their transfer to the significant distances (strong winds and flooding, strong wind, dust storms).

For the time period of NPP operation, the natural meteorological phenomena did not create emergencies at Rivne NPP.

Hurricanes (wind speed ≥ 33 m/s of long duration).

For the last 30 years, the long-lasting winds with the wind speed ≥ 33 m/s were identified in 5 cases on the territory of Rivne NPP, in 9-10 cases on the territory of Volynska and Khmelnitskiy oblasts. The hurricane winds were observed in 1983 (March 7-8) in Izyaslavskiy and Slavutskiy regions of Khmelnitskiy oblast; in 1984 (November 2-4) such winds were registered by the meteorological stations in the cities Yampil and Khmelnitskiy; in 1986 (January 20-21) – by the meteorological stations in the cities Khmelnitskiy, Rivne, Sarny and Manevichi; in 1992 (September 6) – by the meteorological stations in the towns Shepetivka and Yampil; in 1993 (January 23 and 24) the hurricane winds passed along the territory of Volynska oblast. At that, the highest speeds at certain years achieved 34-40 m/s, and the maximum duration of particular hurricanes was 14-31 years.

Heavy rain

Among all natural meteorological phenomena observed in the territory of Ukraine, heavy rains are the most frequent ones. They are characterized with great spottiness. The area of heavy precipitation is usually not large and can extend to the significant territories only in some cases covering the entire regions. Such rains were observed in 13-14 cases for the analyzed period on the territory of Rivne and Khmelnitskiy oblasts. The rainfalls exceeded 100 mm/day in five cases in Rivne region and in two cases in Khmelnitskiy oblast.

The intense rainfalls accompanied with the strong wind that caused floods and catastrophic destructions in the settlements, power transmission lines, roads and other facilities took place in 1969 (October 28), in 1990 (May 25), in 1993 (July 22 - 23), in 1997 г. (June 23).

Repetition of heavy rains in a year with the amount of precipitation ≥100 mm / day constitutes 9% in Volynska and Khmelnitska oblasts and 4.5% in Rivne region.

Hail

The hail with the size of 20 mm and more was observed 7 times on the territory of Rivne and Khmelnitska oblasts, and 12 times on the territory of Volynska oblast. The maximum number of days with the hail in a year on these territories was 6-10 days, the average number was 2 days. The longest duration of the hailfall was 1-2 hours.

Repetition of the hail with the hailstone diameter of greater than 30 mm was about 20% of all hail observed cases for the analyzed period.

The maximum size of the hailstone achieves 50-80 mm in most regions of Ukraine. The big hail is peculiar for the period from the end of April to beginning of May – mid September [85].

Strong dust storms

Occurrence of dust storms is conditioned by the influence of strong wind on the dry ground surface, which results in the transition of a large amount of dust or sand. The significant impact on formation of the dust storms comes from the character of underlying surface.

Practically, it is not possible to determine the region with the dust storm distinctly, since it is quite a migrating phenomenon. In most cases, the dust storms occur in the small areas and have a local character. However, the long intense dust storms can extend to the signification territories, embracing several administrative regions.

For the last 30 years in Ukraine, the severe dust storms were reported in 1966-1972, 1974 and 1984. Especially intense and long-lasting dust storms were observed in January-March 1969 (the dust storms covered 15 oblasts of Ukraine). In the recent years, the dust storms were not observed, which obviously is explained by sufficient precipitation and reduction of strong winds.

The probability for occurrence of intense dust storms in the northern and western regions of Ukraine (where Rivne NPP is located) makes about 5%, i.e. they can occur here once per 20 years.

Snow storms, snow-blasts, blizzards

Severe snow storms can be dangerous for Rivne NPP operation, since they intensify loading onto the roofing of NPP buildings and installations, where the safety important systems can be located.

According to the data from [85], the severe snow storm is a storm, when the amount of snowfall constitutes 20 mm and more for 12 hours and less. Repetition of these snowfalls for the region of Rivne NPP is 0.25 [85], which means that such a phenomenon occurs once per four years. This region includes such oblasts as Rivne, Khmelnitska, Ternopilska and Zhitomyrska. These oblasts are characterized by similar repetition of severe snow storms. The general accounting of snow storms in these oblasts gives a more representative statistics. Duration of the observation period is provided in [85], and is 22 years. The amount of severe snow storms for the area of Rivne NPP location is presented in Table 3.19.

Table 3.19. Amount of severe snowstorms in the area of location of Rivne NPP.

Oblast	Amount of precipitations, mm				Total
	21-30	31-40	41-50	> 50	
Rivnenska	13	4		2	19
Zhytomirska	10	4	1		15
Khmelnitska	12				12
Ternopilska	13	1	4		18
Total	48	9	5	2	64
Repetition, %	75	14.1	7.8	3.1	100

Based on the data provided in Table 3.19, the value of probability was calculated with regard to exceedance of the snow storms with a certain amount of snowfalls in the area of Rivne NPP location and the diagram was prepared (Fig. 3.8).

The experimental points at the diagram are approximated by distribution:

$$F(h) = 0.25\exp(-(ah+b)),$$

where: a = 0.112, b = -2.162.

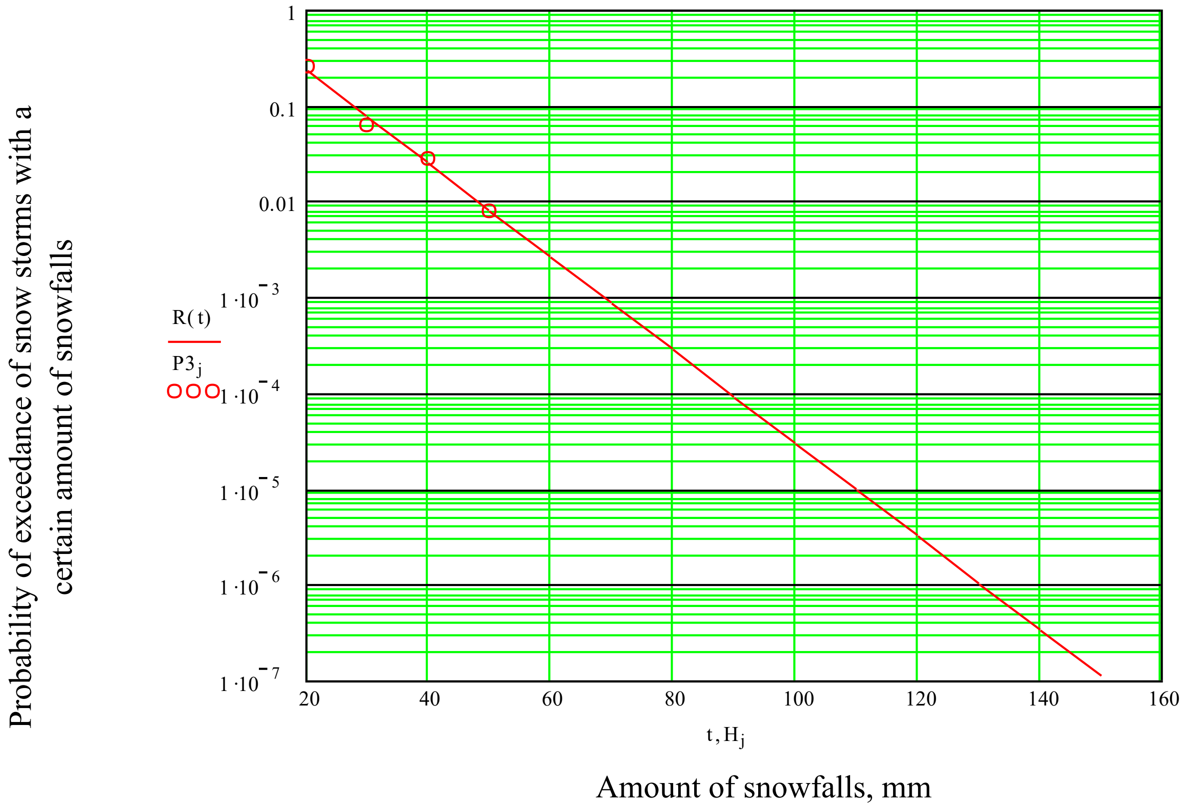


Fig. 3.8. Probability of exceedance of snow storms with a certain amount of snowfalls in the area of Rivne NPP location

The maximum amount of snow that fell on the territory of Rivne region during the heavy snow storms is from 37 to 63 mm.

The experimental points given at Fig 3.8 are approximated with the exponential distribution. Based on this distribution, the probabilities of exceeding of the precipitation during snow storms were calculated, some of them are provided in Table 3.20.

Table 3.20. Probability of exceeded precipitations during heavy snow storms

Probability of exceeding the amount of precipitations during heavy snow storms, 1/year	10^{-2}	10^{-3}	$2{,}4\times10^{-4}$	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Amount of snowfalls, mm	48.0	68.5	70	89.0	109.5	130.0	150.5
Snow pressure, n/m^2	480	685	700	890	1095	1300	1505

The location site of Rivne NPP is related to the first snow zone [116]. The design criteria with regard to the external effects that were in place at the moment of NPP construction required the accounting of the snow cover weight, which was 50 kgf/m^2 (500 n/m^2) per 1 m^2 of horizontal surface. At that, the overload coefficient OC was accepted to be equal 1.4 for the reactor hall and other buildings and installations that contain safety important systems. In accordance with the current requirements of the normative document [116] the Rivne NPP site is located in the fourth snow zone.

The normative values of the snow load for this region is 140 kgf/m^2 (1400 Pa). The indicated difference in the regulations of the current normative document and the one used during the NPP design is not critical for the building structures, buildings and installations, since it is foreseen by Rivne NPP to clean the site from snow across the entire complex of the buildings by the departmental personnel in accordance with [124].

Although the NPP location area is characterized with the long-lasting thaws, as a result of which the snow manages to melt. In accordance with [116], the snow load is related to the short-term loads. In these regions, the snow melts down periodically and accumulates again during the winter season. Thus, for instance, the average amount of thaw days is 40-50 days for Rivne region, and the longest duration of thaw days is 30-40 days.

For such regions, one of the characteristics of precipitations in the form of the snow is the biggest decade heights of the snow cover. Therefore, it is necessary to consider the loads associated with the decade heights of the snow cover for making the full-scope characteristics of the snow load.

The data on the biggest decade heights of the snow cover are provided in [79, 80] and presented in Table 3.21.

Table 3.21. The highest decade peaks of snow cover

Highest decade peaks of snow cover, of different occurrence, %	95	90	75	50	25	10	5
Height of snow cover, cm	1	2	6	11	17	21	25
Snow pressure, n/m^2	24	48	144	264	408	504	600

For the snow load calculation, the average density was used at the highest decade height of the snow cover according to the snow-surveys for the region of Rivne NPP location (the meteorological station Sarny), which constitutes 216–240 kg/m^3 [79, 80].

The snow load can be dangerous for the horizontal surface of the buildings and installations. In accordance with the Provisions on operation of production buildings and installations of Rivne NPP, it is foreseen to have snow cleaning of the roofs across the entire complex of buildings to be performed by the personnel of departments-owners of these buildings.

In such a way, considering the foreseen activities accomplished at Rivne NPP [124], the impact associated with the snowstorms can be excluded from further analysis.

Heavy snow blasts.

The heavy snow blasts occur at the prevailing wind speed of 15 m/s and more during a day or night. During a blizzard the heavy snow drifts are formed at the roads, the visibility worsens.

The specifically dangerous snow blasts with the duration of 12 hours are observed rarely in this region. For the analyzed period, the long-lasting snow blasts were observed 12 times on the territory of Rivne region, 12 times on the territory of Khmelnitskiy oblast.

Repetition of heavy snow blasts is 11-20% on the territory of Rivne region, and 21-30% on the territory of Khmelnitskiy oblast.

Impact of temperature variations on Rivne NPP operation and environment.

High temperature impact.

One of the main climate indicator, which shows the physical and geographic peculiarities of the region, is an average monthly temperature of the air in the hottest month of summer – July. However, this indicator reflects only the general laws of the temperature mode and is not sufficient for solution of the practical tasks in determining the temperature mode of the NPP systems.

To obtain a more precise description of the temperature mode at the NPP site, it is necessary to apply the average decade temperature of the air, which is used for determining the water temperature in the spray ponds. For different meteorological stations located in different zones of Ukraine, the data on the average monthly and average decade temperatures are provided in [125]. The data on these temperatures are given in Attachment F.

The maximum air temperature is an extreme characteristic of the temperature mode of NPP operation. The maximum air temperature refers to the hottest part of the day and is observed for about 14-15 hours. The annual cycle of the maximum air temperature similar to the annual cycle of the average air temperature is observed during the time of its highest value. On the territory of western Ukraine, it is generally accepted that the dangerous temperature is the maximum temperature of 30 ºC and greater and the mostly dangerous one is the temperature of 35 ºC and greater [85].

The data on probability of the maximum summer air temperature in Rivne region (the meteorological station Sarny) are provided in [85] and presented below (Table 3.22).

Table 3.22. Annual average probabilities of exceedance of the maximum air temperature

Probability of exceedance of maximum air temperature, 1/year	0.964	0.151	0.01	0.001	0.0001
Air temperature, ºC	30	35	40	42	44

Based on these data, the Weibull distribution was formulated, the view and diagram of which is represented in Attachment F. As it can be seen from the attachment, the maximum temperature in the RNPP area with the probability of 10^{-7} 1/year constitutes 52.0 ºC.

The number of days with the maximum air temperature of 25 ºC and greater is 35 days in the area of Rivne NPP location and with the temperature over 30 °C – 5 days [79, 80]. The total duration of the air temperature greater than 25 °C is 200 - 250 hours per year [125]. Thus, during a day, the average duration of the air temperature can be 6-7 hours, and greater than 30 ºC it can be 1.5 - 2 hours.

It is seen from the duration of the extremely high temperature that its impact can be imposed to low inert system from the thermal point of view. Also, it can be a reason for failures of the systems, which had the temperatures that were high already before this impact due of the influence of the high average annual or average decade temperatures on the system. The average maximum air temperature of the hottest period is used for calculation of ventilation systems cooled with the external air [126, 127].

The above indicated values relate to the maximum air temperature, achieved during at the afternoon, and cannot fully characterize the temperature mode of the Rivne NPP site, since the processes associated with the heat transfer have certain inert behavior.

One of the main climate indicators that reflects the physical and geographical peculiarities of the region is an average monthly temperature. However, it indicates only the general laws of the temperature mode and that is why it is not quite informative for solution of some practical tasks.

To describe the temperature mode of RNPP site in more detail, the parameters of air temperature are used, which are provided in [79, 80].

The types of applied distribution functions and their parameters are presented in Attachment F. Based on these data, the probabilities of air temperature exceedance were calculated (see Table 3.23).

Table 3.23. Probability of air temperature exceedance

Probability of average monthly temperature exceedance in July							
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Temperature, ºC	19.8	21.6	22.8	23.6	24.4	25.0	25.6
Probability of average decade temperature exceedance in July							
Temperature, ºC	24.6	27.5	29.7	31.5	33.0	34.4	35.6
Calculated external air temperature of the hottest 5-day period							
Temperature, ºC	25.6	28.6	30.8	32.6	34.2	35.6	36.9
Probability of average maximum temperature exceedance in the hottest month							
Temperature, ºC	27.3	29.8	31.6	33.1	34.4	35.6	36.7
Probability of maximum temperature exceedance							
Temperature, ºC	35.8	38.9	42.0	44.7	47.3	49.7	52.0

Influence of low temperature.

The minimum air temperature is an extreme characteristic of the temperature mode. The minimum air temperature describes the coldest part of the day and is observed at night. The early cycle of the minimum air temperature is similar to the annual cycle of the average air temperature and is observed at the moment of its lowest value. On the territory of western region of Ukraine, it is generally accepted that the dangerous temperature is the minimum temperature of minus 30 ºC and lower and the mostly dangerous one is the temperature of minus 35 ºC and lower.

Data on the probability of minimum winter air temperature are presented in [44] for Rivne NPP (meteorological station Rivne) and is provided in Table 3.24.

Table 3.24. Probability of minimum temperature exceedance

Probability of minimum air temperature exceedance	0.364	0.141	0.017
Air temperature, ºC	-20	-30	-35

Based on these data, the Weibull distribution was formulated, the view and diagram of which is represented in Attachment F. Application of the Weibull distribution for description of the extreme temperatures distribution was performed using the recommendations of the work [85]. As it can be seen from the attachment, the minimum air temperature in the RNPP area with the probability of 10^{-7} 1/year constitutes -50.5 ºC.

The number of days with the minimum air temperature of minus 25 ºC and lower is 40 days in the area of Rivne NPP location and with the temperature less than minus 30 °C – 10 days [86]. Duration of the extremely low temperatures during a day is not long lasting. The extremely low temperatures can affect the low inert system (from the thermal point of view). Also, it can be a reason for failures of the systems, which had the temperatures that were low already before this impact.

To describe the temperature mode of RNPP site in more detail, the parameters of air temperature are used, which are provided in [79, 80]. The types of applied distribution functions and their parameters are presented in Attachment F. Based on these data, the probabilities of air temperature exceedance were calculated (see Table 3.25).

Table 3.25. Probability of air temperature exceedance by the absolute value

Probability of exceedance of average monthly temperature in January							
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Temperature, ºC	-9.6	-14.5	-17.5	-19.7	-21.5	-23.1	-24.6
Probability of exceedance of air temperature of the coldest 5-day period							
Temperature, ºC	-20.8	-22.4	-23.6	-24.6	-25.4	-26.2	-26.9
Probability of exceedance of air temperature of the coldest day							
Temperature, ºC	-24.6	-27.8	-30.2	-32.1	-33.8	-35.3	-36.7
Probability of exceedance of minimum temperature							
Temperature, ºC	-31.0	-36.0	-39.7	-42.9	-45.7	-48.3	-50.7

According to the reports on the results of meteorological observations [86- 89, 108- 110] in the RNPP area, the air temperature for the recent years did not exceed the values registered during the previous years of observations.

Thus, impact of the low and high temperatures onto the normal plant operation for Rivne NPP and, consequently, on exclusion of accidents and situations that can negatively influence the environment, can be excluded from further analysis.

3.2 Man-made extreme impact

3.2.1. Explosions and fires.

A full description of the vulnerability analysis for power units with regard to explosions and fires at the facilities in the 10-km area and on-site of Rivne NPP is provided in [119, 120, 128- 130].

Explosions

The main explosive objects/facilities located at Rivne NPP site and off-site can be referred to the objects, where the explosion can become a reason for destruction. These are:

- automobile transport;
- railway transport;
- river transport;
- industrial explosive objects.

The main parameters of the vulnerability assessment for the power units, buildings and installations in terms of various explosions relate to the design criteria of explosion resistance and parameters of air shock wave (ASW), specifically: the value of maximum gauge pressure at the ASW front and length of the compression phase. Comparison of these parameters with the design safety criteria allow us to demonstrate the vulnerability of the object.

The document [131] presents the results of explosion parameters calculation for liquid explosive materials during accidents on the railway and road transport and their influence on the Rivne NPP facilities and as a consequence, impact on the environment and people.

Explosions associated with the shock wave, which occurs as a result of explosions at the facilities of Rivne NPP site, assessment of their impact on the buildings and installations are presented in [132]. The following was analyzed as possible sources for occurrence of air shock wave at the RNPP site:

✓ vessels/tanks that are operated under pressure:
  - hydrogen receivers at the open site at OGK;
  - nitrogen receivers and air collectors at the nitrogen-oxygen station of 1st line;

✓ nitrogen receivers and recipients and oxygen receivers at the nitrogen-oxygen station of 2nd line:
  - cylinders for liquefied gas storage at the warehouse;
  - air collectors near the plant common compressor station, compressor station at the open switchgear and compressor facility for pneumatic testing of the reactor vessel;

✓ storage facility for combustibles:
  - underground tanks with diesel fuel by the standby diesel power station (SDPS) of power units 1-4, common plant SDPS of power units 3, 4;
  - tanks at the warehouse of diesel fuel;
  - drums at the warehouse of tare storage of combustibles and lubricants.

✓ transportation (tank lorries at the site – fuel transportation lorry ТСВ7- У.).

The performed analysis showed the following results:

✓ since air and nitrogen are the inert explosive gases, then the air receivers and collectors with this substances can not be sources for occurrence of the shock wave;

✓ receivers with the explosive environment (hydrogen, oxygen) are located at the distance of more than 800 m from the installations that contain safety important systems (reactor hall, turbine hall, SDPS, reactor building, "dirty" overpasses), which have the resistance not lower than 10 kPa. According to the provided data in [133], the safety radius, i.e. distance, at which the impact of the shock wave can be not accounted for, at the resistance of installations of 10 kPa is 260 m;

✓ warehouse with barrels for storage of the liquefied gas is located at the significant distance from the above indicated facilities (about 550 m);

✓ tanks with the diesel fuel near the SDPS and plant general SDPS are equipped with the flame arresters, that is why the steam explosion in it is unlikely, but even with the conservative assumptions that such an event can take place, the underground siting of these tanks at the depth of 2.5 m from the ground level excludes the possibility for shock wave spreading and effect;

✓ warehouse of tare storage of combustibles and lubricants is at the distance of about 600 m from the facilities containing the safety important systems. Besides, a series of other equipment is located between these facilities, which play a role of barriers;

✓ electrolysis room, equipped with the continuous automatic monitoring system for checking the presence of hydrogen in the air of the electrolysis and gas analysis rooms. The rooms are designed with the mandatory nitrogen blowdown of all components and hydrogen lines, with natural and emergency ventilation, mechanic ventilation, as well as protection from the discharges of static electricity. The rooms are related to Category A, has the fire resistance level II and B-1 class for fire and explosion safety and can not be a source for occurrence of the shock wave [133];

✓ warehouse of the diesel fuel is located at the distance of about 50 m from the auxiliary building 2, about 200 m from the SDPS of power unit 3, and about 150 m from ZPSO with the normative distance of 30 m, thus it is not dangerous [96];

✓ fuel transportation lorry ТСВ7- У with the canister capacity of 7200 l, with the trailer unit of 19000 l with the diesel fuel. Transportation of the diesel fuel can cause partial destruction of certain parts (divisions, roofing, doors, gates etc.) of the buildings. For safe plant shutdown, no potential danger from impact can occur.

Conclusion: the forecasted level of the external impact by the shock wave from the sources of the plant site onto the facilities that contain safety important systems, environment and people, does not represent a potential danger for normal NPP functioning.

Fires

The main fire hazardous objects located outside the Rivne NPP site are the objects/facilities, where ignition can be a reason for fire (or a dangerous factor of fire impact). They are:

- wooded area;
- fires on the land transport (automobile and railway transport);
- high voltage power transmission lines;
- brushland and grass cover.

The main potential fire sources outside the NPP site are the woods adjacent to the Rivne NPP area. The land use structure of the 30-km Rivne NPP area includes the agricultural land (27.1% of all the territory), as well as woods (49.6%).

From the northern side at the distance of 500 m from the plant site, there is a forest land with the area of 1200 ha of Rafalivskyy forestry, which consists of conifer and broad-leaved trees on the dry soils.

From the eastern side of the plant site, there is an adjacent grass cover with the area of 900 ha at the distance of 300 m from the main building [79, 80].

Within the 10-kilometer zone there are no [79, 80]:

- ✓ warehouses and storage buildings with the explosive and toxic substances (solid, liquid and gaseous);
- ✓ main oil, gas and product pipelines.

The further analysis does not consider these sources due to their long distance from the NPP.

Data on the potential fire sources located outside the NPP site are presented in Table 3.26.

Table 3.26. Potential fire sources outside the NPP site

Fire source		Distance from the power unit, m	Characteristics
1	Cultivated forest from the northern side of the NPP, inflammation	500	Forest, bushes with the area of 1200 ha
2	Grass cover from the eastern part of the NPP, Inflammation	300	With the area of 900 ha
3	Turf deposits, inflammation	2000	With the area of 804 ha
4	Transport department for auto machines, gas station, spillage and inflammation	500	Diesel fuel, Petrol – 100 t
5	Motor transportation division of RNPP, gas station, spillage and inflammation	3000	Diesel fuel – 600 m^3, Petrol – 700 m^3 Lube oil – 10 m^3
6	Transport department of the NPP, spillage and inflammation: a) motor transport service	5000	Petrol – 310 m^3 Diesel fuel – 210 m^3 Lube oil – 46 m^3
	б) machines section		Petrol – 60 m^3 Diesel fuel – 52 m^3 Lube oil – 40 m^3
7	Transport department-15637 gas station, spillage and inflammation	3500	Petrol - 25 m^3
8	Local gas stations, spillage and inflammation a) “Zhuravlyna”	3000	Petrol – 150 m^3 Diesel fuel – 50 m^3 Lube oil – 60 m^3
	б) OJSC “Sarnynaftoproduct”	4000	Petrol – 90 m^3 Diesel fuel – 30 m^3
	в) “OLAS”	2500	Petrol – 100 m^3 Diesel fuel – 100 m^3 Lube oil – 50 m^3
9	Warehouses of NPP – warehouse of varnish-and-paint products, inflammation	700	Varnish, paints, solvents – 5 t

Fire source		Distance from the power unit, m	Characteristics
10	Railway road Sarny – Kovel, spillage and inflammation	1000	Diesel fuel, petrol, ammonia, sulfuric acid – 125 carriages/year
11	Automobile road Kyiv – Kovel, spillage and inflammation	8000	Transport of highly inflammable liquids in autocanisters.
12	High-voltage transmission lines	1000	750 kV

Input data on the fire sources located at NPP site are provided in Table 3.27 [133]. The main fire hazardous facilities located at NPP site are A and B category production facilities.

Table 3.27. Characteristics of fire hazardous sources at the NPP site.

No as per the master plan	Fire source	Amount of substances or capacity of tanks, canisters, m^3
97 97Б 97Д	Kindling fuel oil handling facility Warehouse of mazout and mazout lines	6000 m^3 360 m^3
96Б 96В	HVAC Warehouse of mazout and downcomer	1780 m^3 60 m^3
95Б 95В	Warehouse of diesel fuel and downcomer	1400 m^3 60 m^3
109	Construction of bitumen storage	500 m^3
22.3	Auxiliary buildings unit at open switchgear - 750 kV: Warehouse of lubricants and lubricant canisters	280 m^3 8 m^3
106.3	Warehouse building for tare storage of fuel and lubricant materials and highly-flammable liquids	30 t
94	Fire station, gas filling unit	Petrol - 50 m^3 Lube oil - 5 m^3
132.1	Oil receivers	Lube oil - 100 m^3
26	Standby diesel power station of Units 1,2	Diesel fuel - 600 m^3
26	Standby diesel power station of Unit 3	Diesel fuel - 100 m^3 Lube oil - 25 m^3 Diesel fuel - 300 m^3 Lube oil - 25 m^3
26	Standby diesel power station of Unit 4	Diesel fuel - 300 m^3 Lube oil - 25 m^3

No as per the master plan	Fire source	Amount of substances or capacity of tanks, canisters, m^3
27	General standby diesel power station for power units 3,4 Diesel fuel discharge tank (undeground).	25 m^3
	Site internal transmission line as a source of inflammation	Voltage – 330 kV

Assessment of the external fire impact on the NPP buildings and installations are presented in Table 3.28.

Table 3.28 Comparison of safe distances, justified as per norms and standards, from the Rivne NPP facilities to potential fire sources.

External fire sources		Distance, m	
		Normative minimum	Actual
1	Burning of woods that consist of coniferous trees and foliaged trees (softwood and hardwood)	100	200 - 500
2	Burning of dry grass and underwood (bushes)	3	100 - 300
3	Burning of turf deposits	100	≈ 2000
4	Transport department for auto machines Gas station; diesel fuel, petrol – 100 t	350	200 -500
5	Motor transportation division of RNPP: - petrol – 700 m^3; - diesel fuel – 600 m^3; - lube oil – 10 m^3	350	≈ 3000
6	Transport department of the NPP a) motor transport service: - petrol – 310 t; - diesel fuel – 210 t; - lube oil	350	≈ 5000
	б) machines section: - petrol – 60 m^3; - diesel fuel – 52 m^3; - lube oil – 40 m^3		
7	Transportation service-15637, gas station: petrol – 25 m^3	350	≈ 3500
8	Local gas stations: a) “Zhuravlyna” - petrol – 150 m^3; - diesel fuel – 50 m^3; - lube oil – 60 m^3	350	≈ 3000
	б) OJSC “Sarnynaftoproduct”: - petrol – 90 m^3; - diesel fuel – 30 m^3	-	≈ 4000

External fire sources		Distance, m	
		Normative minimum	Actual
	в) "OLAS": - petrol – 10 m^3; - diesel fuel – 100 m^3; - lube oil – 50 m^3		≈ 2500
9	Warehouses of NPP, warehouse of varnish-and-paint products	350	200 - 700
10	Railway road Sarny – Kovel. Materials: petrol, ammonia, sulfuric acid	100	≈ 1000
11	Automobile road Kyiv – Kovel	25	≈ 8000
12	Drop of high-voltage support. Short circuit corona discharge	30	≈ 1000

The comparative table 3.28 demonstrates that the fire sources are located at the distances that are greater than the safe distances. Thus they do not pose danger and direct thermal impact on the buildings and installations and main plant equipment, so as on the safe operation on power units. The likelihood of causing danger due to smoking of the rooms from the supply ventilation systems and thereby affecting the operating personnel is not feasible, since supply of the external air to the rooms of MCR, ECR is not performed at the time when the smoking takes place.

Conclusion: external fires that may occur outside and inside the NPP site do not affect the safety important facilities and can be excluded from further analysis, since they do not impose negative impact on the environment and people.

Leakage of chemical and toxic gases

The analysis is made for the events involving leakage of the chemical substances from the Rivne NPP site, as well as releases of the chemical substances at the transport, chemically dangerous enterprises (production plants) that can affect the normal operation of Rivne NPP and lead to violations in its operation and occurrence of accidents [132]. On the territory of Rivne and Volynska oblasts, there are no gas pipelines, oil pipelines, factories and chemical plants within the 30-km area of Rivne NPP.

Impact of the toxic gases and aerosols is considered from the point of view of ensuring performance ability of the operating personnel who works in the main control room (MCR) and emergency control room (ECR). Releases of the toxic gases and aerosols at the NPP site should be divided into two groups:

- releases under the normal operation conditions;
- releases during accidents.

Under the normal operation conditions, releases can occur from such sources as the centralized maintenance department, repair and construction department, transportation department, solid radioactive waste processing complex. Releases from these departments and complex are the product of technological processes.

The releases composition includes such hazardous substance as sulphur dioxide, nitrogen oxide, carbon monoxide soot, inorganic dust, butanol, ethanol, ethyl acetate, toluene, manganese and its compounds, fluorides, white spirit, ash, wood dust, butyl acetate, acetone, petrol, saturated hydrocarbons, welding aerosol, sulfuric acid, calcium oxide.

For the purpose of the environmental impact assessment for power unit 3, the maximum concentrations of these substances in the atmospheric air were calculated. The calculations counted for the most adverse meteorological and temperature conditions. The calculation results showed that the maximum near-surface concentrations with consideration of the background concentrations for any of the above indicated ingredients did not exceed 50% of the admissible limit values [132]. For the operating personnel who are in the MCR and ECR during one shift, the concentration of these substances do not pose danger. In light with that, the impact of release sources on RNPP personnel is not further considered in the analysis.

Releases from Rivne NPP departments during accidents.

During accidents, dangerous releases can occur in case of breaking of steady-state canisters with toxic substances (chloride, ammonia, hydrazine hydrate, sulfuric acid). Impact of the harmful releases into atmosphere during breaking of the canisters with toxic substances was determined using the methodology [135].

Data for analysis

At the NPP site, there are steady-state canisters where chemically dangerous materials are stored. Description of the storage places with chemically dangerous substances is provided below.

The warehouse for reagents is a specially equipped facility where chemically dangerous materials are stores. The facility is located outside the restricted area at the distance of 280 m from the power unit [136]. The warehouse with hydrazine hydrate and ammonia has a sump loaded with chloride lime where the solutions are drained in case of an accident. After decontamination, the drains are transferred to the tank of acid waters of demineralized water system. All the reagent tanks are the tanks of atmospheric type, i.e. the reagents are stored without pressure. The tanks are made of carbon steel and have anticorrosion coating. To avoid reagent vapors coming into the rooms, the warehouses have a system of removing gases via the filtration devices (air cleaning barrels) outside the facility. The warehouses are equipped with the exhaust and supply ventilation with the ten-fold exchange via the filters (air cleaning barrels). The floor of the reagent warehouse has anticorrosion surface and confining clamps. He slopes are made towards the sumps, where the reagents are pumped by pumps as described earlier.

The building of the chlorinator is a specially equipped facility for chlorination of sanitary wastewater and it is located on the territory of water and wastewater treatment facility. The setup and location of the existing chlorinator facility No 1 and constructed facility No 2 is provided in Attachment G.

Impact of toxic materials related to the accidents at the reagent warehouse.

Arrangement of the reagent warehouse, methods of storage and foreseen measures with regard to elimination of the accident consequences at this warehouse exclude the likelihood of having a big amount of vapors. A large specific weight of the substances (greater than the specific weight of air) prevents creation of the dangerous concentrations in the locations of air suction by the ventilation and air conditioning systems, which are used for the MCR and ECR. Impact of the toxic substances due to the accidents at the reagent warehouse cannot pose danger [131], because:

✓ complete breaking of the tanks is unlikely since the substances that are stored in them are not explosively dangerous. In fact, a leak through any looseness can appear, but it will be detected and isolated by the operating personnel;

✓ tanks for nitric acid storage are made of corrosion resistant steel, and for ammonia storage – coated inside with enamel EP-0010;

✓ the entire inventory of ammonia and hydrazine hydrate, as well as 83% sulfuric acid and 43% nitric acid are stored in the tanks installed in the confined rooms; so releases of the toxic gases in these tanks are mainly localized within these rooms;

✓ tanks with sulfuric acid (1x100 m^3) and nitric acid (1x70 m^3), are installed at the open site and are equipped with trays;

✓ ammonia and hydrazine hydrate are transported in the tanks made of corrosion resistance materials, which significantly reduce likelihood of their breaking;

✓ ammonia is transported and stored in the form of the weak aqua solution, which does not relate the chemically dangerous substances;

✓ hydrazine hydrate is transported and stored with the small concentration.

The calculation results for the radius of chemically dangerous substances isolation regions were obtained using the methodology [137] and are presented in table 1.36 [131].

Table 3.29. Depth of possible spreading (isolation region radios) of the cloud of hazardous chemical substances.

Hazardous chemical substance	Hazardous substance content, m^3	Degree of vertical atmosphere resistance	Radius of region isolation, m
Steady-state canisters			
Sulfuric acid	100	Inversion	50
Aqua ammonia	30	Inversion	100
Nitric acid	70	Inversion	80
Hydrazine hydrate	8	Inversion	200
Transport canisters			
Sulfuric acid	60	Inversion	50
Aqua ammonia	7,8	Inversion	100
Nitric acid	60	Inversion	80
Hydrazine hydrate	0.2	Inversion	200

The values presented in the table with regard to spreading of the chemical substances cloud are defined on the basis of the possibility for simultaneous breaking of only one of the installed tanks, balloons (movable canisters), which have the biggest single capacity.

The dangerous chemical materials stored at the reagent warehouse do not pose danger, because:

- they are stored in the specially designed tanks equipped with the natural and emergency protection system;
- they are served by the personnel who received a special training on management of the chemically dangerous substances;

- these are low-volatile materials, their vapors are heavier than the air and are lifted by the raising air flows insignificantly, thus preventing the spreading and formation of significant concentrations in the air intake places;

- the depth of the cloud spreading of the sulfuric acid that is stored in the steady-state canisters at the open site of the reagent warehouse is less than the distance to the power unit.

In such a way, all accidents involving the chemically dangerous substances stored at the reagent warehouse do not pose danger for the MCR and ECR personnel, environment and are excluded from further analysis.

Environmental impact associated with the accidents at the chlorinator.

The depth of the chlorine spreading in the air in case of the canisters damage at the chlorinator depends on the equipment applied at the chlorinator (e.g. availability of spillage restrainers in case of canisters damage (ridging, trays, etc.), ventilation method of the space). It also depends on the amount of the chloride in the facility and likelihood of its entry to the atmosphere outside the facility.

The equipment applied in the chlorinator, methods of chloride storage and foreseen measures for elimination of the accident consequences exclude the likelihood of the chloride vapors entry into the atmosphere. A large specific weight of the substances (greater than the air specific weight) prevents formation of the dangerous concentrations in the places of air intake by the air ventilation and conditioning system, applied for the MCR and ECR.

The detailed description of the chlorinator and its protection equipment is provided in Attachment G.

The impact by chloride related to the accidents in the chlorinator does not pose danger, because:

- ✓ tanks with the chloride are stored in the specially designed facility equipped with the emergency protection system;
- ✓ tanks with the chloride are served by the personnel who received a special training on management of the chemically dangerous substances;
- ✓ the substances are low-volatile, their vapors are heavier than the air and are lifted by the raising air flows insignificantly, thus preventing the spreading and formation of significant concentrations in the air intake places.

In such a way, the accidents with the chloride stored at the chlorinator do not pose danger for the MCR and ECR personnel and are excluded from further analysis.

Accidents associated with the releases of the chemically dangerous substances at the chlorinator and reagent warehouse do not pose danger for the MCR and ECR personnel and are excluded from further analysis.

Aircraft crashes

This section represents the calculation results for the aircraft crashes on the main buildings and installations at the Rivne NPP site.

To identify the frequency of the aircraft crashes on the main buildings and installations at the Rivne NPP site, which can result in the plant accidents and have negative consequences for the environment and people, all the aircraft transport analyzed in accordance with the standard [138] is divided into three types. Such a division is conditioned by the peculiarity of the air space infrastructure of Ukraine. Depending on the character of operation, the aircraft of civil aviation can be classified into [139]:

- aircraft of commercial aviation;
- aircraft of general aviation;
- aircraft of military aviation.

Due to absence of the representative statistics on aviation events in Ukraine with regard to the aircrafts of commercial aviation classes 1-3, the frequency of crashes of the commercial aviation aircraft was taken from the literature sources. For calculations, the frequency for commercial class aircraft crash was used, which constitutes 1.74×10^{-9} km-1 [141]. A close value can be obtained by analyzing data on the accident/incident rate at the USA airlines. In [141] the assessment is performed for the value suggested in [140]. The assessment is accomplished on the basis of data analysis for the accident rate for the commercial class aircrafts at the USA airlines for the period from 1983 to 2002, which is $1.1 \div 1.7 \times 10^{-9}$ km^{-1} and is well agreed with the obtained value.

The statistical data on the aviation events on the territory of Ukraine with the aircrafts of general aviation are provided in Table 3.30. At that, the analysis does not include the aviation events occurred outside the country, during takeoff and landing operations in the area of the airports. The statistical data for the previous years were not considered, since new rules were introduced in Ukraine with regard to the aircraft flights, and the structure of the air space was changed and set forth in accordance with the international norms [142].

Based on the data provided by the Ministry of Defence and Ministry of Emergencies of Ukraine [79, 80], the accident rate was defined for the Armed Forces of Ukraine for the period from 2001 to 2014. The analysis did not include the aviation events occurred outside the country, during takeoff and landing operations in the area of the airports. Amount of the events with the aircraft of the Armed Forces of Ukraine is provided in Table 3.30.

Table 3.30. Statistic data on aircraft incidents on the territory of Ukraine occurred with civil aviation aircrafts and military aircrafts.

Year	An -2 type	General purpose aircraft	Helicopter	Military aircraft
2001				
2002		1 – light airplane; 1 - “Becas” X-32 airplane		
2003			1 – Mi - 2	1-Mi-8
2004		1- “Becas” X-32 airplane	1 – Mi- 2	
2005	1–An -2	1 –Як-52 airplane	3 – Mi - 2	
2006		1- L-200 “Morava” airplane, 1- CTSW 2006 airplane	1 - Ka-26	
2007		1- “Becas” X-32 light airplane	1 - Mi-2, 1 - Ka-26	
2008		1 – “Schmel” Z-37airplane, 1 – “NARP-1” airplane, 1 – “Viking” amphibian airplane	1 - Mi -2 1 - Mi-8	
2009			1 – AS-350	

Year	An -2 type	General purpose aircraft	Helicopter	Military aircraft
			"Ecureuil" 1- Alouette	
2010	1-Ан-2		1- SA-341- «Gazelle» 2- Ка-26	
2011	1-Ан-2	1- "Becas" X-32 airplane	1 - Mi -2	
2012	1-Л-410	1 – "Diamond DA-42" helicopter 1- "SOKATA TB-20" airplane		1-Mi-8MT
2013	1-Ан-2	1 – fall of sport airplane "ZODIAC-601"		
2014		1 - "Becas" X-32 light airplane	1 - Mi-8T	
Up to 31.05.2015			1 - MI-24	
Total	5	15 (within them 1 powered paraglider)	18	2

Based on the data provided in Table 3.30, the frequency of small aviation aircraft crashes was defined for different aviation type and aircraft per 1 km^2 of the territory of Ukraine, as presented in Table 3.31. In the calculation of the aircraft crash frequency, the area of Ukraine was accepted to be 604 thousand km^2.

Table 3.31. Frequency of crashes of class 4 aircrafts and military aircrafts per 1 km^2 of the territory of Ukraine

Type of aircraft	Number of aircraft incidents	Frequency of crashes per 1 km^2 of the territory of Ukraine
Military aviation	2	2.37E-07
Commercial aviation (including AN-2 type airplanes)	20	2.37E-06
Helicopter	18	2.13E-06

According to the performed analysis, the frequency of calculated aircraft crashes on the objects of power units and facilities of Rivne NPP site are the following: reactor hall – 9.82E-08 (1/year), main building (maximum size is provided, including deaerator department and racks with the electrical devices) – 9.02E-08 (1/year), standby diesel power station – 3.14E-08 (1/year), power unit pump station – 1.96E-08 (1/year), spray ponds of the essential service water system – 2.27E- 07 (1/year), open facility of transformers – 7.11E-08 (1/year), open switchgear-750/330 kV – 2.10E-06 (1/year).

Since the frequencies of aircraft crashes on the main facilities of power units except for the open switchgear are lower than the ones established in the methodological recommendations [143] for exclusion using the frequency criteria (1E-07), then external impact associated with the aircraft crashes at the Rivne NPP site can be excluded.

CONCLUSIONS

The 30-km area of SS Rivne NPP is located within the Russian platform to the west and northwest from the Ukrainian fundamental crystalline formation. This part of the platform does not have a generally accepted geotectonic name. In the scientific sources, it is called a Galician-Volynian basin, Volyn-Podilskian plate, Volyn-Podilskian shield, flank of the Volyn-Podilskian shield. According to the geomorphological zonation, the entire analyzed territory refers to the subregion of the Volhynian Polissya, which occupies the southwestern part of Odessa Oblast of the Polissya accumulative lowlands.

The main geomorphological peculiarities of the 30-km area of SS Rivne NPP are: significant gravity of the alluvial plains in the surface structure, broad development of the monticulate-morainic relief, presence of the denudation relief forms on the cretaceous basis and development of the karst relief forms.

In the geomorphological zonation within the subarea of Volhynian Polissya, the following areas are identified: Verkhnepripyat accumulative (alluvial-moraine) lowland, Volyn (Lyuboml-Stolinska) morainic ridge, Sarnenska accumulative lowland and Kostopylska denudation plain. All these geomorphological zones are located within the 30-km area of Rivne NPP.

The surface waters of the explored territory fully belong to the basins of the Styr River, Veselukha River, Goryn River, which are affluents of the River Prypyat that flows into the River Dnieper. The main direction of the streamlines to the north is characterized with the decrease of elevations of surface in this direction. The structure of the river network is traced with the peculiarities of the relief of the physical and geographical zone, where the 30-km rea of Rivne NPP is located. The depth of the plain's encroachment line is 5-20 m, and the density of the river network is a little lower than in the forest-steppe zone and is 0.15-0.22 km/km^2. The territory is quite rich in water resources; it has a dense river network, but is badly drained. The peculiar feature is presence of a large amount of artificial water sources, especially channels.

The 30-km area if Riven NPP is situated in the Volhynian Polissya, which represents a south-western region of the mixed forest zone. The plant life of the studied territory is characterized with typical peculiarities of the Polissya nature – prevalence of mosses, meadows, and forests of boreal type in the flora, the plants represent a vividly expressed boreal complex with prevailing pine and mixed forests and mesotrophic mosses. The cenofond is characterized with presence oa several rare communities of the national and regional levels. From the sozological point of view, the flora differs by the presence of great number of the groups of red book species, glacial relics, frontier-areal types.

The zoogeographic zonation represents the following systematic locations of the 30-km area of Rivne NPP:

1. European- Siberian boreal subarea;

1.2. East European district, region of the mixed, leaf forests and forest steppe;

1.2.a. Section of the east european mixed forest and forest steppe;

1.2.a.a. Subsection of Western or Volhynian Polissya.

The wild life of the studied region is represented by the complexes typical for Polissya, where there are about 50 mammalian species and 190 birds species. From the entomological point of view, a Central European forest fauna is well represented here, such species can be found that come from the east bounded by the Dnieper.

In general, the fauna of the 30-km area of Rivne NPP comprises habitation of 36 species listed in the Red Book of Ukraine (18 insect species, 1 species of reptiles, 11 species of birds and 6 species of mammals). The flora of the 30-km area of Rivne NPP includes 37 rare plant kinds, where 23 are listed in the Red Book of Ukraine.

The nature reserved fund is represented with 48 objects of different level of reservation, within which the most valuable is the reservation park "White Lake".

As a result of the performed analysis of the external extreme impacts for Rivne NPP, the following tasks were accomplished:

1. The list of external extreme impact of the natural and manmade nature, peculiar for RNPP site, was compiled;
2. Screening and boundary analysis was performed with respect to the external extreme impacts; and using the qualitative and quantitative screening criteria the impact to be excluded from the further analysis was identified.
3. The impact was identified that will be further analyzed within PSA for external hazards.

The analysis results are provided in Table 3.32.

Table 3.32. Results of the screening and boundary analysis of the external extreme impact.

External hazards (EH)	Type of analysis	Results	Comments
EH induced by extreme natural phenomena			
Hydrometeorological processes and phenomena			
Flood (submergence/ affluxion)			
- floods in the Styr River	Detailed screening and boundary analysis	Excluded from analysis	Insignificant impact of the expected HA contribution into CDF, impact on the environment and people. Contribution into CDF– 0.0008 %
- flood rise	Detailed screening and boundary analysis	Excluded from analysis	External impact is characterized by indicators that are lower than the design limits
- intense rains	Initial exclusion	Excluded from analysis	Insignificance of the expected contribution impact on the environment and people.
Ice phenomena at the stream flow (ostructions, ice dam)	Initial exclusion	Excluded from analysis	Location of the hazard sources at a distance from the NPP
Change of water resources (extremely low run-off, abnormal decrease of water level)	Initial exclusion	Excluded from analysis	Insignificant impact of the expected HA contribution into CDF, impact on the environment and people. Contribution into CDF – 0.13 %
Tornadoes	Detailed screening and boundary analysis	This hazard is left for further analysis at the next stages	EH impact on vulnerable objects (spray ponds of the essential service water system, open switchgear) can lead to the accident "Loss of all 6 kV normal vital busbars" and "Loss of essential

External hazards (EH)	Type of analysis	Results	Comments
			service water system". Contribution into CDF: - failure of essential service water system – 0.43 %; - failure of pumps stations of circulation water system – 0.0001 %. Thus, the tornado induces damages that lead to the specific, above indicated accidents are excluded from further analysis due to little contribution into CDF, as well as low probability of negative impact on the environment and people. However, failures in operation of the spray ponds together with failures in operation of the power supply system cannot be excluded from further analysis. Since such failures can lead to accidents with consequences that may negatively impact the environment and people.
Wind	Initial exclusion	Excluded from analysis	External impact in advance has a quite lower frequency of occurrence than other EHs and cannot lead to more consequences.
Extreme snow falls	Initial exclusion	Excluded from analysis	External impact is characterized with indicators lower than the design limits.
Air temperature	Initial exclusion	Excluded from analysis	Impact can be excluded from the analysis, due to insignificant contribution into CDF (0.71% - impact of high temperature on the cooling towers).
Glaze	Initial exclusion	Excluded from analysis	Insignificance of the expected contribution impact on the environment and people.
Lightning strike	Initial exclusion	Excluded from analysis	Insignificance of the expected contribution impact on the environment and people.
Clogging of water intake facilities	Initial exclusion	Excluded from analysis	Insignificance of the expected contribution impact on the environment and people.
External hazards of manmade origin			
Fall of aircraft	Detailed screening and boundary analysis	Excluded from analysis	Impact exclusively based on the frequency criteria (IE frequency less

External hazards (EH)	Type of analysis	Results	Comments
			than 1E-07). Contribution into CDF – 5.19%.
Common cause faire	Initial exclusion	Excluded from analysis	Location of the hazard source at a distance from the NPP
Explosions at the facilities	Detailed screening and boundary analysis	Excluded from analysis	Location of the hazard sources at a distance from the NPP
Releases of explosion-hazardous, inflammable, toxic vapors, gases and aerosols into atmosphere	Detailed screening and boundary analysis	Excluded from analysis	Insignificant impact of the expected HA contribution into CDF, impact on the environment and people. Contribution into CDF – 0.53 %

LIST OF REFERENCES

1. Energy Strategy of Ukraine until 2030, approved by Directive #1071-p. of the Cabinet of Ministers of Ukraine as of 24.07.2013
2. Strategic Development Plan of the State Enterprise “National Nuclear Energy Company “Energoatom” for 2017-2021
3. Convention on Assessment of Transboundary Environmental Impact, ratified by the Law of Ukraine #534 – XIV as of 19.03.1999 [electronic source]. – Access link: http://zakon2.rada.gov.ua/laws/show/995_223.
4. Minutes of Meeting of Interdepartmental Steering Committee (ISC) on Issues Related to Implementation of Convention on Assessment of Transboundary Environmental Impact (Espo Convention) as of December 15, 2016.
5. Letter of NNEGC “Energoatom” #3313/18 as of 07.03.2017
6. Letter of NNEGC “Energoatom” #13391/18 as of 28.09.2017
7. Law of Ukraine “On Environmental Impact Assessment” (Report of the Verkhovna Rada of Ukraine, # 29, 2017, , p.315)
8. Directive 2001/42/EC of the European Parliament and Council as of June 27 2001 “On Environmental Impact Assessment of Individual Plans and Programs” (EC Official Bulletin, L 197, July 21, 2001)
9. Decree of the Cabinet of Ministers of Ukraine “On Approval of Order of Public Hearings in the Course of Environmental Impact Assessment” #989, as of December 13, 2017
10. Decree of the Cabinet of Ministers of Ukraine “On Approval of Order of Documents Submittal as for Conclusions of Environmental Impact Assessment and Order of Keeping Unified Register for Environmental Impact Assessment” # 1026, as of December 13, 2017
11. Law of Ukraine “On Order of Taking Decisions on Location, Design, Construction Of Nuclear Facilities And Installations Of National Significance Intended For Radioactive Waste Management” #2861-IV, as of 08.09.2005
12. NP 306.2.141-2008 “General Provisions On Safety Of Nuclear Power Plants”
13. Law of Ukraine “On Environmental Audit” #1862-IV as of 24.06.2004
14. Comprehensive (Overall) Program on Safety Improvement at Nuclear Power Plants” approved by the Cabinet of Ministers #1270, as of 07.12.2011
15. “Recommendations on the Content of Materials on Assessment of Environmental Impact from Operating Facilities”
16. ДБН А.2.2-1-2003 “Scope and Content of Materials on Assessment of Environmental Impact during Design and Construction of enterprises, Buildings and Installation”
17. Law of Ukraine “On Environmental Protection” # 1264-XII as of 25.07.1991
18. Law of Ukraine “Ecological Review”#45/95-BP as of 09.09.1995
19. Law of Ukraine “On Permitted Activity in the Field of Nuclear Energy Use” #1370-XIV as 11.01.2000
20. Law of Ukraine “On Usage of Nuclear Energy and Radiation Safety” #39/95-BP as of 08.02.1995.
21. Law of Ukraine “On Main Principles (Strategy) of State Environmental Policy of Ukraine until 2020” #2818-VI as of 21.12.2010
22. Law of Ukraine “On High-Risk Locations” #2245- III as of 18.01.2001

23. DSTU ISO 14001:2006 Environmental Control System. Requirements and Main Principles

24. Guideline for Development of Materials on Environmental Impact Assessment (to ДБН А.2.2-1-2003).

25. ДГН 6.6.1-6.5.001-98 "Norms of Radiation Safety of Ukraine. State hygienic standards (НРБУ-97).

26. "Decision on Size and Border of Sanitary protection zone and Observation zone of Rivne NPP", # 132-1-Р-11-ЦРБ on 3 pages (without annexes)

27. State Sanitary Rules "Main Sanitary Rules for Radiation Safety of Ukraine" (ОСПУ-2005), Order #54 of the Ministry of Health Protection as of 02.02.2005

28. ДНАО П.0.03-1.73-87 (СП АС-88). Sanitary Rules for Design and Operation of NPPs.

29. НАПБ А.01.001-2004 Fire Safety Rules of Ukraine

30. ВБН В.1.1-034.03.307-2003 Fire Protection Norms for Design of Nuclear Power Plants with Water-Water Power Reactors

31. НАПБ 06.015-2006 List of Rooms and Buildings of Energy Enterprises of the Ministry of Energy of Ukraine with Identification of Category and Classification of Zones of Fire and Explosion Safety

32. НАПБ Б.03.002-2007 Norms for Categorization of Rooms, Buildings and External Facilities with Regard to Fire and Explosion Safety

33. НАПБ 05.028-2004 Fire Protection of Energy Enterprises, Individual Facilities and Energy Units. Operation Design Instruction

34. НАПБ В.01.034-2005/111 Safety Precautions in Companies, Enterprises and Organization of the Energy Field of Ukraine

35. Law of Ukraine "On Fire Protection" # від 3745-XII as of 17.12.1993

36. Law of Ukraine "On Information" # 265 as of 02.10.1992

37. Law of Ukraine "On Printed Mass Media" as of 16.11.1992

38. Law of Ukraine "On Radioactive Waste Management" #255/95 –ВР as of 30.06.1995

39. Law of Ukraine "On Municipal Authorities" # 80/97, as of 21.05.1997

40. Law of Ukraine "On Citizen Communities" #2640-12 as of 16.06.1992

41. Law of Ukraine "On Property" #0697 as of 07.02.1991

42. Law of Ukraine "On Business Activity" #0698 as of 07.02.1991

43. Law of Ukraine "On Public Petitions" # 393/96 as of 07.02.1991

44. Law of Ukraine "On State Secrets" # 3855-12 as of 21.01.1994

45. Law of Ukraine "On Ratification of Convention about Access to Information, Participation Of the Public in the Decision Making Process and Access to Jurisdiction on Environmental Issues" # 832-14 as of 06.07.1999

46. Order #1830 as of 25.11.11 On Implementation of "Decision on Size and Border of Sanitary protection zone and Observation zone of Rivne NPP # 132-1-Р-ЦРБ"

47. Technical Specification for Radiation Monitoring of Rivne NPP 132-1-Р-ЦРБ, 2016

48. Report on Assessment of Impact from Non-Radiation Factors of Rivne NPP of NNEGC "Energoatom" on Environment for 12 Months 2017

49. Report on Information and Public Relations Control Activity at Rivne NPP for 2014

50. Report on Information and Public Relations Control Activity at Rivne NPP for 2015

51. Report on Information and Public Relations Control Activity at Rivne NPP for за 2016

52. Report on Information and Public Relations Control Activity at Rivne NPP for за 2017

53. Physical and Geographic Zonation of Ukrainian SSR. Edited by V.P.Popova, A.M.Marinina, A.I.Lanko. Publication of Kyiv University, 1968.

54. Lanko A.I., Marinich O.M., Scherban M.I Physical Geography of Ukrainian SSR. Radyanska School. K., 1969.

55. Report on Environmental Status in Rivne region in 2014. –Rivne, 2015 -280 p.

56. Regional Report on Environmental Status in Volynska Oblast for 2012. Volynska Oblast Administration, Ecology and Natural Resources Authority of Ukraine, 2012

57. Regional Report on Environmental Status in Volynska Oblast for 2013. Volynska Oblast Administration, Ecology and Natural Resources Authority of Ukraine, 2013

58. Regional Report on Environmental Status in Volynska Oblast for 2014. Volynska Oblast Administration, Ecology and Natural Resources Authority of Ukraine, 2014

59. Regional Report on Environmental Status in Volynska Oblast for 2015. Volynska Oblast Administration, Ecology and Natural Resources Authority of Ukraine, 2015

60. Regional Report on Environmental Status in Volynska Oblast for 2016. Volynska Oblast Administration, Ecology and Natural Resources Authority of Ukraine, 2016

61. Regional Report on Environmental Status in Volynska Oblast for 2017. Volynska Oblast Administration, Ecology and Natural Resources Authority of Ukraine, 2017

62. Marinich O.M. Geomorphology of Southern Polissya. Edition of Kyiv University. K., 1963

63. Korotun I.M., Korotun L.K. Geography of Rivne region / Company "Print House". Rivne. 1996

64. Andiyenko T.L., Shelyag-Sosonko Yu.P. Plant Life of Ukrainian Polessye in its Protection Aspect. - Kiev: Scientific Idea, 1983. - 216 p.

65. Shelyag-Sosonko Yu.R. Forests of Common Oak Formations on the Territory of Ukraine and its Evolution. - K.: Scientific Idea, 1974. - 240 p.

66. Afanasjev D.Ya. Plants of USSR. Native Meddows. - K.: Scientific Idea, 1968. – 255

67. Scherbak N.N. Zoogeographic Division of Ukrainian SSR //Zoology Bulletin. - 1988, N3. - C. 22-31., Nature of Ukrainian SSR: Landscape and Physical and Geographical Zonation. - K.: Scientific Idea, 1985. - 224

68. Medvedev S.I. Experience of Ecological Zoogeographical Zonation of Ukraine Based on Study of Etnomofauna //Scientific and Research Institute, Biology Faculty, State Kharkiv University . - 1957, T.27. - C. 5-26.

69. Reserves and National Parks of Ukraine /Ministry of Environmental Protection of Ukraine. - K.: High Sch., 1999. - 232 p.

70. Zhezherin V.P. Ornitofauna of Ukrainian Polissya and its Dependence from Landscape Conditions and Anthropic Factors. Kyiv, 1969.-143p.

71. Kistyakivskiy O.B. Fauna of Commercial Poultry of Polissya USSR. Collection of Materials of Zoological Museum, 1952.-112p.

72. Kryzhanovskiy V.I., Zhezherin V.P. Rear Animals and Birds of Ukraine and Their Protection. – Kyiv: Commercial, 1979.-149p.

73. Tatarinov K.A. Spreading and Seasonal Changes of Sandpiper Population on the West of Ukraine //Fauna and ecology of Sandpipers. – Moscow, 1973.-C.62-81.

74. Kistyakivskiy O.B. Birds. Kyiv: Edition of AN USSR, 1957.-236 p.

75. Lopatin I.КК Zoogeography. - Minsk: High School, 1989, - 318 p.

76. Akarchuk P.E. On Location of Garden Dormouse (Eliomys quercinus L.) on the Territory of Rivne region //Zoology Bulletin.- 1973.- № 1.-C. 36-43.

77. Sokur I.T. Animals of Our Country. – Kyiv: Soviet School. – 1971.-103p.

78. Tatarinov K.A. Fauna of the Spinals at the West of Ukraine: Ecology, significance, Proteciton. Lviv, 1973.-192p.

79. Goroshkov I.F. Hydrological Calculations. Leningrad, Gidrometeoizdat, 1979

80. 22.3.133.БД.12.09.Rev.2 (AT03-13.51281 .ОД.1). Rivne NPP. Power Unit 3. Accounting of Full Spectrum of Initiating Events of PSA Levels 1 and 2 for All Routine States of Reactor Facility and Spent Fuel Pit for RNPP Unit 3. Database of PSA for External Hazards. LLC “Atomenergoservice”. 2015.

81. 22.3.133.ОБ.07.01.Rev.2 (AT03-13.51351.ОД.1). Rivne NPP, Power Unit 3, Safety Analysis Report. Accounting of Full Spectrum of Initiating Events of PSA Levels 1 and 2 for All Routine States of Reactor Facility and Spent Fuel Pit for RNPP Unit 3. PSA Level 1 for External Hazards for Nominal Power Conditions. Screening and Boundary Analysis of External Hazards (Natural and Manmade), which can Affect Plant Operation. LLC “Atomenergoservice”. 2015.

82. Annual Report on Results of Meteorological Observations in 2012 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2013

83. 22.3.133.ОБ.04.01.Rev.2 (AT03-13.51311 .ОД.1). Rivne NPP. Power Unit 3. Accounting of Full Spectrum of Initiating Events of PSA Levels 1 and 2 for All Routine States of Reactor Facility and Spent Fuel Pit for RNPP Unit 3. PSA Level 1 for Internal Initiating Events at Plant Nominal Operation. Identification and Groups of Initiating Events. LLC “Atomenergoservice”. 2015.

84. Annual Report on Results of Meteorological Observations in 2010 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2011

85. СНиП 2.04.01-85 “Internal Water Supply Line and Sewerage System of Buildings. СНиП 2.04.03- 85 Sewage, External Networks and Facilities.

86. Natural meteorological phenomena in Ukraine and Moldova. Climate Guidebook. Under Eedition of Candidate of Geographical Sciences. N. Babichenko. UkrNIGMI, Leningrad, Gidrometeoizdat, 1991.

87. СНиП 2.04.03-85 External Sewerage Networks And Facilities

88. Annual Report on Results of Meteorological Observations in 2009 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2010

89. Annual Report on Results of Meteorological Observations in 2013 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2014

90. Annual Report on Results of Meteorological Observations in 2014 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2015

91. Rivne NPP. Power Unit 3. Safety Analysis Report. Probabilistic Safety Analysis. Accounting of Full Spectrum of Initiating Events for All Routine States of Reactor Facility and

Spent Fuel Pit, Development of Living PSA. Quantitative Assessment, Analysis of Results, Analysis Sensitivity and Uncertainty. 22.3.133.ОБ.12.02. ЕР02-2012.610.ОД.2.

92. File Materials of Meteorological Observations for 1945-1997 at the meteorological stations of Manevychi, Sarny, Rivne, Lutsk and Lyubeshov: Air Temperature and Humidity, Precipitations, Wind, Snow Cover, Soil Freezing, Evaporation, Fogs, Atmospheric Phenomena, Natural Meteorological Phenomena. – Kyiv: Industry State Archive of Central Geophysical Observatory of State Hydro-Meteorological Committee of Ukraine, 2000

93. РД–95 10444–91 Recommendations on Determination of Calculated Characteristics of Tornadoes in NPP Siting. – Moscow, Atomenergoproject. 1991

94. СНиП 2.01.01-82 Construction climatology and Geophysical. – Moscow: State Construction Committee of USSR, 1983.

95. Bryukhan F.F., Lyakhov M.E., Pogrebnyak V.N. Tornado Dangerous Areas of USSR and NPP sites. News AN USSR, Geographic Series, 1989, #1.

96. СНиП II-89-80 Building Code and Regulations. Part II. Design Norms. General Layout of Industrial Enterprises

97. Information on Styr River, SS “Rivne NPP”, 2012.

98. 38-223.203.003.ОБ.03.12. Rivne NPP. Power Unit 4 SAR. Volume 3. Chapter 3. Analytical Justification of Buildings, Constructions, Systems and Elements. Part 12. Buildings and Structures. Substructures and Foundations. OJSC KIEP, 2005

99. D.W.Coast, R.C.Murray. Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites, LLNL, University of California, UCRL-53526, Rev. 1, Livermore, California, 1985

100. Nalivkin D.V. “Tornado” Edition. Science M. 1984

101. 22.3.133.БД.12.02.03.Rev.2 (АТ03-13.51213 .ОД.1). Rivne NPP. Power Unit 3. Accounting of Full Spectrum of Initiating Events of PSA Levels 1 and 2 for All Routine States of Reactor Facility and Spent Fuel Pit for RNPP Unit 3. Database on Description of All Routine Plant States. Part 3. Supporting Systems. LLC “Atomenergoservice”. 2015.

102. External Events Analysis and Probabilistic Risk Assessment Application for Iris Plant design. 13th International Conference on Nuclear Engineering Beijing, China, May 16-20, 2005 ICONE13-50409

103. Rivne NPP. Power Unit 4 SAR. Chapter 3. Analytical Justification of Buildings, Constructions, Systems and Elements. Part 4. Probabilistic Scenarios of Consequences from Initiating Events of Manmade Character on NPP Site.

104. Riven NPP, Power Unit 3, Extension. Special Aerometeorology Provision of Rivne NPP. – Odessa: Odessa Hydro-meteorological Institute, 1982.

105. Report on Scientific and Technical Study “Analysis of Aerological Mode of Khmelnitksiy and Rivne NPPs Siting”.– Kyiv: NASU, Scientific And Research Center For Fluid Mechanics. 1999.

106. Natural Meteorological Phenomena on the Territory of Ukraine for the Past Two Decades (1986 - 2005). Edited by Lipinskiy V.M, Osadchyy B.I, Babichenko V.M. Kyiv Nika-Center. 2006

107. 22.4.133.МД.12.16 (ЕР3-2012.1216.ОД.1). Riven NPP. Power Units 3,4. Accounting of Full Spectrum of Initiating Events for All Routine States of Reactor Facility and Spent Fuel Pit, Development of Living PSA. Methodological Guideline. PSA Levels 1 for External Hazards at Nominal Power. LLC “Energorisk”, 2012

108. Atmosphere, Reference Guide. Leningrad. Gidrometoizdat. 1991

109. Annual Report on Results of Meteorological Observations in 2010 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2011

110. Annual Report on Results of Meteorological Observations in 2011 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2012

111. Annual Report on Results of Meteorological Observations in 2012 in the Area of Rivne NPP Location. Kuznetsovsk Town, 2013

112. Flexible Linear Line 750 kV of RNPP Unit 4 (Extension) 336-26 Batch. Distribution of Supports, Mounting Part and Crossings. “Energosetproject” Dnepropetrovsk OKP. 1987

113. Flexible Linear Line 330 kV. 3707-330-26. “Energosetproject” Lviv Branch 1987

114. ПиНАЭ-5.6. Construction Design Norms for NPPs with Different Types of Reactor Types.- M.: Ministry of Nuclear Energy USSR,1986.-21 p

115. СНиП II-6-74 “Loads and Effects”

116. 22.3.145.ОБ.03.7.1.3. Rivne NPP. Power Unit 3. SAR. ASAD. Section 7. Analysis of Design Concepts and Performance Indicators. Deterministic Assessment of Safety Level. Part 1. Classification of Structures, Systems, Elements and Equipment. Book 3. Classification of Structures and Elements of Construction Part. LLC “Energorisk”, 2012

117. ДБН В.1.2-2:2006. Loads and Effects. Design Norms. Kyiv. – Ministry of Construction of Ukraine, 2006

118. Zaporizhzhya NPP. Power Unit 5. Draft In-depth Safety Analysis Report. PSA for External Hazards in Limited Scope – Part 1. Natural Hazards and Planning. 20052dl11r-eha. 2002

119. 38-223.203.003.ОБ.03.10. Rivne NPP. Power Unit 4. Safety Analysis Report. Chapter 3. Analytical Justification of Buildings, Structures, Systems and Elements. Part 10. Methods of Justification and Criteria for Plant Buildings and Structures Stability. OJSC KIEP, 2005.

120. USSR Climate Reference Guide. Edit. 10, Leningrad, Gidrometeoizdat, 1969

121. Climate of Ukraine. Edited by V.M. Lipinskiy and others, Kyiv, 2003

122. Bazelyan E.M., Gorin B.N., Levitov V.I. Physical and Engineering Basis for Lightning Protection. L 1978.

123. Statement of Work for provision of services “Service for Engineering Tests and Analysis” (Development of Periodic Safety Review Report for RNPP Unit 3)”

124. 38-223.203.003.ОБ.03.03. Rivne NPP. Power Unit 4 SAR. Volume 3. Chapter 3. Analytical Justification of Structures, Systems, Elements and Equipment. Part 3. Description and Justification of Plant Layout and General Location of Structures and Buildings. OJSC KIEP, 2003.

125. 061-25-П-УКБ. Provisions on Operation of Production Buildings, Structures, Hydraulic Buildings, Rooms of the Site of Power Units 1,2,3,4, Construction Depot 1,2, Facilities of Social and Cultural and Plant General Use, which are Under Balance of Rivne NPP”.

126. Babichenko V.N. and others. Air Temperature in Ukraine. Leningrad, Gidrometeoizdat, 1987.

127. СНиП 2.01.01-81 “Construction Climatology and Geophysics”.

128. СНиП 2.04.05-91 “Heating, Ventilation and Air Conditioning”.

129. 38-172.203.001.ОБ02. Additional Target Safety Review for RNPP Power Units Considering Lessons Learnt from Fukusima-1 Accident”. Chapter 2. Assessment of External Hazards. ОЦПБ-0.41.002.02.

130. Rules of Electrical Installation Design. Ministry of Energy of USSR. – M.: Energoatomizdat, 1986

131. Rivne NPP. Power Unit 1. Draft In-depth Safety Analysis Report #1. PSA for External Hazards in Limited Scope – Database and Initial Identification of Vulnerabilities. Part 1. RIVISA- 510DL11R.XVI. Rev.1

132. Letter from South Ukraine NPP #86/12596 as of 15.12.2006. Letters from the Ministry of Emergencies #06-13050/35 as of 10.11.2006 and Forecast Control Department of the Ministry of Emergencies #24-128/01 as of 24.03.2005. Letters from Forecast Control Department of the Ministry of Emergencies #32-16/01 as of 18.01.2011. Letters from the State Aviation Transport Department (Ukraviatrans) on Provision of Information on In-flight Movement in the Area of South Ukraine NPP #34.234-26 as of 02.02.2011. Email Letter from Forecast Control Department of the Ministry of Emergencies as of 22.03.2012. Email Letter from Emergencies Prevention Department as of 12.03.2013. File "List of Emergencies for 2012 (1).xls». Email Letter "Golovko Plane (3) 2015" Letter from Stransoprt as of 14.06.2015

133. 38-223.203.003.ОБ.03.05. Rivne NPP. Power Unit 4 SAR. Chapter 3. Analytical Justification of Structures, Systems, Elements and Equipment. Part 5. Parameters of Internal Effects on Constructions, Buildings and Plant Structures that Occur within the Plant Site and Reactor Facility. OJSC KIEP, 2005

134. 38-172.203.001.ОБ02. Additional Target Safety Review for RNPP Power Units Considering Lessons Learnt from Fukusima-1 Accident". Chapter 2. Assessment of External Hazards. ОЦПБ-0.41.002.02.

135. 38-223.203.003.ОБ.07.04. Rivne NPP. Power Unit 4 SAR. Volume 7. Chapter 7. Technological Plant Processes Control System. Part 4. Control Places and Centers at NPP. OJSC KIEP, 2005

136. Methodology for Forecasting of Impact Consequences (Release) of Chemically Hazardous Substances during Accidents at Industrial Facilities and Transport. Approved with the Decree of the Ministry Emergencies # 73/82/64/122 as of 27.03.01.

137. Office Memos of KIEP from 2005.

138. Safety Rules and Procedure for Liquidation of Emergency Consequences from Dangerous Cargos during Railway Shipment. Approved by Decree of the Ministry of Transport of Ukraine #567 as of 16.10.2000 and Decree of the Ministry of Justice of Ukraine #857/5078 as of 23.11.2000

139. DOE–STD–3014–96. Accident Analysis for Aircraft Crash into Hazardous Facilities. DOE Standard, October 1996

140. Pripadichev A.D. Determination of Optimal Aircraft Park. 2009

141. Nelson A. Hanan, Aircraft Crash, Workshop on Methods for External Events Probabilistic Safety Analysis, Moscow, Russia, September 11 – 15, 1995. Prepared by Energy Research, Inc.

142. Rivne NPP. Power Unit 4. Scientific and Research Work. "Analysis of Aircraft Fall Probability and Vulnerability Analysis for Rivne NPP Unit 4 to this Category of External Hazards". Final Report. Kyiv 2004

143. Rules of Aircraft Flights and Servicing of Air Traffic in the classified Air Space of Ukraine. Approved by Decree of the Ministry of Transport of Ukraine # 293 as of 16 April 2003. N. Registered in the Ministry of Justice of Ukraine on 5 May 2003. N 346/7667

144. 22.4.133.МД.12.16 (ЕР3-2012.1216.ОД.1). Rivne NPP. Power Unit 3,4. Accounting of Full Spectrum of Initiating Events for All Routine States of Reactor Facility and Spent Fuel Pit in PSA, Development of Living PSA. Methodological Guideline. PSA Levels 1 for External Hazards at Nominal Power. OJSC "Energoarisk", 2012.

145. РД–95. 10444–91. Recommendations on Identification of Calculation Characteristics of Tornadoes in NPPs Siting. – Moscow: Atomenergoproject, 1991

146. IAEA Safety Guideline 50-SG-S11A. Accounting of Extreme Meteorological Events in NPP Siting (without Tropical Cyclones) Vienna, 1983

147. Simiu E., Skanlan R. Wind Effects on Buildings and Constructions. Moscow, Stroyizdat, 1984

148. Natural Meteorological Events on the Territory of Ukraine for the Last Two Decades (1986 - 2005). Edited by Lipinskiy V.M, Osadchyy V.I, Babichenko V.M. Kyiv Nika-Center. 2006

149. From Shelter to Confinement of Chernobyl NPP Power Unit 4. Construction Aspects. Edited by P.I. Krivosheeva, Yu.V. Malakhova, A.A. Klyuchnikova, Yu.I. Nemchinova, V.Ya. Shenderovich, V.N. Scherbina, R.V.Vasyagina. Kyiv, Logos, 2006

150. Dynamic Calculation of Constructions for Special Effects. Reference Guide. M. Stroyizdat 1981

151. 22.3.133.ОБ.07.01. Rivne NPP. Power Unit 3. Safety Analysis Report. Probabilistic Safety Assessment. Accounting of Full Spectrum of Initiating Events for All Routine States of Reactor Facility and Spent Fuel Pit in PSA, Development of Living PSA. Screening and Boundary Analysis of External Hazards (Natural and Manmade), which can Affect Plant Operation. OJSC “Energoarisk” 2014

152. Birbrayer A.N, Shulman S.G Strength and Reliability of Plant Structures during Special Dynamic Effects. Energoizdat. Moscow. 1989

153. Beschistnov M.F. Industrial Explosions. Assessment and Prevention. M. Chemistry, 1991

154. Beyker U. Explosive Events. Assessment and Consequences. V. 1 and 2, M., Mir, 1986

155. Recommendations on Assessment and Reduction of Consequences of External Accident Impact on NPPs. Atomenergoproject. M., 1991

156. Completion of Construction and Modernization of Khmelnitskiy NPP Unit 2 and Rivne NPP Unit 4. 2.1.8. Report on Toxic Hazards Analysis. Zh-M. Leshmer. 1997

157. Budnitz, R.J. “State-of-the-art Report on the Current Status of Methodologies for Seismic PRA”. Report to the Nuclear Energy Agency. July 1997.

158. Recommendations for Assessment and Reduction of Consequences of External Accident Impact on NPPs. Atomenergoproject. M., 1991.

159. Law of Ukraine “On Energy-Related Lands And Legal Regime For Special Zones Of Energy Facilities”.

Attachment A

MINISTRY OF ENERGY AND COAL INDUSTRY OF UKRAINE
SE “National Energy Generating Company “Energoatom”
SS “RIVNE NUCLEAR POWER PLANT”

Approved by
Chief Engineer – First
Deputy General Director
_____P.I. Kovtonyuk
06.02.2018

TECHNICAL REQUIREMENTS
to
performance of service
“Assessment of Environmental Impact of Rivne NPP Site”

083-01-TB-COHC

Rivne NPP 083-01-TB-COHC	TECHNICAL CONDITIONS	Page 2

AGREEMENT PAGE

Chief Inspector		05.02.18	Yu.O.Pavlov
Deputy Head of Chief Engineer for Nuclear and Radiation Safety		05.02.18	S.N.Borishkevich
Deputy Chief Engineer for Technology and Engineering		06.02.18	V.A.Leonov
Head of Contractual Department		05.02.18	S.M.Kulesh
Head of Radiation Safety Department		05.02.18	O.A.Salagayev
Head of Nuclear Safety Department		05.02.18	V.P.Boris
Head of Safety Analysis Service		05.02.18	M.O.Divisenko
Head of Environmental Protection Service (EPS)		02.02.18	O.M.Gorkovlyuk

DEVELOPERS

Position	Signature	Data	Name
Deputy Head of EPS-Head of Supervision and Engineering Department		02.02.2018	S.O.Kochurov
Engineer on Environment Protection 2 category, EPS		01.02.2018	O.S.Mukomol

TABLE OF CONTENTS

1. GENERAL PROVISIONS:

1.1 These technical requirements define the general requirements to the order of providing the service and its content during accomplishment of the environmental impact assessment (EIA) for Rivne NPP, as an operating nuclear power plant under the safety review for RNPP Units 1, 2.

1.2 These technical requirements are included in the package of the documents developed by RNPP for the public procurements in order to determine the contractor who will be providing services.

1.3 Basis for service provision:

- Energy strategy of Ukraine until 2030, approved by Directive #1071-p. of the Cabinet of Ministers of Ukraine as of 24.07.2013;
- Strategic development plan of the State Enterprise “National Nuclear Energy Company “Energoatom” for 2017-2021;
- Decision of the 6th Meeting VI/2 of the Convention’s parties on assessment of transboundary environmental impact (Espo Convention) ECE/MP.EIA/SEA/4/Add.1;
- Minutes of meeting of interdepartmental steering committee (ISC) on issues related to implementation of convention on assessment of transboundary environmental impact (Espo Convention) as of December 15, 2016.
- Letter of NNEGC “Energoatom” #3313/18 as of 07.03.2017
- Letter of NNEGC “Energoatom” #13391/18 as of 28.09.2017

1.4 Purpose of service provision:

Development of the documents of environmental impact assessment is necessary to evaluate the impact on the environment during operation of Rivne NPP power units. The assessment uses the results of nature protection activities, multi-year monitoring of the environment objects, and comparison of the environment state around NPP before operation and during plant operation (taking into account the available documents on environmental impact assessment for RNPP Unit 4), and forecast of the expected impact level for further operation of the power units of Rivne NPP.

1.5 Customer of the service:

SS Rivne NPP of NNEGC “Energoatom” (location: Ukraine, 34400, Town of Varash, Rivne NPP).

1.6 Provider of the service:

The service provider (contractor) is selected through the procedure of public procurement, at that the documents on environmental impact assessment can be developed by the specialized design organization, which has experience in development of the similar documentation.

The separate specialized sections of the environmental impact assessment can be developed by the external organizations according to the agreement with Rivne NPP.

1.7 The financing source for service provision: own funds of the Company.

1.8 Duration of service provision: December 2019, considering the obtained conclusion on the environmental impact assessment.

083-01-TB-COHC		

2. OBJECT OF SERVICE

2.1 The Service objects are operating power units, installations and structures, which are part of a process complex located on the territory of Rivne NPP site, as well as other facilities within the energy complex that influence the environment in the area of plant location (sanitary protection zone and observation zone).

3. PHASES OF SERVICE PERFORMANCE

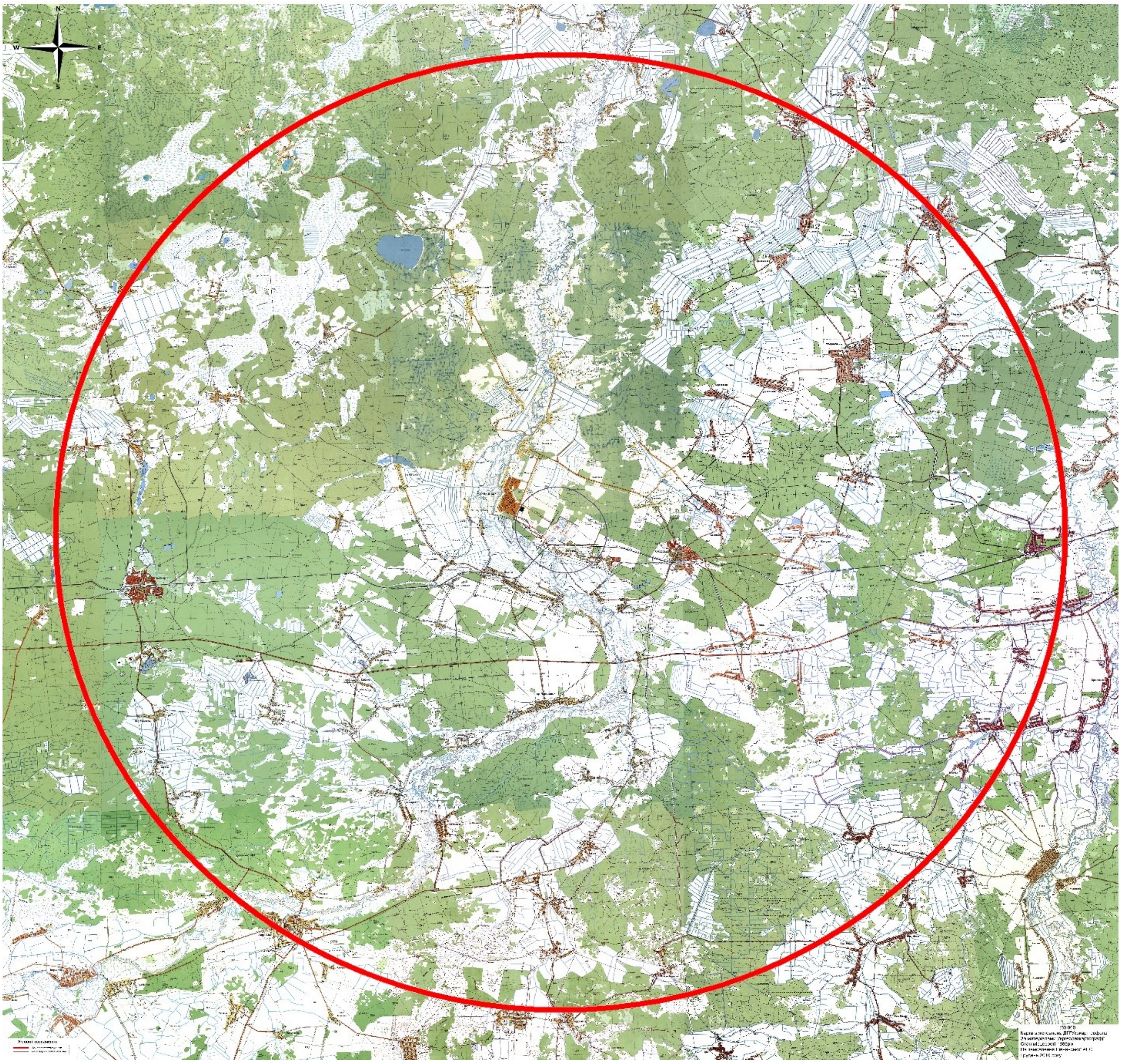
3.1 Procedure for service acceptance-transmission, due dates and reports for each completed phase are defined in the work schedule as per the contract.

3.2 The service on development of documents related to environmental impact assessment for Rivne NPP is accomplished in accordance with the following phases:

# of phase	Phase	Due dates	Deliverables
1	Collection of information (monitoring results, experience of power units operation, implemented or scheduled activities, etc.) necessary for development of the documents on environmental impact assessment, analysis, filing and unification taking into account the conditions as for the scope of studies and detailed level of information to be included to the report on environmental impact assessment (T1)	T0* + 2 months	Systematic, unified catalogue of output data necessary for development of environmental impact assessment. Technical Act. Service acceptance-transmission Report for Phase 1
2	Development of documents on environmental impact assessment (T2)	T1 + 5 months	First revision of the report on environmental impact assessment. Technical Act
3	Preliminary review of the documents on environmental impact assessment by the Customer, preparation of Revision 2 of the report following the review results. Translation of the report on environmental impact assessment into English (T3)	T2 + 1 months	Second revision of the report on environmental impact assessment with English translation version, agreed with the Customer. Technical Act. Service acceptance-transmission Report for Phase 2
4	Follow-up and correction of the report (if needed) on environmental impact assessment during public discussions, transboundary consultations as a results of environmental impact assessment, as well as in the process of receiving a positive conclusion on the assessment of environmental impact from the Ministry of Ecology and Natural Resources	T3 + 9 months	Agreed final report on environmental impact assessment considering the requirements of paragraph 7, article 14 of Laws of Ukraine “On assessment of environmental impact”, positive conclusion on the assessment. Technical Act.

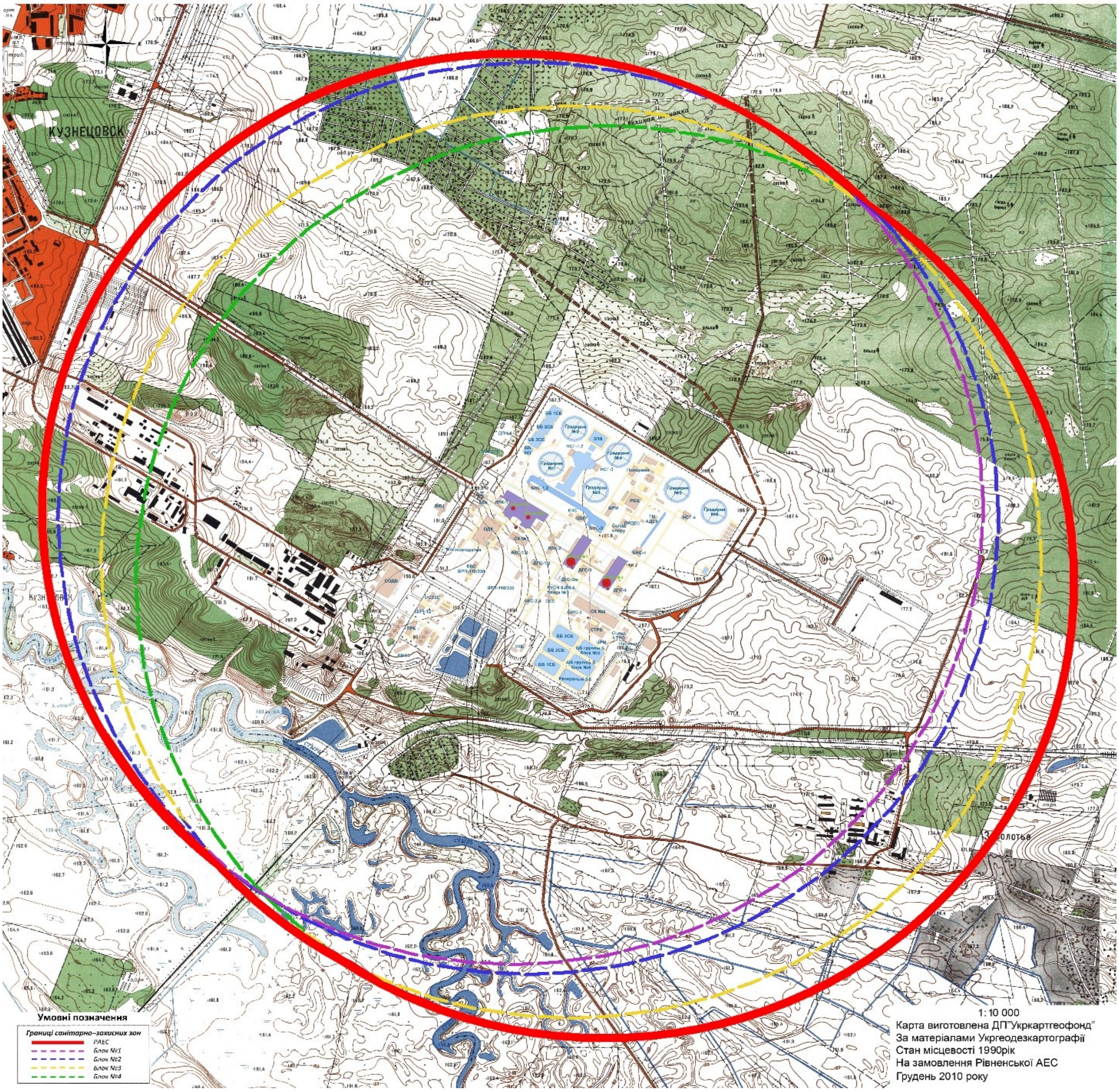
Attachment B

Map
Observation zone of Rivne NPP



Attachment C

Map
Sanitary protection zone of Rivne NPP



CHARACTERISTICS OF TORNADOES BY FUJITA SCALE

To assess the tornado characteristics, a classification system is applied with scaling suggested by Fujita. The basis of this classification is a quantitative and qualitative description of the tornado consequences. The scaling is used to define the damage degree, as well as to classify the tornado in terms of its intensity rate. Classification of tornadoes by Fujita scale is presented in [145, 146]. In accordance with this scale, tornadoes are divided into 7 classes, where each class (rate) is defined by the following parameters:

- maximum horizontal speed of tornado's wall rotating motion - V_k, m/s;
- progressing tornado speed– U_k , m/s;
- length L_k and width W_k of tornado pathway, km;
- pressure difference between periphery and tornado rotation center Δp_k, gPa (kgf/m^2);
- pressure reduction speed dp/dt, kPa/s;
- annual tornado frequency through any point of the region with homogeneous climate conditions of tornado formation, reactor/year.

In addition to the specified parameters, several more parameters exist that can be used in some cases for identification of tornado impact on the NPP buildings and constructions. The complete list of parameters with corresponding calculations is presented in Attachment C.

The character of tornado impact is determined by three factors:

- pressure of wind caused by the direct action of the aerial flow with the tornado moving above the buildings;
- pressure associated with the change of atmospheric pressure field with the tornado moving above the buildings (influence of the changing atmospheric pressure) ;
- strike forces caused by the flying objects during tornado.

To estimate the impact of these factors, it is necessary to have a model of the airflow in the tornado. At present, the engineering calculations apply the form of a vortex in the model, characterized with the following parameters:

- maximum horizontal air flow speed Vmax, m/s;
- maximum horizontal speed of the tornado's wall rotating motion - V_k, m/s;
- progressing tornado speed – U_k , m/s;
- radius corresponding to the maximum air flow speed, Rmax;
- radius of damaged area (breakdown) R_D, m;
- pressure drop Δp and pressure reduction speed dp/dt [146].

To identify the main characteristics of these tornadoes, the results of works [92, 94, 98] were used. The main characteristics and calculation formulas of these tornados are presented below in the section "Identification of Tornadoes Characteristics" and ("Calculation of tornado occurrence probability in the area of RNPP site"). Characteristics of the tornado classes 0-3 are provided in Tables 1 and 2.

Table 1. Probabilistic and speed characteristics of tornadoes of Class 0-3 according to Fujuta Scale

Tornado class by Fujita scale	Probability of exceeding the tornado class ≥k	Speed of progressing wind, m/s	Rotating speed (swirl), m/s	Vertical speed component, m/s	Maximum horizontal wind speed, m/s
0	1.16E-06	6	25	15	31
0.5	1.41E-06	8	33	20	41
1	1.39E-06	10	41	25	52
1.5	1.33E-06	13	50	30	63
2	1.15E-06	15	60	36	75
2.5	6.46E-07	18	70	42	88
2.75	1.01E-07	19	76	45	95
3	-	20	81	49	102
3.4	-	23	90	54	113

Table **Ошибка! Текст указанного стиля в документе отсутствует.**. Characteristics of the tornado classes 0-3, for rotation air flow radius, pressure parameters and vertical wind load

Tornado class by Fujita scale	Radius corresponding to maximum speed of air flow rotation, m	Radius of damaged area (breakdown area), m	General value of pressure drop, kPa	Speed of pressure drop, kPa/s	Total load from tornado, kPa
0	33	31	0.8	0.1	1.0
0.5	37	45	1.3	0.3	1.7
1	40	62	2.1	0.5	2.7
1.5	44	83	3.1	0.9	4.0
2	48	109	4.4	1.4	5.7
2.5	53	139	6.1	2.0	7.8
2.75	55	156	7.0	2.4	9.0
3	57	174	8.1	2.9	10.3
3.4	61	207	10.0	3.7	12.8

The annual frequency of tornado pass through any point of the region with homogeneous climate conditions for tornado formation is defined using the following formula [92, 94]:

$$P_s = \frac{S}{A \cdot T} ,$$

where: S – total area of tornado pass in the analyzed region for the observation period (T), years;

A- area of the region.

The results of the former USSR territory zonation with regard to the tornado danger are presented in [92, 94]. In accordance with these materials, the RNPP site is located in the tornado dangerous region ІД with the area of 7.00×10^5 km^2.

When defining the total area of the tornado pass, it is accounted for that the actual amount of weak tornadoes is greater than the observed ones. The following dependence is accepted in relation to the amount of the actual tornadoes to the registered tornadoes from the intensity class [92, 94]:

α(k) =1,5 at $k \leq 1$;

α(k) =1 at k>1.

The total area of tornado pass is defined using the following expression:

$$S = \sum_{k=0}^{l} \alpha(k) \cdot n_k \cdot L_k \cdot W_k ,$$

where: n_k - amount of tornadoes of class k, registered in this climate zone;

l – the most observed class;

L_k- value of tornadoes length, km;

W_k – width of tornado pass of class k, km.

Expressions for definition of L_k and W_k are presented in Attachment **Ошибка! Источник ссылки не найден.**.

Data on the amount of tornadoes in the indicated region are applied on the basis of [79, 80, 92, 94, 147, 148]. The continuous observation period of T = 74.4 years was analyzed. Data on the registered tornadoes in the ED region from 1942 to 1985 (including) are applied on the basis of [92, 94]. Data for the period of 1986-2005 are applied on the basis of [147, 148]. Based on the data [79, 80] in 2006-2010 and until 31.12.2014 there were 6 tornadoes registered in the analyzed region ІД. Data for 2015 have not been included yet and will be clarified after their generalization in Ukrgidromet (Ukrainian Hydraulic and Meteorological Center).

The summarized data on the amount of tornadoes of a particular class for the tornado dangerous region ІД are provided in Table 3. The table also presents the frequency calculation results for Class k tornado pass through the region of Rivne NPP site.

Table 3 – Data on amount and characteristics of tornadoes for tornado dangerous region ІД (Rivne NPP area).

Tornado class	Amount of tornadoes registered in ІД region	Coefficient α (k)	Amount of actual tornadoes	Length of tornado pass, km	Width of tornado pass, km	Area of tornado pass, km^2	Area of all passed tornadoes of Class k, km^2	Frequency of tornado occurrence
0	20	1.5	30	0.90	0.01	0.01	0.30	5.76E-09
1	37	1.5	55.5	2.86	0.03	0.08	4.44	8.53E-08
2	15	1	15	9.05	0.09	0.81	12.28	2.36E-07
3	5	1	5	28.61	0.29	8.30	40.93	7.86E-07
-	77		105.5	-	-	-	57.95	1.11E-06

It can be seen from the table, the annual probability of tornado pass through the region of Rivne NPP site is 1.11×10^{-6} $year^{-1}$.

The defined integral probabilistic characteristics of tornado pass through the tornado dangerous area is presented in [92, 94]. Based on these materials, the integral function was determined for tornado distribution in any fixed point of the area with tornado class exceeding k for the region of Rivne NPP site. The results of the class k tornado probability calculation are presented in Table 4, and the methodology for calculation of the integral distribution function is provided in the text below (“Calculation of the tornado occurrence probability in the area of Rivne NPP site”).

Table 4 – Probability of exceedance of tornado P_0, class k_p

Tornado pass probability with class k, 1/year	Tornado class, k
1.11×10^{-6}	0
10^{-7}	2.78

Based on the tornado data provided in Table , such a meteorological event as tornado can not be screened out by the frequency criteria [**Ошибка! Источник ссылки не найден.**22] and it is necessary to consider the impact of tornadoes of class 0 – 2.78 on the RNPP buildings and structures. Since the accuracy of defining the tornado boundary class is not high, the further analysis considers the impact of class 0-3 tornadoes for RNPP buildings and structures and class 3,4 tornadoes for the reactor building.

Identification of Tornadoes Characteristics

To define the main tornado characteristics, the results of materials [94, 98] were used. The expressions used for identification of the tornado characteristics are provided in [94, 98]. Based on these expressions, the characteristics of the tornadoes with intensity class 0-3 were calculated in the main text of the report.

Table 5. Calculation formulas for identification of the tornado characteristics

Tornado parameters	Designation	Calculation expression	Source	Note
Maximum horizontal wind speed, m/s	Vmax	Vmax = $U_{k\,r}$+ V_k	[998]	1
Progressing wind speed, m/s	U_k	U_k =1.575 × (k+2,5)^{1,5}	[94]	1
Swirl wall rotation speed (vortex wall), m/s	V_k	V_k = 6.3 × (k +2,5)^{1,5}	[95]	-
Vertical wind speed, m/s	V_v	V_v = 0.60 × V_k	[998]	-
Radius corresponding to maximum speed of air flow rotation, m	R_{max}	R_{max} =0.341 × V_{max} + 22.86 если V_{max} <112, R_{max} =0.682 × V_{max} - 15.24 если V_{max} ≥112,	[998]	2
Radius of damaged area (breakdown area), м	R_D	R_D= R_{max} ×Vmax/33.5	[98]	-
Length of tornado pass zone, km	L_k	$L_k = 1,609 \times 10^{0,5\cdot(k-0,5)}$	[954]	-
Width of tornado pass zone, km	W_k	$W_k = 1,609 \times 10^{0,5\cdot(k-4,5)}$	[94]	-
General value of pressure drop, kPa	Δp_k	$\Delta p_k = \rho \times V_k^2$	[998]	-
Speed of pressure drop, kPa/s	$\frac{dp}{dt}$	$\frac{dp}{dt} = \rho \times V_k^2 \times U_k / R_{max}$	[98]	-

Tornado parameters	Designation	Calculation expression	Source	Note
Total load from tornado, kPa	-	$p = \frac{1}{2}\rho \times V_{\max}^2 + \frac{\Delta p_k}{2}$	[146]	-

Note 1. To define the swirl wall rotation speed and progressing wind speed, the expressions provided in materials [954] are used. To define the maximum wind speed and vertical component of the wind speed (V_v), the results of the materials [98] are used.

Note 2. The radius corresponding to the maximum speed of the airflow rotation was obtained on the basis of approximation of data provided in the materials [998]. Figure 1 below presents the diagram of this dependence and points through which they pass.

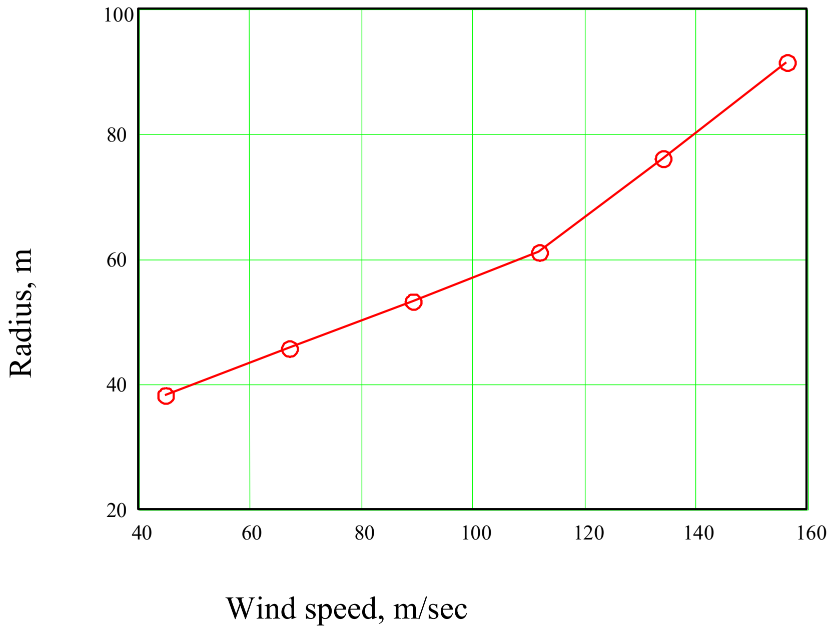


Fig. 1 – Dependence of the radius corresponding to the maximum speed of the air flow rotation ona the maximum wind speed

Note 3. In the expression for general pressure drop and pressure drop speed, the value ρ is a density of air equal to 1.227 kgf/cm^3

Calculation of probability of tornado occurrence in the area of RNPP site

Probability of tornado pass through Rivne NPP site was defined using the methodology presented in [92, 94].

The annual probability of tornado occurrence in the fixed point of the region with the class exceeding k, is the following:

$$P = P_s \cdot (1 - F(k))$$

where: (1 – F(k)) – probability of exceeded Class k tornado among tornadoes registered in this region;

P_s – annual probability of tornado pass through any point of the region defined in the main text of the report.

When defining the total area of tornado pass, we keep in mind that the actual amount of weak tornadoes is greater than the registered ones. α(k) is a correlation of the actual amount of tornadoes to the amount of the registered tornadoes, which is accepted depending on the intensity class equal to (for IД area) [118, 132]:

α(k) =1.5 at $k \le 1$,

α(k) =1 at k>1.

The total area of tornado pass is defined using the expression:

$$S = \sum_{k=0}^{m} \alpha(k) \cdot n_k \cdot L_k \cdot W_k$$

where: n_k – amount of Class k tornadoes;

m – the biggest observed tornado class;

Lk – values of length (km) and Wk – width (km) of the passing area for Class k tornadoes, which are defined using the following correlations [95, 145]:

$$L_k = 1{,}609 \cdot 10^{0{,}5 \cdot (k - 0{,}5)}$$

$$W_k = 1{,}609 \cdot 10^{0{,}5 \cdot (k - 4{,}5)}$$

Due to discrete values of the classes applied to describe the tornadoes, the integral probability is defined ambiguously and for the given k class it uses nk values:

$$F_i(k) = i \cdot \alpha_0 \cdot L_0 \cdot W_0 / S$$ at k=0 (i=1,…n0)

$$F_i(k) = i \cdot \alpha_k \cdot L_k \cdot W_k / S + 1/S \cdot \sum_{j=0}^{k-1} n_j \cdot \alpha(k) \cdot L_j \cdot W_j$$ at k>0 (i=1,…nk),

where: n_j – amount of class j tornadoes registered in the region;

α(j) – relation of the actual amount of the tornadoes to the registered intensity class j tornadoes.

Considering the power law dependence of the passing tornadoes area on the tornado class, the empirical curve rectification can be ensured using the logarithmic probability scale. In this case:

$$-\ln(F(k)) = a \cdot k + b$$

where: a and b – constants defined using the least square method:

$$a = \frac{\langle k \rangle \cdot \langle \ln F(k) \rangle - \langle k \ln F(k) \rangle}{\langle k^2 \rangle - \langle k \rangle^2};$$

$$b = \frac{\langle k \rangle \cdot \langle k \ln F(k) \rangle - \langle k^2 \rangle \cdot \langle \ln F(k) \rangle}{\langle k^2 \rangle - \langle k \rangle^2}.$$

The averaging procedure is marked with the symbol $\langle \cdot \rangle$ in the expressions:

$$\langle k \rangle = 1/n \cdot \sum_{k=0}^{n_k} k \cdot n_k$$

$$\langle k^2 \rangle = 1/n \cdot \sum_{k=0}^{n_k} k^2 \cdot n_k$$

$$\langle \ln(F(k,i)) \rangle = 1/n \cdot \sum_{k=0}^{l} \sum_{i=1}^{n_k} \ln(F(k,i))$$

$$\langle k \cdot \ln(F(k,i)) \rangle = 1/n \cdot \sum_{k=0}^{l} \sum_{i=1}^{n_k} k \cdot \ln(F(k,i))$$

where: $n = \sum_{k=0}^{l} n_k$ - amount of tornadoes observed in the region.

Parameters of calculations and interim results are presented in Table 6.

Table 6 – parameters of calculations and interim results

n	S	$\langle k \rangle$	$\langle k \rangle^2$	$\langle k^2 \rangle$	$\langle \ln(F(k)) \rangle$	$\langle k \cdot \ln(F(k)) \rangle$	a	b
77	57.95432	1.081081	1.168736	1.891892	-2.93159467	-1.957374836	-1.6759	4.743349

Figure 2 illustrates the negative algorithm of the empiric integral distribution of the intensity class k tornadoes for region ІД. The rounded dots are used for marking the values, calculated by the formula of integral probability. A solid line is a line rectifying the points using the least square method.

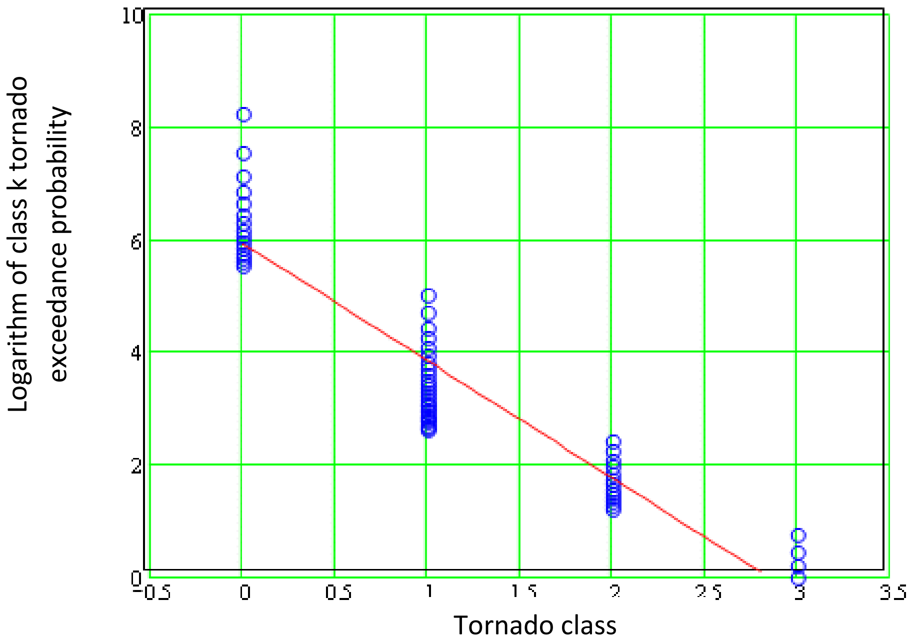


Fig. 2 Logarithm of Class k tornado exceedance probability

Figure 3 shows the dependence of Class k - $P_0(k)$ tornado exceedance probability, formed using the formula:

$$P_0(k) = 1{,}11 \cdot 10^{-6} \cdot (1 - \exp(-(a \cdot k + b)))$$

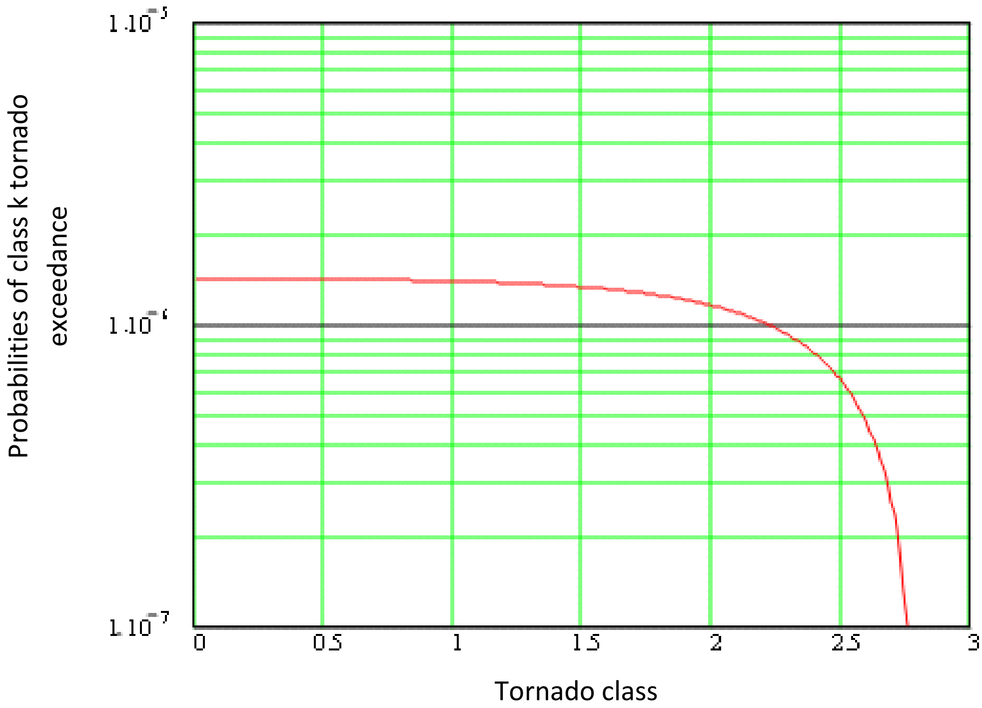


Fig. 3. Dependence of Class k tornado exceedance probability

The calculated class of the tornado intensity, ensuring P_0 probability, is defined from the following condition:

$$F(k_p) = 1 - \frac{P_0}{P_s}$$

whence it follows that:

$$k_p = -1/a \cdot ((\ln(1 - P_0/P_s) + b)$$

The value P_s for RNPP area is defined in the main sections and equals to 1.11×10^{-6}, a and b are provided above. For $P_0 = 10^{-7}$ (accepted as the screening boundary according to [**Ошибка! Источник ссылки не найден.**22]), the value of the calculated tornado class, as per the formula provided above, is $k_p = 2.78$.

Attachment E

ASSESSMENT OF HAZARDS IMPACT (WIND, TORNADO, AIR IMPACT WAVE) ON WIRE-FRAME BUILDINGS AND STRUCTURES LOCATED AT RIVNE NPP SITE

Buildings and structures located at RNPP site are divided into the categories of responsibilities for nuclear and radiation safety, as per ПиН АЭ-5.6, which brings into division of the requirements by strength and load-bearing capacity depending of the assigned category.

Given the accepted layout of the reactor vessel, for the power units with VVER-1000/B3-320 reactor type, where safety-related systems are located not only in the reactor hall but also outside it, the wire-frame buildings and structures of the 1st category of responsibility for nuclear and radiation safety include:

- turbine hall
- deaerator hall with the rack of electric devices;
- unit pump station.

Data on engineering features of the above mentioned buildings and structures are provided in SAR (safety analysis report) and TSS (technical substation of safety).

Location of the safety important systems in these buildings and structures possesses the need for assessment of the impact of hazards (extreme wind, tornado and air shock wave) as factors that contribute to total CDF. Assessment of the hazard impact on the wire-frame buildings and structures located on the plant site was performed for the above indicated structures based on the results of the gained experience and generalized data on generic structures resistance to different loads and effects.

Specifically, such analysis is applied to assess the impact of extreme wind loads, tornado and air shock wave loads for the above listed wire-frame buildings and structures, which were not screened out at the phase of preliminary analysis, and their resistance to hazards was analyzed in more detail. All mentioned loads are characterized with the residual pressure impact onto the structural elements of a building. The numeric values of the loads are provided in Table 1.

Table 1. Numeric loading values

Impact	Tornado pressure[1], kPa	Extreme wind pressure[2], kPaПа	Pressure at air shock wave front[3], kPa	Design criteria by wind pressure[4], kPa
Load characteristics	9.0	1.75	3.1	0.42
Notes:	(1) – tornadoes pressure is accepted as per the table; (2)– Extreme wind pressure is accepted as per the table;			

(3)– pressure at the air shock wave front from the sources of explosion danger at the railway transport is accepted as per data [149];   (4)– nominal wind pressure is accepted as per data [150]

In can be seen from Table 1 that in all considered cases the hazard load exceeds the design criteria for the wind pressure and varies in the range of the gage pressure 1.75 ÷ 9.0 kPa.

Assessment of gage pressure impact onto the structural integrity of the wire-frame building and installation elements was performed on the basis of correlation of the values of calculated loads from the considered hazards with the values of gage pressure during explosions leading to different severity of damage and breakdown of buildings and on the basis of gained experience, experimental studies. The results of the gained experience and studies in the area of explosion resistance of the buildings and structures are presented in the materials:

1. [**Ошибка! Источник ссылки не найден.**51] Birbrayer A.N, Shulman S.G Strength and Reliability of Plant Structures during Special Dynamic Effects. Energoizdat. Moscow. 1989
2. [152] Beschistnov M.F. Industrial Explosions. Assessment and Prevention. M. Chemistry, 1991
3. [153] Beyker U. Explosive Events. Assessment and Consequences. V. 1 and 2, M., Mir, 1986
4. [154] Recommendations on Assessment and Reduction of Consequences of External Accident Impact on NPPs. Atomenergoproject. M., 1991

Assessment of the wire-frame building and structure resistance to loads from hazards is based on the requirement of paragraph 5.1.4 НП 306.1.02/1.034-2000 [**Ошибка! Источник ссылки не найден.**]. In accordance with this requirement, the safety important systems and components should be able to perform their functions with account of possible external impacts in the area of NPP site. It is assumed that the failure of the safety important component takes place as a result of impact (for example, fall) of massive element of construction structures onto it (broken windows and torn off doors can not impose significant impact on the equipment).

Taking into account the construction data on the wire-frame buildings and installations, the data on blast resistance of similar types of structures were selected from the documents [155, 153, 157, 15853] (see Table 2).

Table 2. Blast resistance of standard structural elements of wire-frame buildings and installations

Standard structures	Sources			
	[**Ошибка! Источник ссылки не найден.**51], ΔP (kPa)	[1576], ΔP (kPa)	[153], ΔP (kPa)	[157], ΔP (kPa)
Glazing		≈4,0	≈0,3÷10	≈0,3÷5,0
- greater than 1x1 m	≈3.5			
- less than 1x1 m	≈7.0		Depending on the glass thickness, size and opening area	
Doorways	≈7.0	-	-	≈7.0
Reinforced concrete frame, partition walls and roofs of concrete and reinforced buildings	≈17-30	≈25	-	≈30

Table 3 [**Ошибка! Источник ссылки не найден.**51] provides degree of the structure damage at different gage pressures. As per [**Ошибка! Источник ссылки не найден.**52] the scope of repair required to restore the building can be defined using the formula:

$$c = \Delta P_i / \Delta P_{пр}$$

where: c – a value that defines the degree of damage (according to data [**Ошибка! Источник ссылки не найден.**51] it varies in the range from 0.6 (insignificant damage removed during the routine repair) to 1 (severe damage removed during the overhaul);

ΔP_i- calculated values of gage pressure;

$\Delta P_{пр}$- maximum value of gage pressure.

To evaluate the degree/severity of the wire-frame buildings damage, at which no breakdown of the construction structures take place, the minimum values of the damage degree can be applied as a criteria, i.e. c = 0.6. The calculation results and correlations are presented in Table 3.

Table 3 – Calculation of the possible damage of wire-frame buildings and structures due to external loads impact

Impact	Design load ΔP_i (kPa)	Type of structure	Maximum load ΔP_{np} (kPa)	$c = \frac{\Delta P_i}{\Delta P_{np}}$	Criteria $c = 0,6$ (exceed. «+»/not exceed. «-»)	Expected damage
Смерч	9	Glazing	0.3	30	+	Полное разрушение
			10	0.9	+	
		Doorways	7.0	1.3	+	Complete breakdown
		Wire-frame, partition walls, roofs	17.0	0.53	-	Absent
			25.0	0.36	-	Absent
			30.0	0.30	-	Absent
Экстре-мальный ветер	1.75	Glazing	0.3	5.8	+	Complete breakdown
			10	0.175	-	Absent
		Doorways	7	0.25	-	Absent
		Wire-frame, partition walls, roofs	17	0.1	-	Absent
			25	0.07	-	Absent
			30	0.058	-	Absent
Air shock wave	6.4 (max. value)	Glazing	0.3	21.3	+	Complete breakdown
			10	0.64	+	Partial breakdown
		Doorways	7	0.91	+	Partial breakdown
		Wire-frame, partition walls, roofs	17	0.38	-	Absent
			25	0.26	-	Absent
			30	0.21	-	Absent

Calculation of hazards resistance of the wire-frame buildings and structures (wind, tornado, air shock wave), performed using the results of the gained experience and generalized data on the resistance of standard structures to different kinds of loads and effects, brings to the following conclusions:

- all analyzed hazards can lead to complete or partial loss of glazing;
- tornado can lead to more severe consequences (breakdown of glazing and doorway);
- none of the above indicated hazards cannot lead to breakdown of construction structures of the safety important systems and components.

Appednix F

Wind characteristics in the 30-km area of Rivne NPP

The wind is a horizontal motion of the air in relation to the ground surface. The applied characteristics of wind are wind speed and its direction. These two characteristics are defined by the baric (pressure) field peculiar for Ukraine in general, in this case, and roughness of the underlying surface in the analyzed area.

A wind mode is the main factor that determines the impurity atmospheric dispersion. The wind is associated with the horizontal transfer of polluting materials, their withdrawal from the release source and blowing outside the 30-km zone.

Adverse conditions with regard to mixtures dispersion and atmosphere self-purification are formed during weak winds with the speed up to 2 m/s and calmness.

The analysis of the wind characteristics in the RNPP 30-km area included the observation data [79, 80] from 5 meteorological stations: Lyubeshov, Manevichi, Sarny, Rivne (1966-1997) and Lutsk (1984-1997), as well as aerological station Shepetovka.

Tables 1-5 provide data on repetition of the wind direction at the meteorological stations, accepted as the basis for characterization of wind conditions on the territory of RNPP 30-km area, and the wind speed by directions. Figures 1-5 represents the wind rose for these stations. Characteristics of the wind speed without directions for the analyzed territory is provided in Table 6.

Based on the analyzed data, the wind modes have the following peculiarities on the territory of RNPP 30-km area.

During a year, the winds of the western direction prevail in the 30-km area of Rivne NPP. This very direction is mostly represented during the warm and cold periods, as well as during the year seasons.

In the north of the area, the annual repetition of the western winds is 23.0 % (meteorological station Lyubashov), in the eastern part - 19.4 % (meteorological station Sarny), in the central and western parts 20.4 % (meteorological station Manevichi), in the south-eastern part – 24.6 % (meteorological station Rivne) and south-western part – 21.1 % (meteorological station Lutsk).

During a year, the repetition of calmness in the northern part of the area is 19.4 %, in the western and central part - 11.4 %, in the eastern part - 15.7 %, in the south-eastern part – 8.9 % and south-western part - 3.1 %.

The calmness is distributed by seasons in the following way: in the northern part of the 30-km area the amount of calmness in winder is 14.7 %, in spring and autumn - 18 %, in summer - 26.5 %; in the central and western parts of the area the amount of calmness is the least in winter (7.2 %) and the greatest in summer (15.8 %). In the eastern part of the area the greatest amount of calmness occurs also in summer (23 %) and the least in winter (10.9 %); in the south-east of the area the repetition of calmness in summer is 14.1 %, in winter - 6 %, in spring and autumn 8 %. In the south-west of the area there is a tendency to reduction of calmness repetition. From the data of the meteorological station Lutsk, the calmness conditions are observed rarely here and the amount of calmness is practically alike during all seasons of the year (2.5–3.5 %). Greater repetition than calmness comes here to the wind of changeable direction with the speed of 2 m/s. The annual repetition of these winds is 11.3 %, the greatest in summer – 19.1 %.

Table 1. –- Frequency of wind direction and calmness and average wind speed by directions. Meteorological station Lybeshov

Month, season, year	Direction (rhumb)								Calm ness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	4,2	6,4	14,1	14,1	10,9	17,2	25,3	7,8	14,3
February	5,6	7,8	17,1	16,1	10,3	13,4	21,4	8,3	15,4
March	5,4	7,5	16,5	16,1	12,6	13,6	19,6	8,7	14,2
April	8,7	9,4	13,1	13,3	10,4	12,2	20,7	12,2	17,5
May	10,5	10,0	15,7	12,9	10,7	9,6	16,7	13,9	21,6
June	10,9	8,9	9,0	8,2	8,5	11,5	25,0	18,0	24,8
July	9,4	7,7	9,0	7,3	8,2	14,2	26,5	17,7	24,4
August	7,8	9,0	11,3	10,3	11,3	13,1	23,0	14,2	30,4
September	5,4	5,9	8,4	11,4	12,0	16,8	27,8	12,3	23,0
October	5,4	4,0	10,4	13,3	13,9	17,2	25,0	10,8	18,9
November	3,7	4,7	11,7	16,4	15,4	19,6	21,4	7,1	14,3
December	4,3	4,7	12,1	12,6	13,9	19,1	24,5	8,8	14,5
Winter	4,7	6,3	14,4	14,3	11,7	16,6	23,7	8,3	14,7
Spring	8,2	9,0	15,1	14,1	11,2	11,8	19,0	11,6	17,8
Summer	9,4	8,5	9,7	8,6	9,4	13,0	24,8	16,6	26,5
Autumn	4,8	4,9	10,1	13,7	13,8	17,9	24,7	10,1	18,5
Warm period	7,9	7,8	11,7	11,6	11,0	13,5	23,0	13,5	21,8
Cold period	4,4	5,9	13,8	14,8	12,6	17,3	23,2	8,0	14,6
Year	6,8	7,2	12,4	12,7	11,5	14,8	23,0	11,6	19,4
б) Wind speed by directions, m/s									
January	2,4	2,6	2,4	2,5	3,0	3,7	4,0	3,7	0,0
February	2,4	2,3	2,4	2,8	3,2	3,7	3,9	3,3	0,0
March	2,4	2,8	2,4	2,7	2,8	3,6	4,6	3,5	0,0
April	3,0	2,6	2,5	2,7	2,8	3,3	4,0	3,5	0,0
May	2,7	2,6	2,2	2,3	2,5	2,8	3,0	2,9	0,0
June	2,5	2,3	1,9	2,1	2,4	2,9	3,3	3,1	0,0
July	2,5	1,9	2,0	2,2	2,4	2,6	3,1	2,8	0,0
August	2,5	2,3	2,0	2,1	2,2	2,5	3,0	2,7	0,0
September	2,8	2,1	1,9	2,3	2,7	3,2	3,4	3,1	0,0
October	2,4	2,3	2,3	2,5	2,5	3,4	3,6	3,1	0,0
November	2,9	2,1	2,3	2,7	2,9	3,8	4,3	3,3	0,0
December	2,8	2,4	2,0	2,6	2,9	3,8	4,0	3,2	0,0
Winter	2,5	2,4	2,3	2,6	3,0	3,7	4,0	3,4	0,0
Spring	2,7	2,7	2,4	2,6	2,7	3,2	3,9	3,3	0,0
Summer	2,5	2,2	2,0	2,1	2,3	2,7	3,1	2,9	0,0
Autumn	2,7	2,2	2,2	2,5	2,7	3,5	3,8	3,2	0,0
Warm period	2,6	2,4	2,2	2,4	2,5	3,0	3,5	3,1	0,0
Cold period	2,6	2,4	2,3	2,7	3,0	3,8	4,1	3,4	0,0
Year	2,6	2,4	2,2	2,5	2,7	3,3	3,7	3,2	0,0

Table 2 – Frequency of wind direction and calmness and average wind speed by directions. Meteorological station Manevichi

Month, season, year	Direction (rhumb)								Calm ness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	4.2	6.4	14.1	14.1	10.9	17.2	25.3	7.8	14.3
February	5.6	7.8	17.1	16.1	10.3	13.4	21.4	8.3	15.4
March	5.4	7.5	16.5	16.1	12.6	13.6	19.6	8.7	14.2
April	8.7	9.4	13.1	13.3	10.4	12.2	20.7	12.2	17.5
May	10.5	10.0	15.7	12.9	10.7	9.6	16.7	13.9	21.6
June	10.9	8.9	9.0	8.2	8.5	11.5	25.0	18.0	24.8
July	9.4	7.7	9.0	7.3	8.2	14.2	26.5	17.7	24.4
August	7.8	9.0	11.3	10.3	11.3	13.1	23.0	14.2	30.4
September	5.4	5.9	8.4	11.4	12.0	16.8	27.8	12.3	23.0
October	5.4	4.0	10.4	13.3	13.9	17.2	25.0	10.8	18.9
November	3.7	4.7	11.7	16.4	15.4	19.6	21.4	7.1	14.3
December	4.3	4.7	12.1	12.6	13.9	19.1	24.5	8.8	14.5
Winter	4.7	6.3	14.4	14.3	11.7	16.6	23.7	8.3	14.7
Spring	8.2	9.0	15.1	14.1	11.2	11.8	19.0	11.6	17.8
Summer	9.4	8.5	9.7	8.6	9.4	13.0	24.8	16.6	26.5
Autumn	4.8	4.9	10.1	13.7	13.8	17.9	24.7	10.1	18.5
Warm period	7.9	7.8	11.7	11.6	11.0	13.5	23.0	13.5	21.8
Cold period	4.4	5.9	13.8	14.8	12.6	17.3	23.2	8.0	14.6
Year	6.8	7.2	12.4	12.7	11.5	14.8	23.0	11.6	19.4
b) Wind speed by directions, m/s									
January	2.4	2.6	2.4	2.5	3.0	3.7	4.0	3.7	0.0
February	2.4	2.3	2.4	2.8	3.2	3.7	3.9	3.3	0.0
March	2.4	2.8	2.4	2.7	2.8	3.6	4.6	3.5	0.0
April	3.0	2.6	2.5	2.7	2.8	3.3	4.0	3.5	0.0
May	2.7	2.6	2.2	2.3	2.5	2.8	3.0	2.9	0.0
June	2.5	2.3	1.9	2.1	2.4	2.9	3.3	3.1	0.0
July	2.5	1.9	2.0	2.2	2.4	2.6	3.1	2.8	0.0
August	2.5	2.3	2.0	2.1	2.2	2.5	3.0	2.7	0.0
September	2.8	2.1	1.9	2.3	2.7	3.2	3.4	3.1	0.0
October	2.4	2.3	2.3	2.5	2.5	3.4	3.6	3.1	0.0
November	2.9	2.1	2.3	2.7	2.9	3.8	4.3	3.3	0.0
December	2.8	2.4	2.0	2.6	2.9	3.8	4.0	3.2	0.0
Winter	2.5	2.4	2.3	2.6	3.0	3.7	4.0	3.4	0.0
Spring	2.7	2.7	2.4	2.6	2.7	3.2	3.9	3.3	0.0
Summer	2.5	2.2	2.0	2.1	2.3	2.7	3.1	2.9	0.0
Autumn	2.7	2.2	2.2	2.5	2.7	3.5	3.8	3.2	0.0
Warm period	2.6	2.4	2.2	2.4	2.5	3.0	3.5	3.1	0.0
Cold period	2.6	2.4	2.3	2.7	3.0	3.8	4.1	3.4	0.0
Year	2.6	2.4	2.2	2.5	2.7	3.3	3.7	3.2	0.0

Table 3 – Frequency of wind direction and calmness and average wind speed by directions. Meteorological station Sarny

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	7.4	4.9	7.9	13.9	19.3	16.4	20.4	9.8	11.2
February	8.9	5.8	10.7	16.5	16.8	13.0	17.5	10.8	10.0
March	8.5	6.3	12.0	19.1	15.6	11.5	17.4	9.6	12.1
April	12.9	8.3	10.7	14.8	14.2	10.0	16.0	13.1	14.4
May	14.9	9.4	12.2	14.0	13.9	8.2	13.8	13.6	17.5
June	14.8	9.3	7.0	9.2	11.0	10.3	21.2	17.2	20.8
July	14.3	8.8	7.2	7.7	9.7	11.6	21.9	18.8	22.9
August	12.8	9.2	8.6	11.5	11.9	11.6	19.8	14.6	25.4
September	8.8	5.2	6.6	11.5	16.5	14.8	22.5	14.1	18.9
October	7.2	4.4	7.4	16.1	17.2	15.3	21.4	11.0	15.2
November	6.2	3.5	7.6	17.4	19.7	16.2	20.7	8.7	9.8
December	6.5	5.6	7.9	14.4	17.9	16.8	19.9	11.0	10.1
Winter	7.6	5.4	8.8	15.0	18.0	15.4	19.3	10.5	10.4
Spring	12.1	8.0	11.6	16.0	14.6	9.9	15.7	12.1	14.6
Summer	14.0	9.1	7.6	9.5	10.8	11.2	21.0	16.8	23.0
Autumn	7.4	4.4	7.2	15.0	17.8	15.4	21.5	11.3	14.6
Warm period	11.8	7.6	9.0	13.0	13.7	11.7	19.2	14.0	18.4
Cold period	7.2	5.0	8.5	15.6	18.4	15.6	19.6	10.1	10.2
Year	10.3	6.7	8.8	13.8	15.3	13.0	19.4	12.7	15.7
b) Wind speed by directions, m/s									
January	3.0	2.5	2.9	3.4	3.3	3.3	3.5	3.8	0.0
February	2.9	3.1	3.2	3.6	3.5	3.3	3.3	3.4	0.0
March	3.1	2.7	3.4	3.3	3.3	3.2	3.7	3.5	0.0
April	3.3	3.1	3.2	3.4	3.3	3.4	3.3	3.4	0.0
May	3.1	3.0	2.9	3.2	3.0	2.8	2.7	2.9	0.0
June	2.8	2.8	2.7	2.5	2.8	2.6	2.7	3.1	0.0
July	3.0	2.4	2.6	2.5	2.6	2.6	2.6	2.9	0.0
August	2.4	2.5	2.4	2.4	2.4	2.5	2.6	2.6	0.0
September	2.8	2.6	2.6	2.9	2.7	2.8	2.8	2.9	0.0
October	2.8	2.4	2.5	2.8	2.8	2.9	3.0	3.0	0.0
November	3.7	2.5	2.7	3.5	3.2	3.1	3.4	3.3	0.0
December	3.2	2.7	2.7	3.2	3.0	3.2	3.4	3.4	0.0
Winter	3.0	2.8	2.9	3.4	3.3	3.2	3.4	3.5	0.0
Spring	3.2	2.9	3.1	3.3	3.2	3.1	3.2	3.3	0.0
Summer	2.8	2.6	2.5	2.5	2.6	2.6	2.6	2.9	0.0
Autumn	3.1	2.5	2.6	3.0	2.9	2.9	3.1	3.1	0.0
Warm period	2.9	2.7	2.8	2.9	2.9	2.8	2.9	3.0	0.0
Cold period	3.2	2.7	2.9	3.4	3.2	3.2	3.4	3.5	0.0
Year	3.0	2.7	2.8	3.1	3.0	3.0	3.1	3.2	0.0

Table 4 – Frequency of wind direction and calmness and average wind speed by directions. Meteorological station Rivne

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	5.3	4.0	11.8	14.8	11.8	14.2	28.5	9.6	6.3
February	6.0	4.7	16.8	17.3	11.9	10.6	23.2	9.5	6.6
March	6.4	4.8	16.9	17.9	13.3	11.8	20.8	8.1	6.8
April	10.2	7.7	15.0	14.6	10.5	10.4	19.3	12.3	7.5
May	11.9	8.5	16.9	14.8	11.2	8.5	16.8	11.4	9.8
June	12.4	7.7	10.6	9.2	7.9	10.3	25.4	16.5	12.2
July	12.5	6.6	8.7	7.7	7.4	11.0	28.3	17.8	13.7
August	11.5	8.4	11.4	11.2	9.2	10.8	23.7	13.8	16.6
September	7.6	4.4	9.4	12.4	10.5	13.5	29.0	13.2	10.5
October	5.6	3.3	10.1	15.8	13.8	14.3	26.4	10.7	7.8
November	4.8	3.3	9.8	17.7	15.6	14.8	26.0	8.0	4.5
December	5.0	4.0	10.0	14.5	13.2	15.3	28.0	10.0	5.0
Winter	5.4	4.2	12.9	15.5	12.3	13.4	26.6	9.7	6.0
Spring	9.5	7.0	16.2	15.8	11.7	10.2	19.0	10.6	8.1
Summer	12.1	7.6	10.2	9.4	8.2	10.7	25.8	16.0	14.1
Autumn	6.0	3.7	9.8	15.3	13.3	14.2	27.1	10.6	7.6
Warm period	9.8	6.4	12.4	12.9	10.5	11.3	23.7	13.0	10.6
Cold period	5.3	4.0	12.1	16.1	13.1	13.7	26.4	9.3	5.6
Year	8.3	5.6	12.3	14.0	11.4	12.1	24.6	11.7	8.9
b) Wind speed by directions, m/s									
January	3.7	3.1	3.9	3.9	4.2	5.0	5.8	5.6	0.0
February	4.4	3.7	4.1	4.4	4.3	4.7	5.3	4.9	0.0
March	3.9	3.8	4.2	4.2	4.2	4.6	5.5	5.3	0.0
April	4.5	4.2	4.0	4.2	4.3	4.7	5.1	5.1	0.0
May	4.3	3.8	3.7	3.8	3.8	3.8	4.2	4.5	0.0
June	3.9	3.4	3.2	3.2	3.4	3.5	4.2	4.5	0.0
July	4.0	3.4	2.9	3.1	3.4	3.5	4.0	4.4	0.0
August	3.6	3.6	2.9	3.0	3.2	3.2	3.9	4.2	.0.0
September	3.9	3.4	3.3	3.4	3.7	4.0	4.7	4.9	0.0
October	3.8	3.7	3.7	4.0	3.8	4.3	5.0	5.4	0.0
November	4.3	3.4	4.0	4.4	4.2	4.9	5.8	5.3	0.0
December	4.2	3.7	3.8	4.1	4.4	5.0	5.7	5.6	0.0
Winter	4.1	3.5	3.9	4.1	4.3	4.9	5.6	5.4	0.0
Spring	4.2	3.9	3.9	4.1	4.1	4.3	4.9	5.0	0.0
Summer	3.8	3.5	3.0	3.1	3.3	3.4	4.0	4.4	0.0
Autumn	4.0	3.5	3.6	3.9	3.9	4.4	5.2	5.2	0.0
Warm period	4.0	3.6	3.5	3.6	3.7	3.9	4.6	4.8	0.0
Cold period	4.1	3.5	3.9	4.2	4.3	4.9	5.7	5.3	0.0
Year	4.0	3.6	3.6	3.8	3.9	4.3	4.9	5.0	0.0

Table 5 – Frequency of wind direction and calmness and average wind speed by directions. Meteorological station Lutsk

Month, season, year	Direction (rhumb)								Calm ness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	3.1	3.9	11.9	11.7	13.7	17.7	27.4	10.6	3.3
February	4.7	3.9	14.6	14.1	14.9	13.6	22.9	11.3	3.1
March	5.5	6.0	18.5	18.8	14.8	11.0	16.7	8.7	3.2
April	7.3	5.9	19.5	16.8	13.3	8.1	16.0	13.1	2.4
May	12.6	9.2	15.4	15.8	13.3	8.3	13.2	12.2	3.3
June	12.5	4.4	8.4	9.0	10.0	9.4	24.7	21.6	2.4
July	12.8	6.7	7.0	8.8	9.8	10.2	24.7	20.0	3.9
August	8.8	8.3	10.9	13.1	13.0	10.1	19.2	16.6	4.1
September	6.7	3.6	8.7	10.0	13.5	16.8	26.5	14.2	2.8
October	4.5	2.3	12.4	18.1	16.2	13.8	21.7	11.0	2.6
November	4.9	3.3	11.9	20.5	19.0	12.9	18.9	8.6	2.1
December	5.4	3.4	13.1	13.8	17.7	16.3	20.9	9.4	2.3
Winter	4.4	3.8	13.2	13.2	15.4	15.9	23.7	10.4	2.9
Spring	8.5	7.0	17.8	17.1	13.8	9.2	15.3	11.3	3.0
Summer	11.4	6.5	8.7	10.3	10.9	9.9	22.9	19.4	3.5
Autumn	5.4	3.1	11.0	16.2	16.2	14.5	22.4	11.2	2.5
Warm period	8.8	5.8	12.6	13.8	13.0	11.0	20.3	14.7	3.1
Cold period	4.5	3.6	12.9	15.1	16.3	15.1	22.5	10.0	2.7
Year	7.4	5.1	12.7	14.2	14.1	12.3	21.1	13.1	3.0
b) Wind speed by directions, m/s									
January	4.1	3.4	4.2	4.7	5.4	5.6	5.8	5.4	0.0
February	4.7	3.3	4.9	5.5	4.9	5.3	5.3	5.1	0.0
March	4.1	4.0	5.4	5.1	4.9	5.3	5.4	4.7	0.0
April	4.7	3.9	5.1	5.3	4.6	4.9	5.3	5.3	0.0
May	4.7	4.3	4.4	4.6	4.6	4.5	4.4	4.6	0.0
June	4.3	4.3	4.2	4.2	4.1	4.2	4.2	4.5	0.0
July	4.1	4.0	4.0	3.9	3.8	4.0	4.2	4.3	0.0
August	3.9	3.8	4.1	3.9	3.9	3.7	4.2	4.1	0.0
September	4.2	3.5	4.4	4.7	4.4	4.5	5.1	4.8	0.0
October	4.3	3.4	4.2	5.2	4.8	4.3	4.9	4.5	0.0
November	4.5	4.0	5.0	5.6	4.8	5.0	4.9	4.6	0.0
December	4.4	3.9	5.1	5.5	5.1	5.4	5.9	5.1	0.0
Winter	4.4	3.5	4.7	5.2	5.1	5.4	5.7	5.2	0.0
Spring	4.5	4.1	5.0	5.1	4.7	4.9	5.0	4.9	0.0
Summer	4.1	4.0	4.1	4.0	3.9	4.0	4.2	4.3	0.0
Autumn	4.3	3.6	4.5	5.2	4.7	4.6	5.0	4.6	0.0
Warm period	4.3	3.9	4.5	4.7	4.4	4.4	4.7	4.6	0.0
Cold period	4.4	3.7	4.8	5.3	5.1	5.3	5.5	5.1	0.0
Year	4.3	3.8	4.6	4.9	4.6	4.7	5.0	4.8	0.0

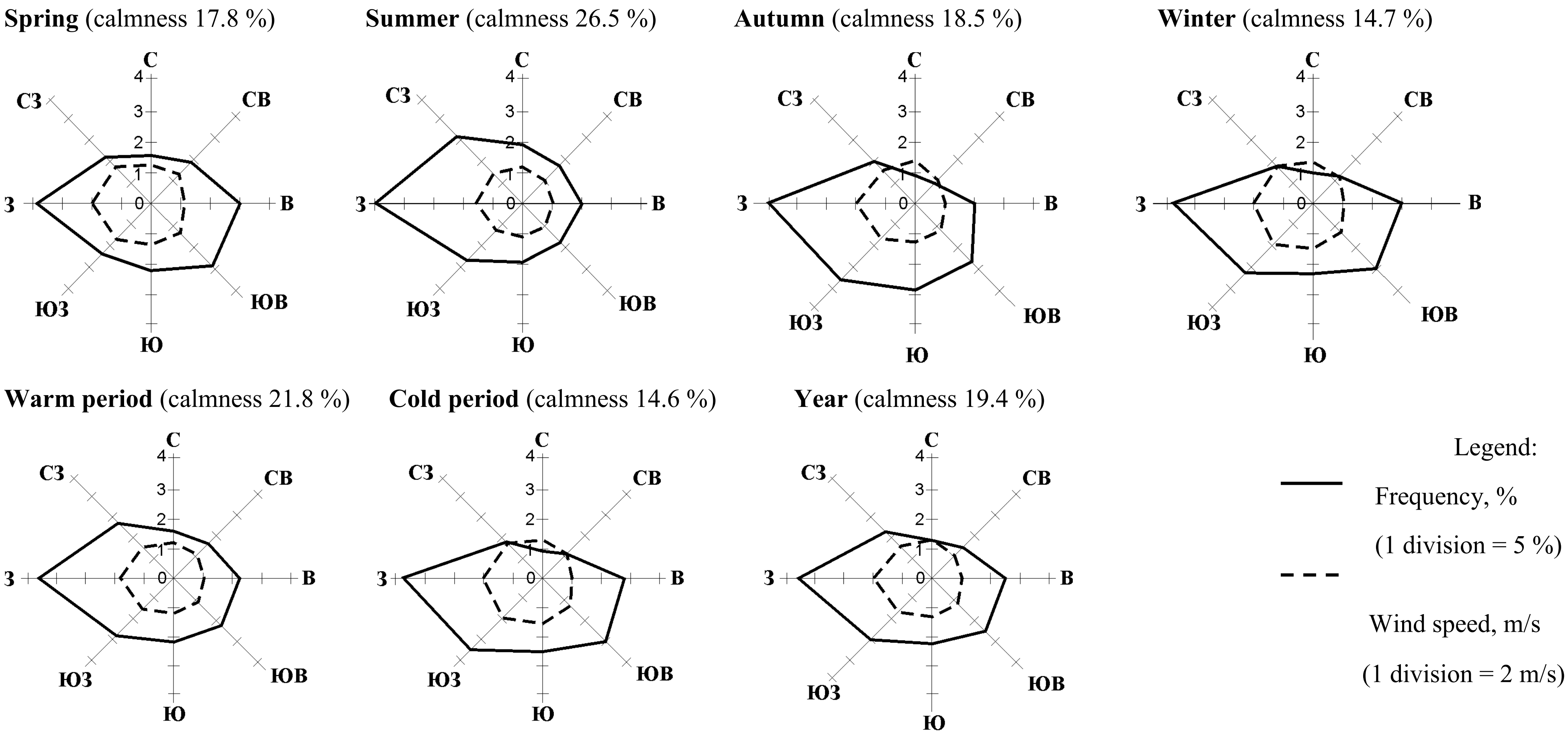


Figure 1 – Wind rose at the meteorological station Lyubeshov (by seasons, periods, and for a year)

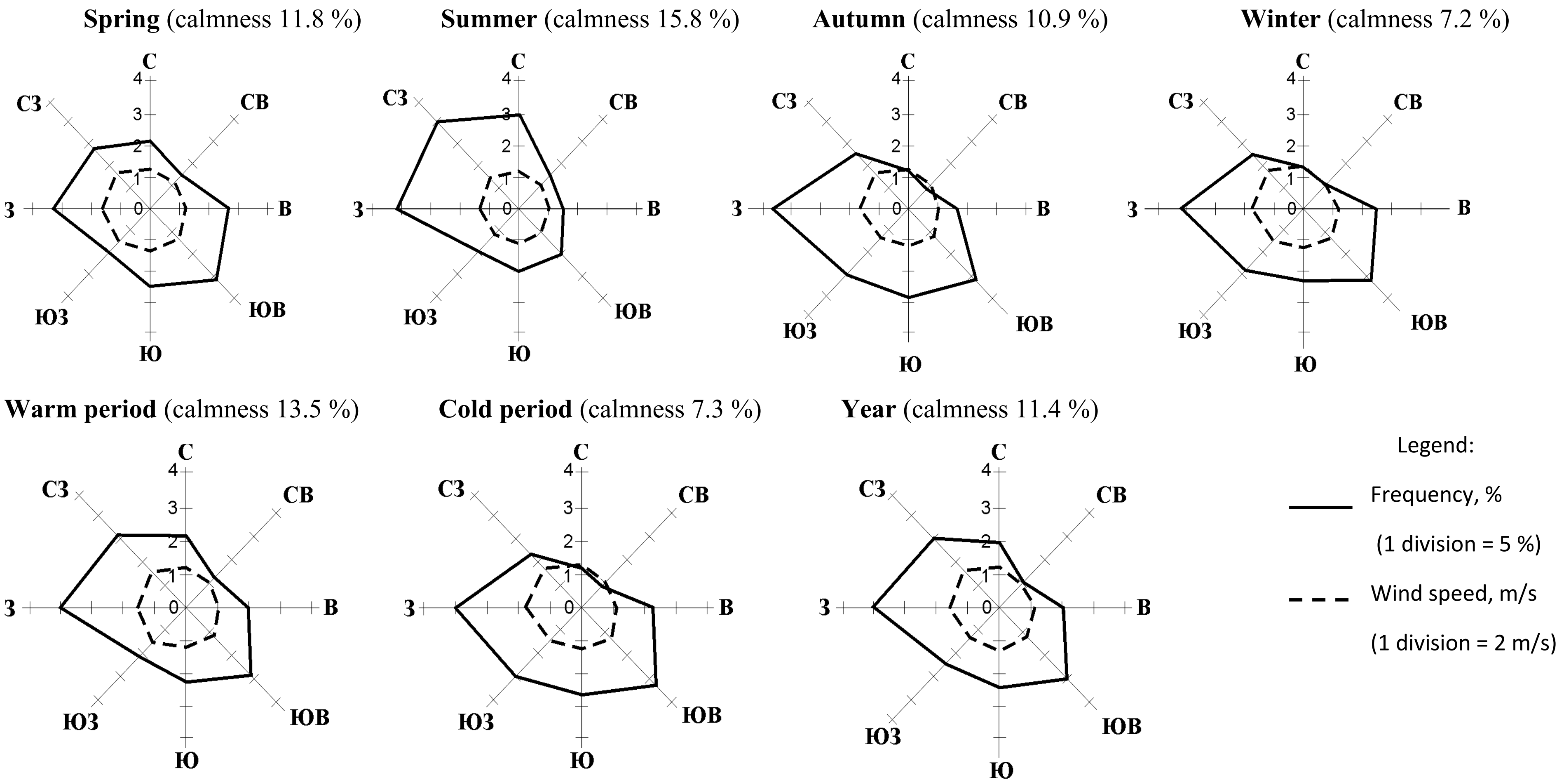


Figure 2 – Wind rose at the meteorological station Manevichi (by seasons, periods, and for a year)

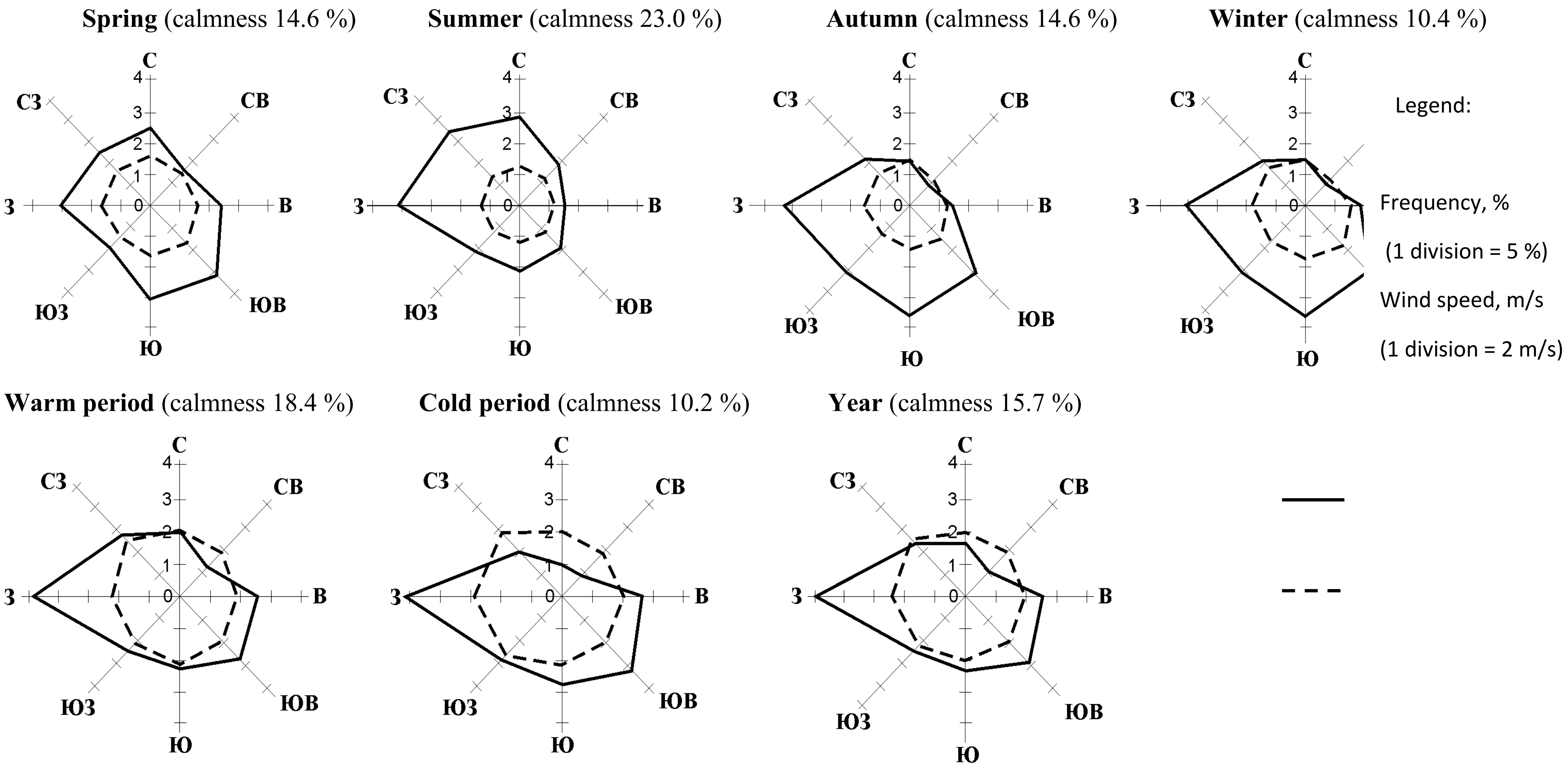


Figure 3 – Wind rose at the meteorological station Sarny (by seasons, periods, and for a year)

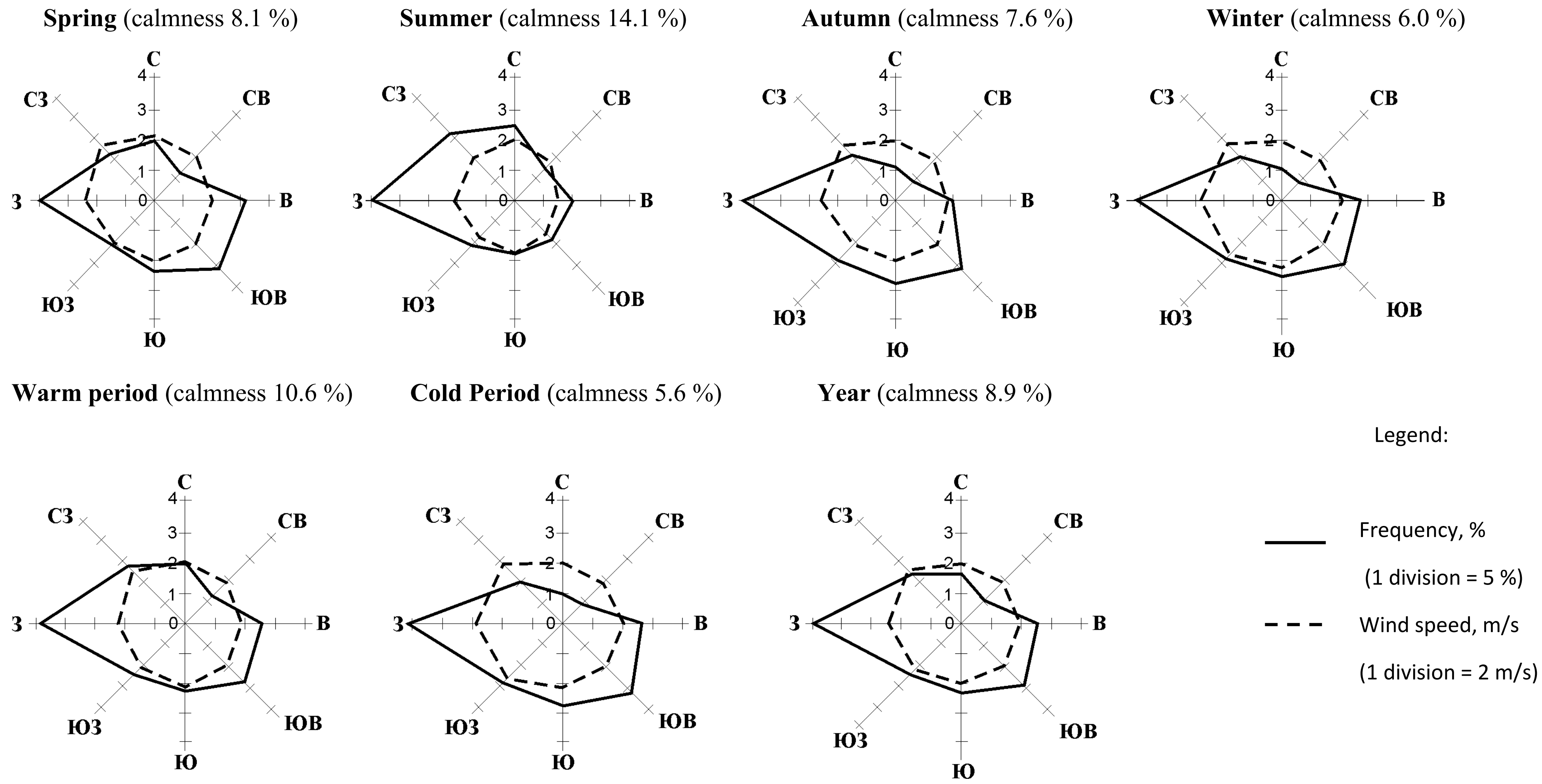


Figure 4 – Wind rose at the meteorological station Rivne (by seasons, periods, and for a year)

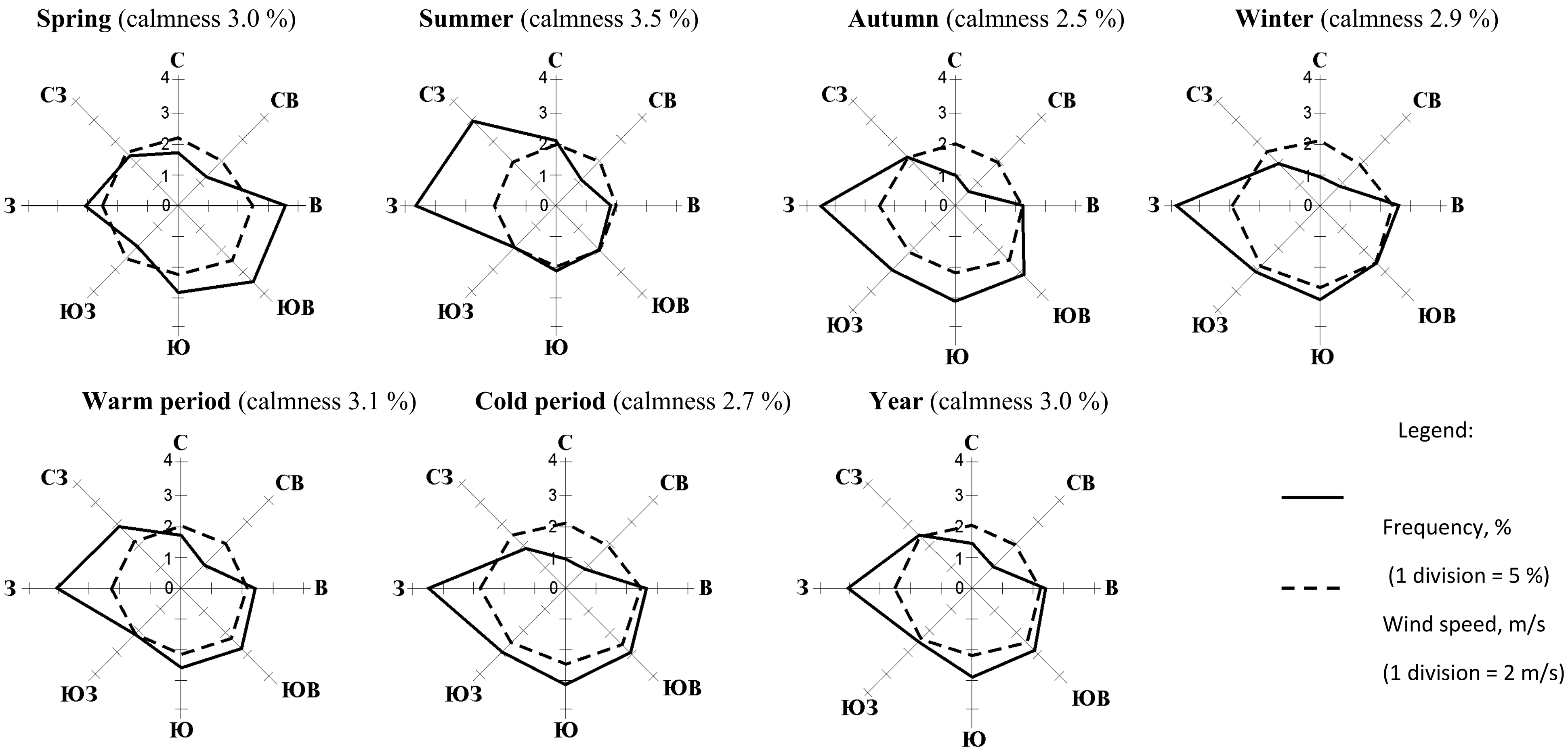


Figure 5 – Wind rose at the meteorological station Lutsk (by seasons, periods, and for a year)

The distribution of wind speed has the following peculiarities in the 30-km area of Rivne NPP. During a year, the highest annual average wind speeds are observed in the southern part of the area, 4.7-5.0 m/s at the western and north-western wind directions. In the central and western parts of the area, including the region of the NPP site, the wind speed decreases to 3.1–3.2 m/s, keeping the same wind direction, western and north-western. To the north, the wind speed increases to 3.7 m/s (with the western winds). The lowest annual average wind speeds (2.1–3.2 m/s) are depicted everywhere at the northern, north-eastern and eastern wind directions.

The peculiarity of wind speed distribution in the 30-km area of RNPP is an increase of the annual average wind speed from the north to the south from 2.5 to 4.1 m/s (Table 6). The same behavior is preserved during other particular months of the year. In the central, western and eastern part of the 30-km area, the average wind speeds are in the range 2.8–3.0 m/s.

Table 6 – Average monthly and annual wind speed without directions in m/s

Station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshov	3.0	2.8	2.8	2.6	2.0	2.0	2.0	1.7	2.2	2.5	3.0	2.9	2.5
Manevichi	3.5	3.5	3.4	3.1	2.7	2.7	2.7	2.5	2.7	2.9	3.5	3.3	3.0
Sarny	3.4	3.4	3.3	3.1	2.6	2.4	2.3	2.1	2.4	2.7	3.3	3.2	2.8
Rivne	4.9	4.6	4.4	4.2	3.7	3.5	3.3	3.0	3.7	4.2	4.8	4.8	4.1
Lutsk	4.7	4.4	4.4	4.1	3.5	3.3	3.1	2.9	3.5	3.9	4.4	4.5	3.9

During the year, the typical wind speed of up to 5 m/s is more often observed in this area (44-52% of all cases). The wind speed of 10–15 m/s is observed for 0.7% of cases in the eastern part of the area, 1.7-1.8 % of cases in the north and central part of the area and about 6% of cases in the south of the area.

The small wind speeds of 0-3 m/s have the biggest repetition in summer in this area. In the northern and western part of the area, such wind speeds are observed in 68-78 % of cases; in the central, western and southern parts, their repetition is somewhat lower (55-67 %). The low wind speeds of 0-3 m/s are observed at all wind directions. They are the most longstanding.

As a rule, the high wind speeds are observed at the prevailing wind directions and are timed to the cold period of the year.

Repetition of the maximum wind speeds in the targeted (calculated) grading (14-15, 16-20, 21-25 m/s) for the analyzed territory are determined from the amount of cases of this or that gradation of the maximum speeds for the multi-year period at the meteorological stations Lyubeshov, Manevichi, Sarny, Rivne. The calculation results are presented in Table 7.

Based on the conducted studies, it can be stated that the maximum wind speed, for the specified grading, repeats more often at the western and north-western wind directions in the 30-km area, and more rarely at the south-western direction (at the wind speed of ≥ 25 m/s). The extreme wind speeds were registered in the southern part of the area and achieved 38 m/s (meteorological station Rivne) and 40 m/s (meteorological station Lutsk) at the north-western wind direction. The high wind speeds are typically observed during the cyclonic activity.

The average number of days in a year with the wind speed equal or exceeding the targeted value for the analyzed territory is presented as per the data from the meteorological station Sarny and it constitutes:

≥ 8 m/s – 53 days, ≥ 15 m/s – 3 days, ≥ 20 m/s – 0.2 days.

The days with the wind speed of ≥ 20 m/s are more often observed during the cold period of the year, and with the wind speed from 8 to 15 m/s – any month of the year.

Table 7 – Frequency of maximum wind speed by directions

In % from amount of cases

Speed scale, m/s	Wind direction (rhumb)							
	N	NE	E	SE	S	SW	W	NW
Northern part of 30-km area, meteorological station Lyubeshov								
14 – 15	4.3	5.4	8.7	2.3	5.4	18.5	46.7	8.7
16 – 20	-	1.0	2.0	-	2.0	29.3	52.5	13.2
21 – 25	-	-	-	3.2	-	32.3	51.6	12.9
≥ 25	Registered wind gust: 28–29 m/s – 7 cases with the wind of W, SW, WSW directions (1966, 1969, 1970, 1975, 1983, 1984, 1986); 30 m/s – 2 cases with the wind of SSW, WSW directions (1981, 1997); 34 m/s – 1 case with the wind of W direction, 1976							
Western and central part of 30-km area, meteorological station Manevishi								
14 – 15	7.1	1.0	4.0	8.0	6.0	11.4	37.3	25.4
16 – 20	6.0	-	8.4	1.7	4.5	9.5	46.4	23.5
21 – 25	-	-	-	14.3	-	-	71.4	14.3
≥ 25	Registered wind gust: 28 m/s – 2 cases with wind WNW and NNW directions (1982); 29 m/s – 1 case with the wind of NW direction (1983)							
Eastern part of 30-km area, meteorological station Sarny								
14 – 15	16.5	4.4	6.9	14.9	10.3	7.0	25.8	14.2
16 – 20	9.3	-	4.6	11.6	14.0	14.0	18.6	27.9
21 – 25	5.6	-	-	16.7	5.6	33.3	27.7	11.1
≥ 25	Registered wind gust: 28 m/s – 1 case with the wind WNW direction; 30 m/s – 1 case with wind NE, SW directions							
Southern part of 30-km area, meteorological station Rivne								
14 – 15	9.0	1.5	5.0	11.7	6.2	12.4	41.0	13.2
16 – 20	4.0	-	4.0	10.0	4.0	7.0	52.0	19.0
21 – 25	-	-	-	-	-	3.3	66.7	30.0
≥ 25	Registered wind gust: 26 m/s, 27 m/s, 31 m/s, 33 m/s – 1 case each; 30 m/s – 2 cases (all cases with the wind of NW direction)							

CHLORINE TREATMENT FACILITIES FOR CIRCULATION WATER OF RIVNE NPP POWER UNITS

For chlorine treatment of the circulation water of power units 1 and 2, the separate chlorination facility #1 (#49 according to master layout plan) was constructed within the construction of line 1 of Riven NPP in the area of the Unit Pumps Station-1 (UPS).

The Ural Division of “Atomteploeletroproekt” and Enterprise p/ya G-4660 in 1985 for power units 3, 4 have designed the installations for chlorine treatment of the circulation water that are within the chlorine storage facility and chlorination facility #2, located in the area of UPS-2 location. The distance from Power Unit 3 to chlorination facility #2 (#49 according to master layout plan) is 60 m, to the chlorine storage (#49 according to master layout plan) - 70 m.

Below, one will find the description of the design decisions on construction of the facilities for chlorine treatment of the circulation water of power units 3, 4 as part of the chlorine storage facility and chlorination facility #2 (further on, chlorination facility).

The chlorine storage facility is a separately situated building with the dimensions in the axis 49.51x18.0 m, and height of 8.4 m.

The conditional elevation of 0.000 of the storage uses the absolute elevation of 189.00 m. The absolute elevation of the first floor is 188.75 m; the adjacent territory is planned at the elevation of 188.50 – 188.20 m.

The degree of building fire resistance is II, as for the fire and explosion safety – category D.

The chlorine storage facility has two sections for storage of the containers filled with liquid chlorine: evaporation section with the process equipment located in it and off-gas division where exhaust gases from blowdown of the process equipment and chlorine pipes are sent for neutralization from chlorine, including emergency chlorine releases removed by the emergency ventilation. The shed is also foreseen for storage of empty container and auxiliary rooms. The evaporated chlorine gas is supplied to the chlorination facility via pipes laid over the ramp.

The following activities are conducted in the chlorination facility: preparation of the chlorine water, its accumulation in the special tanks and its periodic supply for chlorine treatment of the circulation water of power units 3 and 4.

The chlorine storage facility has two isolated compartments with the total area of 432 m^2 for storage of the containers filled with liquid chlorine, the design capacity of each compartment is 50 t. The chlorine is suppled and stored in the special containers with the capacity of 1 t. The liquid chlorine in the containers is supplied to the storage facility by the automobile transport and is off-loaded with the help of the electrical crane. The containers are stored in the vertical position. To place the container from the horizontal to vertical position, the manipulator is used in the compartments of the storage facility. The containers are stored in the closed room and are protected from the sun light. If the inoperable container is detected in the compartments, the design foresees the emergency containers for evacuation of the chlorine from the faulted container. After emergency overfilling of the chlorine into the backup container, the emergency one is blow down with compressed air onto the sanitary (shelf) column.

Evaporation of the liquid chlorine is performed in the evaporation section. The containers are shipped to the evaporation section by the automobile transport using the electrical cranes. The containers are put on the scale in the horizontal position and connected to the pipe by means of the connecting unit. Overfilling of the chlorine from the containers for evaporation purposes is made with the help of the compressed air. The drained conditions of the container is verified using the scale.

After drainage, the faucets on the containers are closed, the chlorine pipe is blown down with compressed air to the off-gas (sanitary) column, the unit connecting to the container is disconnected. Then the plugs are installed, and the personnel checks the leak-tightness of the containers in assembles state at residual pressure. The emptied containers are transported under the shed for empty containers.

Evaporation of the chlorine is conducted in the evaporation room located in the evaporation division. Heating of the evaporator is performed with the help of warm water, with the water temperature in the evaporator not greater than 70 °C.

To avoid spillage of the liquid chlorine, there is a receiver heated with water from the evaporator. The receiver is equipped with the safety valve. The evaporated chlorine is supplied through the receiver to the chlorinators

For evacuation of the residual chlorine from the equipment and pipes, the blowdown with the compressed air is foreseen.

Off-gases of the blow-down, as well as releases of the emergency ventilation and safety valve are directed to the sanitary (shelf) columns installed in the off-gas division. Capturing of the chlorine off-gases is performed in the sanitary column, sprayed with the neutralization solution. The off-gases purified from chlorine, which passed consequently through two sprayed columns, are vented to the atmosphere by the fans.

The pipes with the neutralized solution, off-gases and chlorine released from the safety valves to the sanitary column, as well as the circulation tank with the neutralized solution and sanitary column are made of rubberized steel.

In the design, an emergency refers to the situation, when the chlorine concentration in the compartment of the filled containers exceeds the limited chlorine concentration in the air of working environment. In case of an accident, the hydroanalyzer installed in the compartment is actuated, at that the emergency ventilation is started automatically at exceeding the limited chlorine concentration of 1 mg/m^3, and the general dilution ventilation of the emergency and other compartment is stopped. The release from the general dilution ventilation is made to the sanitary column. At the exit of the sanitary column, the chlorine concentration in the air should be not greater than 1 mg/m^3

The circulation pump of the neutralized solution and sanitary columns should operate continuously.

The light and sound signal appear on the I&C board. Once the signal is received, the personnel begins to perform actions on accident termination.

The chlorine water is prepared in the chlorination facility by adding the doses of gas-exchange chlorine into the service water by means of the chlorinators. The chlorinators are continuous-action vacuum type ЛОНИИ-100К devices with the capacity of 12.8 kg of chlorine per hour, in the amount of 9 pieces. The capacity of chlorination facility is 660 tons of chlorine per year.

Since chlorination of the circulation water is performed periodically (chlorine water is supplied successively into each of the eight circulation waterways of power units 3, 4; two times a day), the prepared chlorine water is accumulated in the special tanks, where it is pumped for chlorination to one of the waterways.

The operation mode of the chlorination facility is non-stop, three shifts, 260 days per year. The chlorinators operate continuously. The service water pump, which supplies water to preparation of the chlorine water, operates continuously. The chlorine water pump, which supplies water for chlorination to the waterways, operates continuously.

The chlorination storage design foresees the general exchange systems of supply and exhaust ventilation, as well as the system of emergency exhaust ventilation from the compartments with filled containers.

The supply of external air into the compartments with filled containers is performed by the air supply facility. The air is removed by fans from the lower zone in the amount of 2/3 from the volume of removed air and from the upper zone – 1/3 from the volume. The fans capacity of the supply and exhaust ventilation system is designed for 2-timed air exchange in the rooms.

The design also foresees the emergency ventilation system, which is initiated by the gas analyzers, when allowed chlorine concentration increases in the compartment with the filled containers. The releases from the emergency ventilation system are moved to the sanitary columns, installed in the off-gas division. The emergency ventilation system is designed for 1-timed air exchange in the rooms.

For evaporation and off-gas ventilation, the design foresees the supply and exhaust systems, which ensure 6-timed air exchange in the rooms. The air removal from the rooms is foreseen from the lower zone in the amount of 2/3 of the removed air volume and from the upper zone – 1/3 from the volume.

Heating in the compartment with the filled containers is not foreseen. In the evaporation and off-gas rooms there is an air heating combined with the supply ventilation. For other rooms, the system of water heating is foreseen.

Along the perimeter of the storage facility, the network of firefighting water pipes has the fire hydrants installed for external fire suppression, and for creation of the water curtain of the fine water spraying for termination of the accident chlorine wave.

As of 31.05.2015, the status of the activities with regard to the chlorination buildings for circulation water of power units 3, 4 is the following. The construction and mounting works were accomplished for the buildings of chlorine storage and chlorination facility, the process equipment was mounted but not in a full scope, the object was not put into operation.

APPROVED

Director of NT Engineering

________________R. V. Maraikin

"26" December 2018

REPORT

ON

SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 2

General Characteristic of Rivne NPP.
Production Waste

Version 2

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ABSTRACT

Book 2 of this report consists of 105 pages of text, 32 figures, 17 tables and 3 attachments.

The operating power units, buildings and constructions that form part of the complex of "Rivne NPP" site of SE "NNEGC Energoatom", as well as their impact onto the environment in the area of Rivne NPP location are the subject of consideration in this book.

The sections of the Environment Impact Assessment (EIA) were developed in order to provide evaluation of the impact of SS "Rivne NPP" on the environment. The following topics are covered in this Book: production complex, which is presented in the section "General Description of Rivne NPP"; full cycle of the production waste management, including quantitative and qualitative characteristics of the radwaste, other types of waste, spent nuclear fuel, which are presented in the section "Production waste". This all includes accomplishment of the entire complex of activities during Rivne NPP operation with the results of environment protection measures, multi-year monitoring results and comparison of the NPP environment condition before and during plant operation.

Book 2 presents the general characteristics of the nuclear power plant "Rivne NPP" and its economic activity, including waste generation and treatment:

– Section 1 provided general characteristics of SS "Rivne NPP", ecological, sanitary and epidemiological, social and economic aspects for implementation of further economic activity, information on the facilities, sites, land, water energy and other resources used, information on products and goods produced, description of the technological process of the economic activity.

– Section 2 provides information on the quantity and nuclide composition of the waste, assessment of its impact on the environment and people. Detailed description is given on the management of the non-radioactive waste, liquid radioactive waste, as well as non-radioactive waste handling. Separately, the topics of SNF handling are described for VVER-440 and VVER-1000 reactors.

The report is prepared in line with the requirements to the scope and content of the documents on the assessment of environmental impact.

The outcome of this report is environmental justification of the acceptance of the economic activity implemented by the operating facilities at Rivne NPP site and identification of safety conditions for social and manmade environment during future activity.

KEY WORDS: SS "RIVNE NPP", SS RNPP, SOCIAL ENVIRONMENT, POPULATION, DEMOGRAPHIC SITUATION, MANMADE ENVIRONMENT, IMPACT, MONITORING, PROTECTION MEASURES.

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REPORT COMPOSITION
SS Rivne NPP site environmental impact assessment

LIST OF DESIGNATIONS, SYMBOLS, UNITS, ABBREVIATIONS AND TERMS

ARMS	Automated radiation monitoring system
AWPF	Added water purification facility
CA	Controlled area
CRWME	State Special Enterprise “Central Radioactive Waste Management Enterprise”
CRWP	Complex for radioactive waste processing
CSFSF	Centralized spent fuel storage facility
DBA	Design-basis accident
DEI	Deep evaporation installation
EIA	Environmental Impact Assessment
ENSREG	European Nuclear Safety Regulators Group
EPS	Environmental Protection Service
ERS	Emergency response system
GTI	Gas treatment installation
HAW	High activity waste
IAEA	International Atomic Energy Agency
IAW	Intermediate activity waste
INES	International Nuclear Event Scale
IRS	Ionizing radiation sources
ISF	Interim Spent Fuel Storage Facility (Wet Type)
KhNPP	Khmelnitskiy nuclear power plant
LAW	Low activity waste
LRW	Liquid radioactive waste
MCP	Main coolant pump
n/i	Not identified
NFC	Nuclear fuel cycle
NNEGC “Energoatom”	National Nuclear Energy Generating Company “Energoatom”
NPP	Nuclear power plant
NT-Engineering	Limited liability company “NT-Engineering”
OZ	Observation zone
PC “Vector”	Production Complex “Vector”
PE “STC”	Production Enterprise “Scientific and Technical Center”
PJSC KIEP	Public Joint Stock Company “Kyiv Research and Design Institute Energoproject”
PSAR	Preliminary safety analysis report
“Radon”	Ukrainian State Corporation “Radon”
RCS	Reactor coolant system
RNPP	Rivne nuclear power plant
RODOS	European system for forecasting of radiation accident consequences
RWS	Radioactive waste storage
SAUMEZ	State Agency of Ukraine on Exclusion Zone Management
SF	Solidification facility
SFA	Spent fuel assembly
SFM	Spent filtering materials

SFP	Spent fuel pit
SG	Steam generator
SM	Salt melt
SNF	Spent nuclear fuel
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SOARS	Program complex for calculation of doses for all settlements of observation zone in case of an accident
SRW	Solid radioactive waste
SRWS	Solid radioactive waste storage
SSE “ChNPP”	State specialized enterprise “Chernobyl nuclear power plant”
SS “Rivne NPP”	Separate subdivision “Rivne nuclear power plant”
SSTC NRS	State Enterprise “State Scientific and Technical Center for Nuclear and Radiation Safety”
SUNPP	South Ukraine nuclear power plant
SWP	Special water purification
VVER-440	Water-cooled water-moderated power reactor with nominal capacity of 440 MWt
VVER-1000	Water-cooled water-moderated power reactor with nominal capacity of 1000 MWt
^{235}U	Uranium 235
WANO	World Association of Nuclear Operators
WEL	Waste extraction location
ZNPP	Zaporizhzhya nuclear power plant

INTRODUCTION

Nuclear power industry (atomic power industry) is a field of power engineering that uses nuclear power for electrification and heating, as well as it is a field of science and technology that develops methods and means for transformation of nuclear energy into electrical and heat energy.

The nuclear energy among other types of the energy comprises such advantages as a high heat generating capability of the nuclear fuel (2 mln times greater than oil, and 3 mln times greater than coal), better economic indicators, and less pollution of the environment. In addition, the reactor operation does not cause combustion reaction, where oxygen is used to support the reaction. Whereas, for other types of energy the oxygen is combusted five times more than it is consumed by all living beings. Besides, the stock of raw materials used for nuclear fuel production is approximately twenty times greater than the stock of organic fuel of all kinds [1].

Most nuclear energy adherents believe that efforts should be focused on elimination of the public distrust as for the safety of nuclear technologies.

Nuclear energy is a reliable source of power supply and it plays a leading role in addressing energy needs of Ukraine. Especially, when the country is under the conditions of economic crisis, when there is no sufficient natural fuel, no funds for modernization of the equipment of thermal and hydroelectric power plants, and for development of non-traditional sources of energy generation. Generation of electricity allows for keeping the wholesale electricity tariff at the acceptable level and reduces the greenhouse gas releases into the atmosphere. The nuclear power plants produce about 50% of the electricity consumed in the country, which is equivalent to combustion of about 40 mln tons of coal per year.

Lifetime extension of the operating nuclear power units is defined in “Energy Strategy of Ukraine for the period up to 2030” as one of the necessary conditions for implementation of goals and tasks of this strategy. The activities related to lifetime extension of the operating power units are regulated by the international agreements ratified by Ukraine, laws of Ukraine and substatutory regulatory acts.

Lifetime extension of the Ukrainian NPPs over the designed period will allow the state to ensure both the support of electricity production at the achieved level prior to introduction of new capacities, and save the necessary funds for power units decommissioning without significant load increase onto the consumer.

The priority of ensuring protection to a human and environment from the negative impact of ionizing radiation, ensuring safety during application of nuclear energy is one of the main principles of the national policy in the area of usage of nuclear energy and radiation protection of Ukraine. Specifically, in line with the Law of Ukraine on Usage of Nuclear Energy and Radiation Protection [2], Article 8, “adherence to norms, rules and standards on nuclear and radiation safety is obligatory when performing any type of the activity in the area of nuclear energy”.

Construction of the high voltage transmission line “RNPP – “Kyivska” substation” became the top-priority activity for Rivne NPP. Under the transmission line construction, the outdoor switchyard -750 kV was reconstructed for possible connection of the line to the power station.

Also, a lot of new equipment, automatic devices produced mostly by the Ukrainian manufacturers has been installed, and the lightning protection system has been improved for the last five years at Rivne NPP. Implementation of the newly constructed transmission line 750 kV “RNPP – Substation Kyivska” in December 2015 brought to reduction of dispatching limitations of the power station, increased the power output from the Rivne NPP’s busbars, which in its turn improved the operation reliability of the entire unified energy grid of Ukraine.

Assessment of the Environmental Impact onto the site of Rivne NPP is provided in seven books.

Book 2 describes general characteristics of the facility and its economic activity, waste production and waste management.

1 GENERAL DESCRIPTION OF THE FACILITY AND ITS ECONOMIC ACTIVITY

1.1 General characteristics of the facility and its economic activity

Rivne NPP is a separate subdivision (structural unit) of the state enterprise “National Nuclear Generating Company “Energoatom” (SE NNEGC Energoatom). The company fulfils its activity in line with its statute and it subordinates to the Ministry of Fuel and Energy of Ukraine, which forms the national policy in the industry. According to the law of Ukraine on “Usage of Nuclear Energy and Radiation Safety”, and by the Decree of the Cabinet of Ministers of Ukraine as of 17.10.1996 No1268 “On Establishment of National Nuclear Energy Generating Company” [3], the NNEGC Energoatom is appointed as the operating company responsible for safety of all the nuclear power plants in Ukraine.

Rivne NPP is located in the western Polissya, in the northern west of Rivne Oblast, nearby the Styr River. Such a selection of location was conditioned by several reasons: low fertility of the sandy soil and great distance from the high population zone. The population density on this territory was 55 people/km^2 in 1973, and today this figure constitutes 3684 people/ km^2 in the town of Varash.

According to the construction norms and rules SNiP P-7-81 “Construction in the seismic areas” [4], the site of Rivne NPP is located in the area with OBE of intensity 3-5, and SSE of intensity 3-6. The plant design was developed with consideration of two level seismicity: operating base earthquake (OBE) of intensity 5 and safe shutdown earthquake (SSE) of intensity 6.

The site of Rivne NPP is situated in the area with moderate climate, which is characterized by mild and humid winter, relatively cool and rainy summer, damp autumn and unstable weather during transition seasons of the year.

The landscape of the territory is flat and open for the wind, which ensures good airing of the site.

The power is supplied to the energy grid through:

-Electricity lines of 750 kV;

-Lines with voltage of 330 kV;

-Lines of 110 kV.

The arrangement of service water supply for the plant is a reverse one with feeding from the Styr River. Six cooling towers are used with the capacity of 100000 m^3/year each to remove the heat from the circulating water. The sprinkling ponds are used to remove heat from the essential service water.

Every year Rivne NPP generates about 13% of the total electricity generation in Ukraine and meets the needs in the electricity above the energy production scope and ensures normal living conditions for more than 5 mln people.

Rivne NPP is also a source of heat for the plant site, the town of Varash and the village Zabolottya.

The design of Rivne NPP implies the defense in depth concept, which is based on the levels of proteciton and incorporates series of subsequent barriers on the way of radioactive release into the environment. The designed safety systems that ensure emergency protection and emergency core cooling of the reactor facility are the following:

- Safety protecting systems;
- Safety isolating systems;
- Safety supporting systems;
- Safety controlling systems.

The power units of Rivne NPP were designed, constructed and erected in accordance with the regulatory documents that were in force at that time.

In 1971, the designing of Western Ukrainian NPP was initiated, which afterwards was renamed into Rivne NPP. The power plant is intended to cover electrical loads in the western part of the country.

SS “Rivne NPP” is the first nuclear power plant in Ukraine with water-water power reactor of VVER-440 type. The unit construction started in 1973. The two first power units with VVER-440/213 were put into operation in 1980-1981, and the third power unit with VVER-1000/320 reactor was commissioned in 1986.

Construction of the power unit 4 of Rivne NPP started in 1984 and in 1991 it was expected to put it into operation. However, because of the Moratorium introduced by the Verkhovna Rada on prohibition to construct nuclear objects on the territory of Ukraine, the further works with 85% of power unit preparedness to be commissioned were suspended.

The construction was renewed in 1993. After cancellation of the moratorium the power unit was examined, the program for its modernization was developed, as well as the dossier for completion of the power unit construction. On October 16, 2004 the power unit 4 of Rivne NPP was put into operation.

The operation time for Rivne NPP power units is presented in Table 1.1.

Table 1.1. Information on the power units of Rivne NPP.

Power unit	Type of reactor facility	Series of reactor facility	Date of unit connection to the grid	Date of putting the unit into commercial operation	Date of design lifetime	Date of lifetime extension
RNPP-1	VVER-440	B-213	22.12.1980	22.09.1981	22.12.2010	22.12.2030
RNPP-2	VVER-440	B-213	22.12.1981	29.07.1982	22.12.2011	22.12.2031
RNPP-3	VVER-1000	B-320	21.12.1986	11.12.1987	11.12.2017	22.12.2037
RNPP-4	VVER-1000	B-320	10.10.2004	07.06.2005	07.06.2035	-

The mailing address of SS “Rivne NPP” is: Rivne Oblast, town of Varash, 34400. The overall management of the facility is fulfilled by Mr. Pavlyshin Pavlo Yaremovich, General Director of the plant, with the functions authorized by the President of NNEGC Energoatom.

The general view of Rivne NPP is presented on Figure 1.1.

Fig.1.1 a) General view of Rivne NPP site, and b) Central entrance to the administrative building of Rivne NPP.

Fig.1.1 a) General view of Rivne NPP site

Fig.1.1. b) Central entrance to the administrative building of Rivne NPP.

Annually the SS “Rivne NPP” produces about 19 milliards kWt×year of electricity, which makes 21.6% from the electricity production by the NPPs or 13.0% from the total electricity production.

As of 2018 Rivne NPP operates four power units:

- unit I (VVER-440) with capacity of 420 thousands kWt from 1980;
- unit II (VVER-440) with capacity of 415 thousands kWt from 1981;
- unit III (VVER-1000) with capacity of 1 thousands kWt from 1986;
- unit IV (VVER-1000) with capacity of 1 thousands kWt from 2004.

The power units of Rivne NPP meet the up-to-date requirements of nuclear and radiation safety, which is confirmed by the reviews of International Atomic Energy Agency (1988, 1996, 2003, 2005, 2008) and World Association of Nuclear Operators (1988, 1989, 1993, 1995, 1997, 2001, 2003, 2005, 2012, 2014, 2015, 2016, 2018 years).

The land plot with the area of 217.895 ha intended for servicing of the entity of electricity production and electricity distribution has been allotted for permanent use by SE “NNEGC Energoatom” and registered by the State act on the right of permanent use of the land plot, series No252110 as of 01.07.2006, issued on the basis of the Solution by Local Council as of 28.04.2005.

In addition to the land plot with Rivne NPP power units, NNEGC Energoatom has land parcels for servicing production and social objects with the total area of 262.3 ha in the permanent use on the territory of Varash local council and Volodymyrets and Manevets regions.

Maximum usage of the designated territory ensures preservation and rational usage of the land resources. The territory is arranged, the area for the power units is settled and planted. Additional allocation of lands for the operation period of power units 1-4 is not required.

The cooling system of Rivne NPP power units does not include the cooling ponds. The entire system for power units cooling is designed such that to use six cooling towers and spray ponds.

The controlled area (CA) is established around the nuclear radiation facility. The criterion for establishing the controlled area are the limits of the annual absorption of radioactive substances through the breathing organs and digestion organs, and doze margins of external exposure of the personnel and public, as well as allowed concentration of radioactive substances in the atmospheric air and water.

The CA size is defined with consideration of the assessed radiation conditions in the area of the plant location during its long-term operation.

The region of Rivne NPP location and the borders of its observation zone (OZ) and controlled area (CA) are presented on Figure 1.2.

The OZ size of Rivne NPP is bounded with the radius of 2.5 km around the radiation hazardous facilities. The observation zone constitutes 30 km.

The sizes of SCA and OZ are officially introduced in accordance with the document of RNPP, specifically “Solution on the size and boundaries of the sanitary and controlled area and observation zone of Rivne NPP”, No132-1-Р-11-ЦРБ [5].

The plant safety systems that ensure public protection during accidents, including the design basis accidents with the most severe consequences, which are designed such that the values of equivalent individual doze rates calculated for the worst weather conditions on on the border of SCA and beyond that does not exceed

3 mZv/year for the thyroid for children due to inhalation intake and 1 mZv/year for the entire body due to external exposure [6].

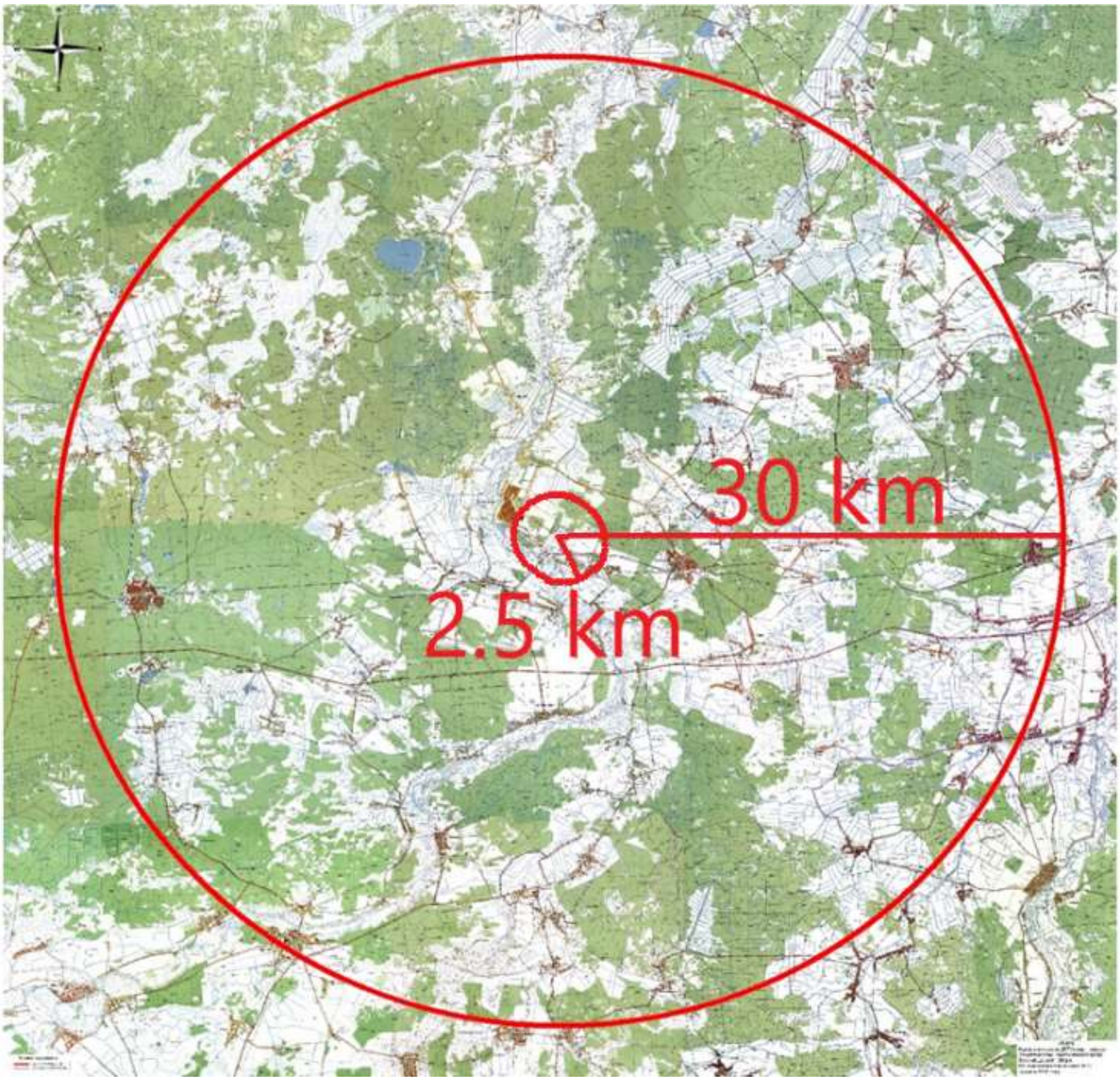

Fig.1.2. The territory of SS “Rivne NPP”

The observation zone includes the territory with possible impact of radiological effluents and releases of the nuclear radiation facility (NPP) and places with implemented monitoring.

The radiation monitoring is accomplished in the observation zone in accordance with the “Technical Specification for radiation monitoring at Rivne NPP” 132-1-Р-ЦРБ [7], approved by the First Vice President – Technical Director of NNEGC Energoatom as of 02.02.16, agreed upon in the letter by State Nuclear Regulatory Inspectorate of Ukraine (SNRCU) as of 25.10.16 No15-28/7070, agreed with the Supervisor of Varash Transregional Department of “Rivne Regional Laboratory Centre of State Sanitary and Epidemiological Service of Ukraine” as of 08.07.16 and by the General Director of Rivne NPP as of 05.07.16.

1.2 Ecological, sanitary and epidemiological, social and economic aspects for implementation of further economic activity of the facility

Reliability and profitability of the electricity produced by the nuclear power plants are recognized worldwide. Under the conditions of unstable markets and increased prices for gas, oil and coal, the importance of nuclear energy in meeting the needs of production areas and public are increasing in terms of relatively cheap electricity.

Rivne nuclear power plant, one of the four operating NPPs of Ukraine, is one of the biggest entity in the region. Annually the plant generates about 19 milliards of kWt-hours of electricity for the unified energy grid of the country and transfers almost 25 mln hryvnas to the local budget as social and economic compensation of risk to the population of the surveillance zone.

Rivne NPP is situated to the northeast of Rivne Oblast, 80 km from the region center, in the Volodymyrets region, at the bank of the Styr River. Rivne NPP is the closest nuclear power plant to the neighboring countries: approximately 60 km from the border with the Republic of Belarus and 130 km with Poland.

The main priority of the plant’s activity is to produce the ecologically clean thermal and electrical energy.

The planned safety improvement measures and international projects are implemented annually at Rivne NPP.

Owing to the NPP activity, the working places are preserved in other fields and this fact is very important for stability and rise of the Ukrainian economy.

For the purpose of justification of the above mentioned, the comparative analysis of the impact of nuclear and thermal power plants can be provided.

The thermal power plants (TPP) make more impact on the environment than NPPs. Because of chimneys, the TPPs release the effluent gases into the atmosphere, which contain not only nitrogen and remaining amount of oxygen but also carbon dioxide, water vapor, sulfur dioxide, nitrogen oxides and fly ash, which were not captured by the electrical filters.

The bigger problem in terms of environmental impact is the solid radioactive waste of coal dust TPPs such as ash and slag. Significant areas of land are designated for storage of this waste. During the long-term storage of ash and slag, different kinds of products are leached, which then enter the ground waters.

The most dangerous one for the atmosphere is the release of carbon compounds that leads to the greenhouse effect, which further on can cause global warming of the Earth. This phenomenon will bring to the following events:

- Increase of number of storms and hurricanes;
- Flooding of the low-lying ground (water level increase for 1 meter will flood the territory, where 1 milliard people live);
- Relocation of fertile areas and reduction of harvests due to droughts and ground erosion in some regions and excessive humidity in other regions;
- Extinction of some species of animals and plants;
- Losses of fresh water resources in some regions, formation of deserts.

The negative impact on the environment is imposed by the substances that result from burning of organic matters: sulfur dioxide and nitrogen oxides. During their interaction with the water drops of the clouds and rain, they form acids and then acid salts, which are very often toxic. This compounds fall to the ground in the form of acid rains, which influence the flora and acidify the waters and soils.

The calculated and actual values of the radioactive contamination from the NPP show that the additional impact versus the natural background is not significant, it is 10 times less than the allowed one.

The ventilated air released through the ventilation stack of the plant is thoroughly cleaned and it practically has no such substances that can change the composition of the atmosphere.

Commissioning of the radwaste reprocessing complex will initiate implementation of the national policy program in the field of radioactive waste management aimed at protection of the environment, protection of life and health of the population from the impact of ionizing radiation, improvement of the operation conditions of the facility and replacement of the old equipment with the new one.

The following goals will be achieved with implementation of the project on Establishment of the Complex for Processing of Solid Radioactive Waste (CPSRW):

- Minimization of the amount of radwaste, which is temporarily stored at Rivne NPP site;
- Beginning of the process of solid radioactive waste (SRD) storage facilities emptying;
- Rational usage of the capacities of the current SDW storages;
- Reduction of the personnel doze rate;
- Getting of the radwaste packages, which meet the requirements on the radwaste received for disposal in accordance with the norms and rules in effect in Ukraine.

1.3 Data on buildings, sites, areas of occupied commercial lands and data on pre-material, land, water, energy and other used resources

SS “Rivne NPP” of NNEGC Energoatom comprises 8 industrial sites.

Rivne NPP uses the following resources to meet the production needs [8]:

- The territory of nuclear power plant – 482 ha;
- Industrial site – 215 ha;
- With the permission of special water usage it is allowed to pump the fresh water from the surface ponds in the volume of 73164 m^3 per year;
- Electricity for in-house needs – 8% from the overall production.

1.4 Description of production, status of main production funds. Safety class

Rivne NPP produces heat and electricity.

The main characteristics of the Rivne NPP production process are the following:

Number of nuclear reactors – 4;

Reactor type – VVER-440 and VVER-1000

Total electricity production capacity – 2880 MWt.

Every year Rivne NPP generates about 13% of the total electricity production in Ukraine and with this scope of production it covers the need of electricity and normal living conditions for more than 5 mln people.

Rivne NPP is also a source of heat for the industrial site of the plant, the town of Varash and village Zabolottya.

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The power units of Rivne NPP include such equipment as:

- VVER-440 (В 213) reactor – units 1, 2 and VVER-1000 (В 320) – units 3, 4;
- К-220-44 turbine type – units 1, 2 (2 turbines per power unit) and К-1000-60/3000 turbine type – units 3, 4;
- Turbine generator of TBB-220 type – units 1, 2 (2 turbines generators per power unit) and TBB-1000 – units 3, 4.

The design of Rivne NPP included two power units of VVER-440 reactor and two power units with VVER-1000 reactor. Each power unit, in addition to the normal operation systems, has the systems that ensure radiation and nuclear safety of the plant, as well as reactor trip, cooldown, decay heat removal regardless of the mode the other power units are operated.

Technical characteristics of the power units of Rivne NPP are provided in Table 1.2.

Table 1.2. Technical characteristics of the power units of Rivne NPP

Parameter	Value	
	VVER-440	VVER-1000
Reactor capacity, MWt	1375±27	3000
Primary pressure (core exit) kgf/cm (MPa)	125±1.2 (12.25±0.1)	160±3 (15.7±0.29)
Coolant temperature at the reactor exit, ^0C	300	320
Coolant heatup in the reactor, ^0C	30.3	30.3
Average coolant consumption for core cooling, t/year	42700±400	84800^{+400}_{-480}

Parameter	Value	
	VVER-440	VVER-1000
Steam production capacity of all SGs, t/year	2700	5880
Steam humidity at the SG outlet, %	0.25	0.2

Lifetime extension of the operating nuclear power plants is defined by the “Energy Strategy of Ukraine for the period to 2030” [9] and it is the priority in NNEGC Energpatom’s activity.

The design lifetime of the operating power units of Ukraine is 30 years. In 2017 power unit 3 of Rivne NPP with VVER-1000 reactor has reached this margin. In 2012, maintenance activities were accomplished at the sealing surface of upper unit and main reactor joint. This was the exceptional in its scope maintenance and it was conducted for the first time in Ukraine under the framework of preparation to RNPP Unit 3 lifetime extension. In addition, assessment of technical condition of the equipment, pipelines, buildings and constructions was performed [10].

In 2016, the extended outage of 114 days was conducted at power unit 3 to implement activities related to technical support to operation (TSO). Particularly, activities related to introduction of reactor diagnosis system, mounting of hydrogen recombination equipment for the beyond design-basis accident conditions and other activities were performed.

In addition, this outage included the series of post-Fukusima activities aimed at make-up of the spent fuel pool, steam generators and essential water system in case of loss of water in the spray ponds using the water from the mobile pump stations. The activity was conducted for the possible case of loss of all ac power by putting the mobile diesel generator into operation. After implementation of all the above mentioned activities, it is expected to receive the License for safe operation of power unit 3 for the extended-lifetime period.

In accordance with ДСП 6.177-2005-09-02 [11] the entity/facility, which refers to the category with nuclear technologies application, is defined by the degree of potential risk to the population during its design operation mode and in case of occurred radiation accident.

Determination of the entity’s potential risk/hazard takes into account possible exposure of the personnel and population caused by the radiation accident at this entity/facility. Three categories of the entities and enterprises are established.

During the production activity of Rivne NPP or accident on its territory, radiation impact onto the population is possible, that is why the entity belongs to category I in accordance with ДСП 6.177-2005-09-02 [11].

Rivne NPP includes main, auxiliary and storage buildings and constructions.

For maintenance of work of power units on an industrial platform there are main and shops with characteristic for them sites.

The following workshops are located on the industrial site of NPP power units [12]:

- the departament of thermal and underground communications (DTUC);
- power repair unit (PRU) with shops, namely:
- Production Preparation Work departament (PPWD);
- welding departament (WD);
- repair and construction work departament (RCWD);
- departament for repair of general station systems (DRGSS);
- repair departament of thermal mechanical equipment (RDTME);

- departament for repair of electrical equipment (DREE);
- Repair departament for main turbine equipment (RDMTE);
- departament of lifting mechanisms (GCPM);
- the departament of providing systems (DPS);
- turbine workshops №1, №2 (TW-1,2);
- chemical departament (CD);
- ventilation and air conditioning work departament (VACWD);
- hydrotechnical work departament (HWD);
- electrical work departament (EWD);
- labor supply management (LSM);
- Transport work departament (TWD) (section of truck cranes and mechanisms and railway section).

DTUC. The main activity of the DTUC is to provide reliable electric and heat supply, drainage and water supply to consumers connected to the DTCU engineering networks.

Start-up boiler-house (SBH) and oil-shale economy.

According to the design decisions, the start-up boiler plant is designed to supply the steam to the operational needs of the power units during the planned preventive maintenance (PPM) and for some other needs depending on the situation.

For the period of construction of the nuclear power plant and after the start of the first power units, there was a situation where the work of the PWC was necessary for the provision of the city, construction base and industrial area of the units with heat and steam. After the commissioning of power units No.3, No.4 there was no need for PPM operation; Start-up boiler room is practically all-time in the reserve. Short-term boiler launches are not related to the need for steam production. Every year tests of the boilers of the PWK are carried out in order to check the reliability of work, maintenance in working condition and training of service personnel at a minimum load for no more than 24-48 hours per year.

In the boiler house there are 4 boilers of type ГМ-50-14-250.

Steam boiler ГМ-50-14-250 - vertical-water-tube with natural circulation, two-drum chamber furnace. The boiler is intended for combustion of fuel oil of mark M-100. The nominal steam output of the boiler is 50 tons per hour. The boiler top box is formed by screen tubes with front, back and side panels. The fuel supply to the furnace is carried out with the help of mechanical fuel oil nozzles located on the side panels of the furnace (two burners on each wall).

The boiler has the following equipment: a fan (type ВДН-12,5), a smoke exhaust (type ДН-19ГМ) and a chimney with gas outlets. The fan and the smoke exhaust system are equipped with regulating devices and operating mechanisms, which are controlled from the control panel of the control panel. For dissipation in the atmosphere of harmful substances contained in the products of combustion of fuel, a pipe with an internal diameter of 3.2 m and a height of 60 m (source of emissions 1) is installed.

The oil-mill is intended for receiving, storing and supplying fuel oil to the boiler-house to boilers.

The oil is delivered to the enterprise by rail in tanks. Drainage of oil is carried out on a drainage outlet.

Pre-warmed fuel oil in the tanks (steaming is provided for heating) through the drain trays fuses into the receiving intermediate tank (V = 400 m^3) and

further, by pumping pumps is transported to storage tanks of fuel oil. Steel tanks (3 tanks) have a volume of 2000 m^3 each. From fuel oil tanks, the supply of fuel oil to mechanical nozzles of boilers by means of a heating and cleaning system is carried out by pumps installed in the fuel oil pump room. During the operation of the pumps, the release of hydrocarbons into the air through the tightness of the end seals (unorganized emission source 4).

Intermediate receptacle and fuel oil tanks are equipped with breathing valves, which are designed to regulate the pressure of fuel oil vapor in the reservoir during the injection and storage (source of emissions 3.269.270.271).

Diesel generators serving the DTUC are installed [12]:

- in the premises of the crisis center of the production and laboratory corps (PLC) - a diesel generator-generator ДГМА-25М1-3 with the power of 25 kW (source of emissions 59);
- at the control point of the control (CPC PB) DPCH-6 - diesel generator type ДГМА-25-1М-3 with a capacity of 25kW (source of emissions 84);
- in the premises of the pumping station PPK - a pump of technical water with diesel (diesel generator type 1Д 12-400). In the period of acceptance and commissioning after repair (1 time / year) the pump undergoes tests within one hour at a load of 80% of rated power (source of emissions 60).

Diesel generators, as a stand-alone power supply, are included in emergency situations in the case of power failure. In the mode of normal operation of the NPP, diesel generators are in a state of constant readiness for start-up ("standby" mode). All diesel generators periodically undergo tests to check the working status in accordance with the technological cards of the enterprise.

Purification of oily-oiled wastewater (POOW)

Sewage, contaminated with petroleum products, is collected by separate pipeline systems and enters wastewater treatment plants that are contaminated with petroleum products. After clearing the waste water returns to the technological cycle of the SS Rivne NPP, and the precipitate (from tanks and tanks) is pumped to the sludge (sections №2, №5). In the process of settling from the surface of the sections of the sludge storage there is an allocation of atmospheric hydrocarbons (unorganized emission sources 131,132).

Station of biological purification.

The station of biological cleaning is intended for the purification of commercial-fecal wastewater, which comes to the cleaning of shower rooms, special spills from third rinsing. Purified sewage is disinfected with sodium hypochlorite and pumped into spray pools or on wastewater treatment plants of the block No 4. The sources of emissions into the atmosphere are secondary sedimentation (sources 219,220) and contact reservoirs (sources 221,222). The sedimentation and contact tanks are deepened, and pollutants entering the atmosphere pass through the breathing openings.

Various metal-working machines are installed in the repair shops of the DTUC: turning, grinding, drilling, grinding. Emissions from the machine tools into the air flow through the doorway (unorganized emission sources 143, 144, 146, 153). Welding works are carried out both indoors (source of emissions 152) and outdoors (unorganized source of emissions 154).

Power repair unit (PRU) [12].

The main activities of the PRU are the implementation of all types of repair of the mechanical and electrical equipment of the units, the preparation and implementation of planned preventive repairs of the units of the Rivne NPP units. The unit consists of workshops with different activities.

Production Training Building (PTB). In the warehouse manufacturing department are: smithy (source of emissions 5), repair and mechanical building (RMB) and central repair building (CRB-1);

Metalworking machines (source of emissions 9), grinding machines for sharpening the cutting tool and stripping of parts (source of emissions 11) are used in RMW.

Metalworking machines are used in the CRB-1, the emissions of which are carried out both through roof fans and through the doorway (unorganized sources 215, 216).

Welding departament (WD). Welding works, plasma and gas cutting of metal are carried out at the PRU welding department. For plasma cutting, the apparatus for air-plasma cutting A1612 УХЛ4 is used. Slicing of steel is carried out on a cutting table. In the room of the plasma cut, an exhaust ventilation from the table of steel cutting and a general exhaust ventilation from the premises is organized (source 128,129). Gas cutting of metal, if necessary, is carried out in the open air (unorganized source 130). The washing of gas equipment is carried out in a work departament in the premises of the joint auxiliary building (JAB) on the use of acetone and ethyl alcohol (source of emissions 149).

Stationary welding stations are located in a combined auxiliary building (CAB) and in machine gutters of blocks 1,2,3. Stationary welding stations are equipped with umbrellas with exhaust ventilation (sources 6,7,8,264), in the CRB-1 - source 147.

In addition, welding works are carried out in the open air throughout the site of the industrial site (unorganized sources 20-25, 148).

Repair and construction work departament (RBC) [12]. The repair and construction work departament carries out coloring, woodworking, repair work. In the departament at the wood processing plant there are 5 woodworking machines, which are connected to the aspiration system. To clean the air emitted from the substances in the form of suspended solids, a group cyclone УЦ-38 (source 12) was installed.

On the territory of the site on the open site a machine tool for cutting the stone of the brand MC-703 is installed. Slicing works are performed periodically, on request (unorganized source 83).

Painting of various metal structures with the use of enamels of type KO and ЕП is carried out in the studio of paint and varnish works of RBC. The removal of organic solvents in the air is carried out by means of exhaust ventilation (source 150).

In the warm period of the year (April-September), the coloration of buildings and buildings using enamels of the type НЦ, ПФ, KO and ЕП-enamels (unorganized sources 61-65) is carried out on the industrial area of the power units.

Repair departament for electrical equipment (RDEE). At the site for the repair of electric motors and ventilation (CRB-2), the electrical power equipment (electric motors, welding machines) is being repaired.

The technological process of repairing electric motors consists of the following main operations: disassembly of the electric motor on the components and components; removal of windings (including cleaning of the winding wire from the old varnish insulation by burning in a thermo-oven at a temperature of 350-400 °C), repairing windings and applying a new insulation using insulating varnishes, drying the insulation in a drying chamber at a temperature of 120 °C, assembly of the repaired engine, exterior decoration (tinting) of the engine. Burning, impregnation with varnish and drying are carried out in the impregnating, which is located in the JUB.

The process of burning the winding in a thermopiche is accompanied by the destruction of insulation and the release of nitrogen dioxide, carbon monoxide and soot. In the process of impregnation of the winding and staining of engines, organic solvents, which are part of the varnishes, enamel are released.

The sources of emissions in the impregnating are: source 266 - pipe from the burning furnace; source 267 - pipe from the bath with varnish; source 268 - pipe from the drying cabinet.

On the site are also conducted welding, gas-cutting, metal working (sources 217, 218).

In the section for the repair of switchgears, drill machines (unorganized source 223), lathe (unorganized source 224) and a grinding machine (unorganized source 225) are operated.

Repair departament for main turbine equipment (RDMTE). Gas cutting of metal, as necessary, is carried out in the open air throughout the industrial site (unorganized sources 233, 234, 235).

In the work departament for the repair of compressors in the room nitrogen-oxygen station number 1 (RNOSN-1) installed turning, screwdriving, grinding machines (unorganized source 265).

The **departament of lifting mechanisms** (DLM). The source of discharges in the DLM is a grinding machine (work departament in the UDC) - source 273.

Work departament on repair of general-purpose systems (CIRS).

The sources of emissions in the CRS are:

- unorganized source 151 - gas cutter (home town near SRB-2);
- unorganized source 232 - gas-supply post bl. 1.2;
- unorganized source 272 - a grinding machine (a work departament in the UDC);
- source 274 - lathes (work departament in the UDC).

Repair departament for heat-mechanic equipment (RDHE). The source of the release is a lathe in a work departament on the territory of the SODV (unorganized source 145).

On the balance of the EPP there are standby mobile compressor stations PKSD-5,25 and mobile aggregates АДД-4002 У1, which are intended for the development of compressed air for the pneumatic tool and the generation of current for welding machines. PKC-5,25 and АДД-4002 У1 are equipped with diesel engines of the Д-242 model with a power of 44 kW (emission source 77).

Hydrotechnical work departament (HWD). For the purpose of destruction of bacterial flora and prevention of contamination of heat exchange surfaces, circulation of the circulating and added water with chlorine is carried out. The gaseous chlorine is stored in a liquefied state in steel cylinders. Chlorine supply is carried out directly into the circulating water pipeline. It is possible that a small amount of chlorine enters the premises of a chlorinator due to non-densities. The room is equipped with inflow-exhaust ventilation. The removal of chlorine into the air is carried out with the help of exhaust fans (source of emissions 81.82).

10 mobile pumping units with diesel engines (МНУ-500) are additionally installed on open platforms. Mobile pump units are designed to provide water supply in an emergency. Periodically, once a quarter or once a month, the МНУ-500 undergoes tests to confirm their nominal characteristics (emission sources 252-261).

Departament for providing systems (DPS). The main activities of the DPS are the creation of conditions for the operation of security systems of the Rivne NPP and the provision of consumers with gaseous (high and low pressure) and liquid nitrogen, gaseous oxygen and compressed air.

Reserve diesel power plants. Back-up diesel power stations serve as power supply for NPP safety systems. RCDE, as an autonomous power supply, connects only in case of power failure.

The station is equipped with reserve diesel power stations for each power unit. RCDU for power units №1,2, №3, №4 consists of three fully independent channels (cells), each of which is providing power to consumers of this channel. In addition, there is a general-purpose RCA which consists of 2 cells. RCDE of power units №1,2 are equipped with six diesel generators of type 15D-100 (capacity 1700 kW); RCDE of power units №3, №4 - six diesel generators of type АСД-5600 with the power of 5600 kW; ZRDES - two diesel generators type ASD-5600 power of 5600 kW.

In the mode of normal operation of the NPP, diesel generators are in a state of constant readiness for start-up ("standby" mode).

All diesel generators are periodically tested both at idling speed and on load once a month for 30 minutes.

Diesel fuel is used as a fuel for diesel generators and diesel pump units.

Testing of safety systems is carried out every month with the inclusion of diesel generators in a working mode of up to 1.0 hours at a power of 50-80% of the nominal. The number of tests, duration and test mode are set in the process cards.

Each diesel generator has a separate exhaust pipe for exhaust gases. In the course of tests of diesel generators, pollutants are emitted into the atmosphere (emission sources 15,196,197,198,199,200 - RCDES bl.1,2; emission sources 16,201,202,48,204,205 - RCDES bl.3,4; emission sources 49,206 - GRDES).

In the premises of the storage facilities number 1 and number 2 installed diesel generators type DGMA-50M2-2 power of 50 kW (source of emissions 54.55); in the premises of engineering and technical means of protection b.1.1, c. 3, approx. 4 - diesel generators of type ДГМА-100М2-2 with capacity 100 kW (source of emissions 56,57,58).

The CPS serves the base composition of diesel fuel. Diesel comes from the Rivne NPP rail transport by rail. For unloading from railway tanks one-way overpass is intended. Drainage of diesel fuel from railway tanks is carried out using pumps. Unorganized sources of emissions of hydrocarbons into the atmosphere are the hatch of the rail tank during the discharge of diesel fuel into reservoirs (source of emissions 18) and pumps, during which the release of hydrocarbons into the air through the volatility of the end seals (source of emissions, 19).

Two storage tanks with a capacity of 700m3 (№1, №2) are intended for storage of diesel fuel. Reservoirs with diesel fuel are equipped with breathing valves, which are designed to regulate the pressure of a pair of petroleum products in reservoirs in the process of pumping or pumping oil products and at storage (sources of emissions 17,203).

The system of underground pipelines diesel is transmitted to consumers. The main consumers of diesel fuel is the RDEC bl.1,2,3,4 and GRDES.

Near each RDEC organized storage of diesel fuel - underground tanks capacity of 100m3 each - only 12 tanks. Each reservoir is equipped with a breathing valve (source of emissions 236,237,238,239,240,240,242,243,244,245,246,247).

In order to ensure the supply of clean water to steam generators in an emergency, diesel pump pumps are installed in an additional emergency water supply system (3 units). They are in a state of constant readiness for start-up ("standby" mode). Periodically, once a month, DNU tests are conducted at a load of 50% of rated power for one hour. During the PPR (1 time/year) the pump operates within one hour at a load of 80% of rated power (emission source 78.79.80).

During 2017, the Rivne NPP Purchase Mobile Diesel Generating Stations (MDGS) intended to provide emergency power supply in the conditions of the long-term total power failure of power units with the refusal of all AC sources (including RCDs and ZRDES): two mobile diesel generating stations МДГС-440 with a diesel engine С550Д5е for power units № 1,2, one for each unit (sources of emissions 250,251) and one МДГС-800 for power units number 3 and number 4 with diesel engines SUELMO and С1100Д5В (source of emissions 248,249) [12] .

Other sources of emissions and discharges of pollutants into the air that serve the CPS are:

- blowing tanks at the nitrogen-oxygen stations AK-1, AKS-2 and KS-2. In the process of work of the compressors, so-called, purge water, which is contaminated with mineral oil, is formed. Flushing water is collected in underground reservoirs - purge tanks. Purge containers are equipped with breathing apertures (sources of emissions 226-231).

Transport workshop (TC). The division of operation of mechanisms and cranes (DM TCC) and the railway section. The industrial area of the power units includes a section on the operation of mechanisms and truck cranes and a railway station of the TC [12].

Up to 50 units of vehicles are served on the DMTC: tractors, truck cranes, forklift trucks, dump trucks and others. Repair workshops carry out technical inspections and minor repairs of vehicles.

The main production sites that have sources of pollutant emissions into the air are:

- battery compartment (source of emissions 133);
- vulcanization unit (source of emissions 134);
- Welding department (source of emissions 135);
- turning department (source of emissions 136);
- gas station, gas station-2; fuel tanks and fuel dispensers (emission sources 137,138,139,140,263).

A woodworking workshop is organized at the railway station of the Truskavets. The workshop is equipped with a combined machine KSM-1. The removal of substances in the form of suspended solid particles from the machine to the atmosphere is carried out by means of an exhaust fan with preliminary purification in the cyclone (source of emissions 42).

Chemical department (CD). Reagent department.

Exploitation of the power equipment of the NPP requires the creation of the necessary conditions for the organization of the water regime, which provides the minimum rates of corrosion of the metal and reducing the scale of sediment in the reactor circuits. For such purposes, the treatment of the source water is carried out using reagents. As chemreagents are used sulfuric acid, ammonia water, nitric acid, hydrazine hydrate, monomethanolamine, sodium hydroxide.

Sulfuric acid is delivered to the plant by rail and stored in three tanks: two tanks with a working volume of $68m^3$, one - $92m^3$. Tanks are indoors. During the pouring of sulfuric acid into reservoirs, acid vapor is released through the breathing holes into the shop room. The removal of sulfuric acid in the atmosphere is carried out through the roof holes (unorganized emission source 13).

Amvoda (25%) is delivered to the station in barrels of $1m^3$ volume and stored under a canopy. As needed, the amoed with a vacuum system is pumped into the working tank to prepare the solution of the required concentration.

Hydrazine hydrate enters the plant in the form of 64% aqueous solution in 200-liter polyethylene or stainless steel barrels and is stored under a canopy. With the help of a vacuum pump, hydrazine hydrate is pumped into a tank of the working solution (V = 30m3), where a solution of the required concentration is prepared. The diluted solution is used for technological purposes.

Monoethanolamine enters the plant in 200-liter barrels at a concentration of 98.8%. With the help of a vacuum pump, monoethanolamine is fed into a reservoir of 30m3, filled with 50% water in the amount required for the preparation of 10% solution. The working solution is used for technological needs.

Working tanks of amvids, hydrazine hydrate and monoethanolamine are in the same room. The room is equipped with inflow-exhaust ventilation. In the process of pumping operations, the vapor recovery of reagents from the tanks through the breathing holes in the closed room; From the room with the help of an exhaust fan, ammonia, hydrazine hydrate, monoethanolamine is removed into the atmosphere (source of emissions 14).

Nitric acid at a concentration of 56% comes in tank vehicles of 15m^3. For storing nitric acid a reservoir with a working volume of 68.4 m^3 is located, which is located on the open site. Nitric acid is pumped into the reservoir with a centrifugal pump. During injection, the release of nitric oxide vapor into the air through a technological hatch (unorganized emission source 50).

Edible sodium enters the enterprise as a liquid high-concentrated solution (at least 40%) in railway tanks. Using vacuum pumps through an intermediate tank-tank, caustic sodium is pumped into alkaline reservoirs. From tanks of storage, caustic sodium is given to consumers.

Edible sodium in its properties refers to non-volatile compounds; Emissions of sodium hydroxide during pumping and storage of caustic soda do not occur.

At the facilities for purification of added water (FPAW), processing of feed water, which is used in the technological process. As a result, it is softened by removing calcium, magnesium and bicarbonate ions. At the same time, water is acidified with sulfuric acid.

Sulfuric acid is delivered by rail and stored in tanks (2pcs). The reservoirs are equipped with breathing holes. During the injection of sulfuric acid into the reservoirs, the acid vapor is released into the room. The exhaust ventilation is organized in the premises, with the help of which sulfuric acid is removed into the air (source of emissions 66).

Turbine departament №1, 2 (TC-1, TC-2) Oil supply system [12].

The oil supply system of power units is intended for lubrication of bearings of turbines and generators, shaft sealing of generators, regulation and protection of turbines, lubrication of power units.

For ventilation of the oil system, exhausters (exhaust fans) are intended for creation of a slight dilution in drainage oil pipelines and carter bearings.

The exhauzer consists of a casing, a rotor on which the impeller and the electric motor are fixed. The oil pairs sucked by exhauers under pressure come to the interstitial space of the oil cooler, through which pipes pass the cooling circulating water. The condensed oil is merged into an oil tank, and non-condensed vapors are emitted through the exhaust pipe into the atmosphere. Emissions occur throughout the year (emission sources 67-76, 207-214).

Ventilation and conditioning work departament (VCWD) On the balance sheet of the Rivne NPP, there is a sufficient amount of refrigeration equipment: household refrigerators and air conditioners, soda water cooling plants, refrigeration units and process air conditioners. The total amount of refrigeration equipment is about 1300 units. Refrigerant R-407C is used as refrigerants.

In the course of normal operation of the refrigeration equipment, there is no release of the refrigerant from the system. Absorption of freon into the air occurs only during repair, inspection of refrigeration equipment (unorganized emission sources 85-88).

Department of labor supply (LSD) To serve the dining room, chladone compressors are used as refrigerants in which the refrigerant R-406 is used (emission sources 46.47).

Electric departament (ED) When operating the electrical equipment (SF6 switches) of the open switchgear BPP-110, SFG-1 is used (unorganized plane emission source 262).

Quantitative and qualitative characteristics of pollutant emissions sources are given in Appendix D.

1.5 Data on products, nomenclature and scope of its production. Data on raw, land, water, energy and other used resources

Rivne NPP produces heat and electricity. Electricity production is accomplished at four power units with VVER-440 reactor and VVER-1000 reactor, with total installed capacity of 2835 MWt. The capacity factor is 74.2%.

SS “Rivne NPP” generates annually about 19 milliards kWt×year.

Data on the products (end-products and semi-products) provided by the facility for consumers every year or services provided as per the accounting records are given in Table 1.3.

Table 1.3. Products of Rivne NPP.

No	Type of product (service)	Yearly output
1	Electrical energy	19 milliards kWt×year

The following resources are used at SS “Rivne NPP” to cover the production needs:

- The territory of nuclear power plant
- site
- usage of circulating water
- water evaporation for cooling purposes
- electricity for in-house needs
- diesel fuel (fro emergency energy supply)
- oil (for turbines).

In the process of production activity at the Rivne NPP, fuel materials (fuel oil, anthracite, diesel fuel, gasoline), welding materials for repair works (welding electrodes, propane-butane mixture), lubricating and cooling liquid (COP), paint and varnish materials, chemreagents (sulfuric acid, ammonia, nitric acid, hydrazine hydrate, monoethanolamine), and the like.

As fuel in the start-up residual boiler-house the fuel oil of the mark M-100 is used [12].

Fossil fuel oil - product of oil refining, the balance after atmospheric distillation of oil; is about half the mass of crude oil. Furnace fuel of the mark M-100 belongs to the category of heavy fuel. For fuel oil is basically the same indicators as for the oil from which it is produced.

The elemental composition of fuel oil includes: carbon, hydrogen, sulfur, oxygen and nitrogen.

Carbohydrate compounds are the main component of fuel oil, mainly aromatic and naphthenic hydrocarbons, as well as polycyclic and acyclic hydrocarbons of the saturated series (olefins).

Mineral impurities in fuel oil are basically alkali metal salts. When burning fuel oil mineral impurities are transformed into oxides, which form a fraction of the ash of fuel oil. Another part of the ash is formed by the combustion of organometallic compounds directly into the combustible mass of fuel oil, namely compounds of vanadium, nickel, iron, and the like. The content of these compounds increases in heavy oil fractions. With increasing sulfur content of fuel oil, the content of vanadium of organic compounds in it increases.

The water content in fuel oils varies within 0.5-3%. Moisture in fuel oil reduces the heat of combustion of fuel oil (each percentage of moisture reduces by 418 kJ), complicates the operation of oil fuel economy and may lead to disruption of the fuel oil combustion regime, as well as leads to corrosion of pipelines and equipment as a result of dissolving some aggressive sulfur compounds in water.

Sulfur in fuel oil is mainly in the form of organosilicon compounds (sulfides, thiophanes, thiophenes, disulfides) and sulfur of elemental.

Depending on the content of sulfur in fuel oil, it is distinguished: low-sulfur fuel oil (up to 0.5%), sulfur (up to 2%) and high sulfur (up to 3.5%). Combustion of fuel oil, which has a significant amount of sulfur in its composition, leads to air pollution with sulfur dioxide, which requires additional costs for installing higher chimneys or a system for cleaning flue gases from sulfur dioxide [12].

The heat of combustion of fuel oil varies within 39-41.5 MJ/kg, depending on its composition. The heat of combustion of combustible mass depends on the ratio of the main combustible elements C and H, as well as on the content S, O and N. The presence of low-fuel oil resins and asphaltenes, which is characterized by a reduced ratio of H/C and high sulfur and oxygen content, reduces the heat of combustion of fuel oil.

Anthracite is used for blacksmithing work in the forge. Anthracite - a kind of coal. Unlike charcoal, anthracite has a small yield of volatile matter (about 7%), due to which it burns mainly in a layer with a short flame and smokeless. He is a hard-burning fuel. The content of external ballast is 12-25% (ash content - 7-20%, moisture - 5-7%). The heat of combustion of anthracite is 25.2-29.3 MJ/kg.

Welding materials used for repair works (electrodes), must have certificates of the manufacturer, which would certify their quality and compliance with the requirements of standards. Depending on the type of metal structures, different types of electrodes are used: for especially critical structures of low carbon, medium carbon and low-alloy steels, electrodes of the type UONI, EA are used; For ordinary and responsible structures of low carbon steel - electrodes type ANO-4.

Propane-butane mixture is used for gas welding and oxygen cutting of low-carbon steel. It is a rarefied mixture of gases of propane and butane. This gas is stored and transported in steel cylinders with a capacity of 40 and 55 liters under pressure. Cylinders for propane-butane (DEST 15860-84) are designed for a maximum pressure of 1.6 MPa. The maximum gas selection should not be greater than 1.25 m^3/h.

When machining of ferrous and nonferrous metals on metalworking machines (cutting, drilling, grinding, etc.) for cooling the tool and parts and lubricating the surface of friction as a COP emulsol is used. Emulsol is a mineral oil containing an emulator and stabilizer. As an emulsifier, high molecular weight naphthenic acids are used, and as a stabilizer, ethyl alcohol, ethylene glycol or water. Emulsols are used in the form of 3-10% of water emulsion.

Paints and paints (enamels, varnishes) are a mixture of pigments and fillers with synthetic or oil varnishes. To obtain working viscosity, enamels are diluted with organic solvents. In the process of coating and drying, volatile organic compounds contained in LFM are released into the atmosphere.

Petroleum products (gasoline, diesel fuel), supplied to the Rivne NPP, are accepted, provided their qualitative characteristics are matched to the requirements of the TU.

Motor gasoline - light fractions of oil that boil within 40 - 205^{o}C; used as fuel for automotive carburetors. Mark automotive gasoline for octane numbers [12].

Diesel - oil fractions 190-360oS with a viscosity at 20oC1,5-8 сСт (mm^2/s). Diesel is used in diesel engines and other internal combustion engines with compression ignition. Mostly they get direct distillation of oil.

As a chemreagent for treatment of the initial water in order to reduce the rate of corrosion of the metal and reduce the scale of sediments in the reactor circuits are used: sulfuric acid, ammonia water, nitric acid, hydrazine hydrate, monoethanolamine, sodium hydroxide.

Sulfur and nitric acids are used for regeneration of cation exchangers of special water treatment plants, for acid washing of special equipment equipment, for the preparation of deactivation solutions.

Sulfuric acid is a colorless oily liquid that freezes in a crystalline mass at a temperature of plus 10°C. The technical concentrated sulfuric acid has a density of 1.84 g/ml and contains about 98% H_2SO_4; with water is mixed in any proportions with the release of a large amount of heat (up to 92 kJ per mole (22 kcal per gram of a molecule of acid). During the heating of sulfuric acid, a pair of sulfuric anhydride is formed, which, in the case of combining with a water vapor of air, forms an acid fog. Sulfuric acid, in case of contact with the skin, causes strong burns, very painful, difficult to cure. When inhaling a pair of sulfuric acid, the upper respiratory tract is irritated and cooled.

Anhydrous nitric acid (HNO_3) is a colorless liquid, yellow during storage, boiling point 82.6ºC, freezing temperature - 41.6ºC. Mixes with water in all respects. Strong oxidising agent, characterized by all the properties of acids.

Nitric acid refers to chemicals acutely directed action, in contact with the skin causes strong burns, when inhaled nitric acid vapors irritate the mucous membranes of the upper respiratory tract.

Hydrazine hydrate ($N_2H_4*H_2O$) is a colorless liquid, which is similar to ammonia odor. Highly flammable, poisonous. Hydrazine hydrate is readily soluble in water and alcohols. Comes to an enterprise in the form of a 64% aqueous solution (density hydrazine hydrate - 1,03 g/ml), used directly in the technological cycle in the form of 1-5% solution [12].

Hydrazine hydrate - a strong reducing agent, is easily decomposed under the influence of temperature. In the mixture with oxygen is explosive. Toxic to the human body.

Hydrazine hydrate is used in the technological cycle of the Rivne NPP to correct the water-chemical regime of the first and second circuits of 1-4 power units.

At the Rivne NPP, ammonia water comes in the form of aqueous solution containing 25% NH_3 (density 0.9 g/ml at a temperature plus 15 °C). The aqueous ammonia solution has alkaline properties. The pH of a 1% solution is 11.7. Aqueous ammonia solutions can cause poisoning of the body. During inhalation of air containing 5% ammonia, a sharp breathing disorder begins, tears, eye pain, severe coughing, dizziness, stomach ache, vomiting. At high concentration, ammonia can cause burns of the mucous membrane of the eye and lead to blindness.

Monoethanolamine is a colorless, viscous, hygroscopic liquid with a specific ammonia odor; mixed with water in any ratio, well soluble in ethanol, benzene. Density - 1,012 g/ml, boiling point - 170 °C. MEA and its solutions have alkaline properties, when exposed to the skin causes burns.

Chlorine is used to process circulating and additional water.

Chlorine is a greenish-yellow gas with a characteristic irritating odor. The density of dry gaseous chlorine is 3.214 kg/m^3 (at 0 ^{0}C and 101.3 kPa). The gaseous chlorine is 2.5 times heavier than air. It is easily liquefied at a temperature of minus 34^{0}C and a pressure of 101.3 kPa, forming an oily liquid of yellow-green color. The density of chlorine in liquefied state is 1560 kg/m^3. Pure chlorine is a non-flammable and explosive substance, but liquid chlorine containing more than 5% (by mass) of nitric trichloride, is explosive, extremely sensitive to shock, friction, and heating.

Chlorine is stored in a liquefied state in steel cylinders of 25-30 kg under pressure of 6-7 kPa.

The bactericidal effect of chlorine consists in the fact that in the presence of chlorine in water is formed quite unstable chlorinated acid (NOSI), which quickly decomposes on the hypochlorite ion (OSI) - and hydrogen (H +). Hypochlorite ion, in turn, decomposes into atomic oxygen and chlorine. The bactericidal action is determined mainly by the concentration of chloric acid and by a slightly less hypoclory ion. The small gap of the molecule and the electrical neutrality allow the chlorinated acid to pass through the bacterial membrane of the cell and oxidize the enzymes that regulate the processes of cell proliferation [12].

Refrigerants R-406A and R-407C are used as refrigerants in refrigeration units, air conditioning units. R-406A is a mixture of known freons: R22 (difluorochloromethane), R142b and R600a at a ratio of 55: 41: 4% and is an effective substitute for freons R12 and R500. R-407C is a hydrofluorocarbon refrigerant (not containing chlorine) that does not destroy the ozone layer; designed to replace the R-22 in many air conditioning systems. R-407C is a mixture of hydrofluorocarbons R-32 (difluoromethane), R-125 (pentafluoroethane) and R-134a (1,1,1,2 tetrafluoroethane) in a mass ratio of 23: 25: 52%, respectively.

Freons (methane and ethane derivatives) are used as refrigerants. In addition to the fluorine atom, freons are chlorine atoms. Freons - colorless, odorless gases or liquids, well soluble in organic solvents, poorly soluble in water. Freons do not burn, explosion-proof even when in contact with an open flame; chemically resistant to acids and oxidizers. Freons, as a rule, are low-toxic compounds with low biological activity. In the body freons are not subjected to metabolic transformations and are excreted through the respiratory organs in an unchanged state.

Table 1.4. Characteristics of raw materials, auxiliary materials and fuel used in the enterprise [12].

No	Shop, production, name technological operations	Name of raw materials	Qualitative composition of raw materials. Characteristic raw materials	Cost in a year	Composition of GPAs produced at production sites
1	Start-up boiler room.	Oil fuel M-100 (ГОСТ 10585, зм. №1,2,3,4)	Ash - 0,05% Sulfur content - 0,94% $Q^{r}_{н}$ - 41,15 MJ/kg (according to the quality passport)	100 t	Nitrogen oxides (in terms of nitrogen dioxide) Carbon monoxide Sulfur dioxide Substances in the form suspended solid particles
2	Repair work. Smithy	Hard coal	Ash - 22,9%; Sulfur content - 1,7%; $Q_{Н}$ = 20,89 MJ/kg	3,0 т	Nitrogen oxides (in terms of nitrogen dioxide) Carbon monoxide Sulfur dioxide Substances in the form suspended solid particles
3	Electric welding work; gas cutting	Type of electrodes УОНИ, ЭА, АНО etc. Propane-butane mixture	Propane Butane	12.959 t 1.424 t	Metals and their compounds in terms of metals (iron, manganese, chromium, vanadium, copper) Fluorine and its compounds Nitrogen oxides (in terms of nitrogen dioxide) Carbon monoxide
4	Chemical departmenr	Sulfuric acid	The mass fraction H_2SO_4 - 94,7 %	4000.0 t	Sulfuric acid

No	Shop, production, name technological operations	Name of raw materials	Qualitative composition of raw materials. Characteristic raw materials	Cost in a year	Composition of GPAs produced at production sites
	Reagent department. AWPS	Ammonia water	The mass fraction NH_3 - 25 %	70.0 t	Ammonia
		Nitric acid	The mass fraction HNO_3 - (56%)	75.0 t	Nitric acid
		Hydrazine hydrate	The mass fraction N_2H_4 - 64 %	50.0 т	Hydrazine hydrate
		Monoethanolamine	The mass fraction MEA - 100 %	30.0	Monoethanolamine
5	Painting of buildings. Painting of metal structures.	Enamel НЦ-25	Volatile part - 66%	10.0 t	Volatile Organic Compounds
		Enamel ПФ-115	Volatile part - 45%	7.5 t	Volatile Organic Compounds
		Enamel КО-822	Volatile part - 65%	12.0 t	Volatile Organic Compounds
		Enamel ЕП-525	Volatile part - 29%	12.0 t	Volatile Organic Compounds
		Solvent 646	Volatile part - 100%	13.6 t	Volatile Organic Compounds
		White spirit	Volatile part - 100%	3.4 t	Volatile Organic Compounds

Main indicators of Rivne NPP as of 19.06.2018 is provided in Table 1.5.

Table 1.5. Main indicators of Rivne NPP.

Indicators	Unit 1	Unit 2	Unit 3	Unit 4	NPP
Electricity produced for the current day, mln. kWt×year	4.5	4.5	N/A	10.8	19.9
Electricity produced for the current month, mln. kWt×year	182.5	183.3	N/A	437.6	803.4
Electricity produced for the previous month, mln. kWt×year	309.5	308.6	N/A	736.9	1355
Electricity produced from the beginning of the year, mln. kWt×year	1346.8	1292.6	0	4061.9	6701.4
Capacity factor for the current month, %	98	99,6	N/A	98.6	63.9
Capacity factor for the previous month, %	99	99.9	N/A	99	64.2
Capacity factor from the beginning of the year, %	78.9	76.6	0	99.9	58.1

Production of the electrical energy by the power units of Rivne NPP started from 1981. Figure 1.3 provides information on the amount of milliards of kWt×year of the produced electricity as per years of operation.

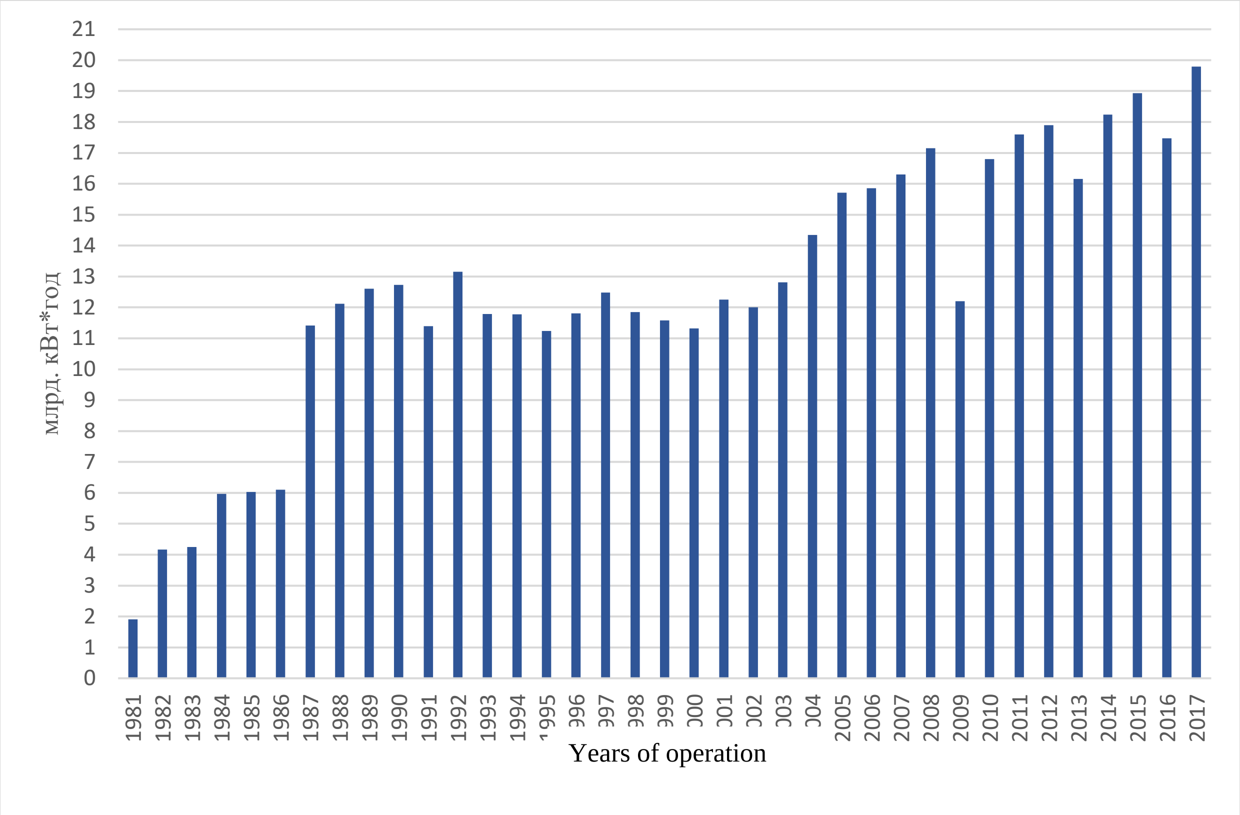

Fig.1.3. Annual electricity produced by Rivne NPP.

1.6 Technological process of the facility's economic activity

1.6.1 Electricity production

The work process of the facility's economic activity, taking into account all environmental impact factors and technical solutions, is aimed at elimination or reduction of hazardous releases, effluents, leaks, exposure into the environment.

The basis of RNPP design uses the principle of module line-up: each power unit, in addition to the normal operation systems, has the systems that ensure radiation protection and nuclear safety of the plant, as well as reactor trip, cooldown, decay heat removal regardless of the mode the other power units are operated.

Operation of VVER-440 and VVERR-100 reactors is based on regulation of the chain fission reaction of ^{235}U that is part of the nuclear fuel (Attachment A and Attachment B). The power units consist of two circuits: primary circuit (radioactive) – water circuit, which removes heat from the reactor; secondary circuit (non-radioactive) – steam circuit, which receives heat energy from the primary side and converts it into the mechanical energy for turbine rotation and then into electrical one in the turbine generator.

The main building of four operating power units (two VVER-440s and two VVER-1000s) contains the reactor hall, turbine hall and adjacent deaerator department and rooms of in-house switchgear.

The main components of the reactor facility are:

- reactor;
- steam generators;
- reactor coolant pumps;
- pressurizer;
- hydroaccumulators of reactor core cooling system;
- communication pipelines located under the containment in the compartments with massive walls made of concrete and reinforced concrete.

Description of the Rivne NPP site and complementary facilities.

The layout of the main and complementary/additional buildings location is presented on Figure 1.4.

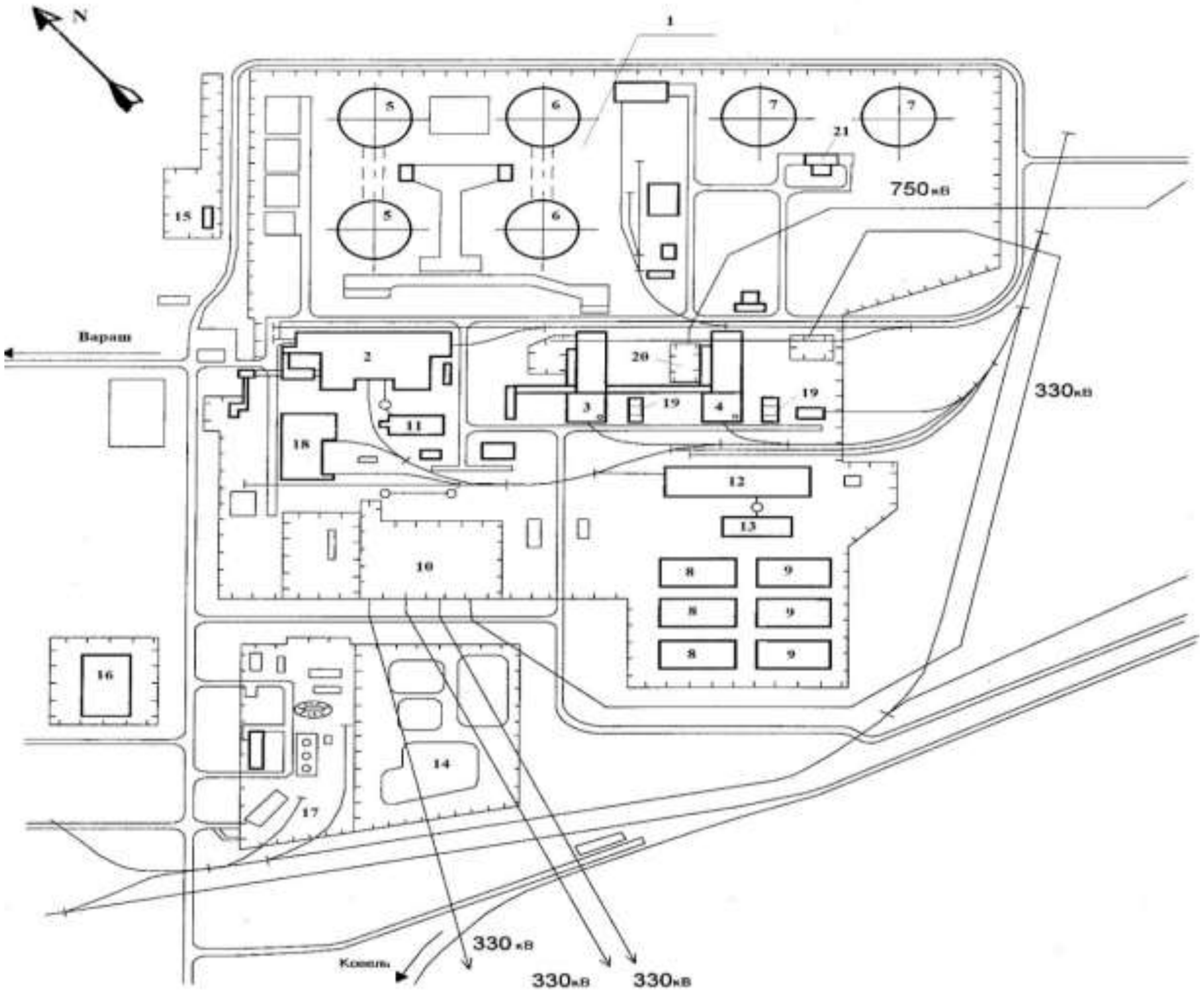

Fig.1.4. Layout of Rivne NPP site

Explicaiton of buildings and structures of SS "Rivne NPP"

1 NPP site
2 Power Units 1 and 2
3 Power Unit 3
4 Power Unit 4
5 Cooling towers of Units 1 and 2
6 Cooling towers of Unit 3
7 Cooling towers of Unit 4
8 Sprinkling ponds of Group A loads cooling system of Units 3 and 4
9 Sprinkling ponds of Group B loads cooling system of Units 3 and 4, including the backup pond
10 Open switchgear 110-330 kV
11 Auxiliary building of Units 1 and 2
12 Auxiliary building of Units 3 and 4
13 Radioactive waste processing and storage building
14 Sludge collector
15 Fire house
16 Auxiliary water processing facility
17 Auxiliary boiler
18 Unified auxiliary facility
19 Diesel-generating standby electric power station
20 Open switchgear

1.6.2 Departments of Rivne NPP

The organizational structure of the NP "Rivne NPP", in conditions of normal operation of the power units of the station, is presented in Fig. 1.5.

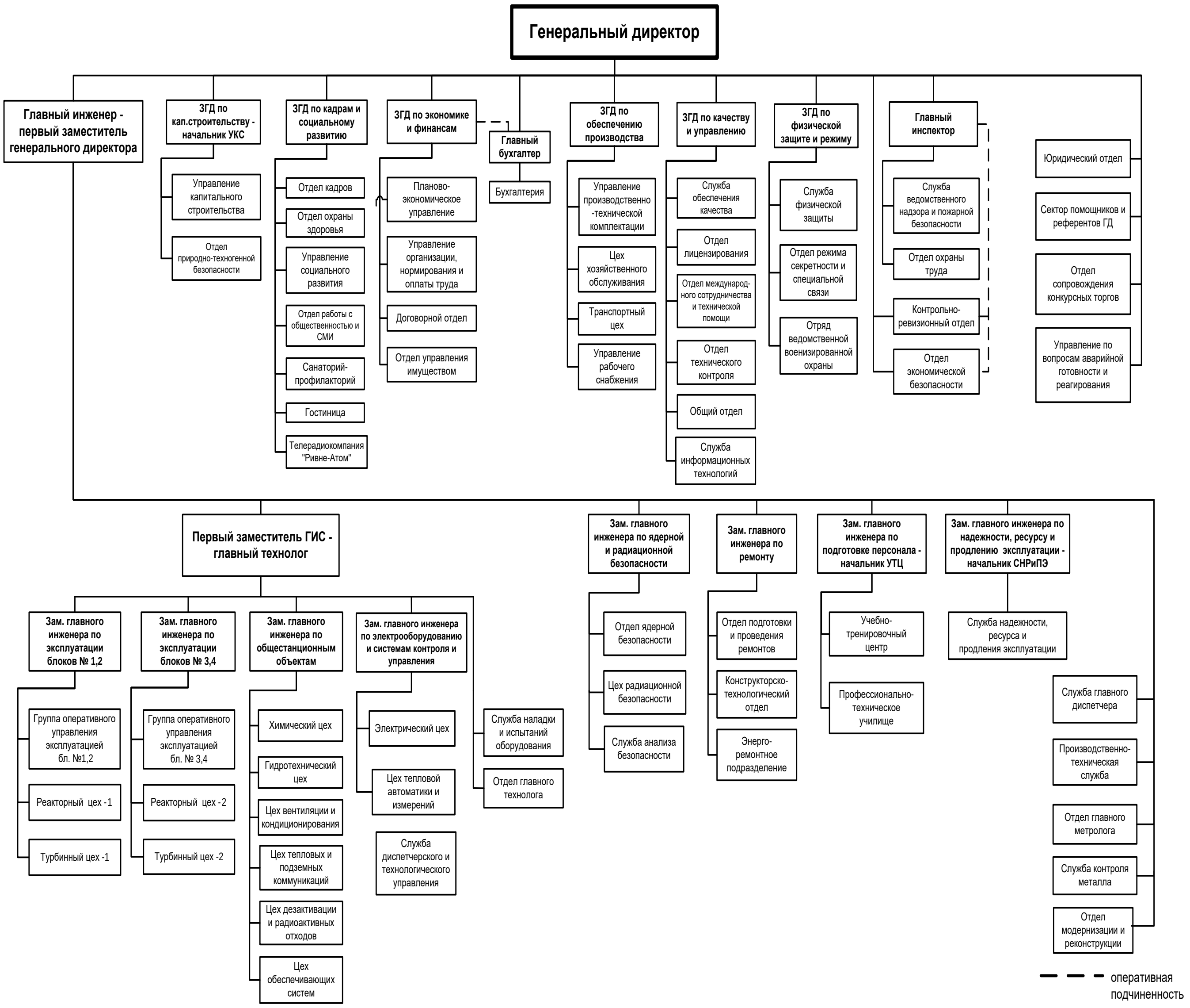

Figure.1.5. Organizational structure of Rivne NPP

1.7 Engineering network and communication

Power supply network.

Rivne NPP is connected to the unified energy grid of Ukraine through the following power transmission lines [8]:

- 2 lines with the voltage of 750 kV;

- 4 lines with the voltage of 330 kV;
- 5 lines with the voltage of 110 kV.

Water supply to Rivne NPP.

The service water supply to NPP has a reverse arrangement with makeup from the Styr River. Six cooling towers with capacity of 100000 m^3/year each are used for heat removal from the circulating water. Sprinkling ponds are used for heat removal from the essential water.

SS “Rivne NPP” is the biggest water consumer of water from natural resources. According to the permit conditions the plant has the right to take water 73.164 mln.m^3 per year from the Styr River without losses for the nature. In fact, the plant consumes lower volumes. Every cubic meter of the river water is used up to 100 times in the cooling system of Rivne NPP. Water consumption by the plant is possible on the basis of the Special Consumption Permission UKR No 1/Рвн as of 06.08.2015, which is valid until 06.08.2020. The service water supply, which covers the losses of the reverse water supply system (evaporation in the cooling towers and from water surfaces of the channels, filtration, system blowdown), is performed from the Styr River to the pump station of additional water (water intake limit is 73164 thousands m^3/year, 267840 m^3/day, 2.32 m^3/sec). The portable water is supplied to Rivne NPP from the underground water intake Raphalivske-1 (Ostriv Village), which has 9 wells (water intake limit is 3386 thousand m^3/year, 9277 m^3/day).

The plant has “Norms of annual average water consumption and water intake per the unit of product”.

The system of cooling water supply to Rivne NPP consists of the reverse circuluation systems, reverse essential cooling system (which ensure safety of Rivne NPP) and reverse non-essential cooling system (normal operation equipment).

Loss of water due to the special measures (water catching devices, inclination of the territory to the cooling tower side) is insignificant. With average annual air speed of 3.9 m/sec, loss of water from the cooling towers constitutes 0.15% of the reverse water, 2% from the sprinkling ponds (totally – 0.23% of the lost reverse water).

The blowdown of cooling towers takes 0.42% of the reverse water. Currently, six cooling towers of the similar type are in operation. Losses of circulation water of power units 1,2 constitute 91000 m^3/year for each unit, and for power units 3,4 - 188920 m^3/year each.

For the rational usage of the natural resources, it is foreseen to repeatedly use the water after purification of the discharged water from oil product and rain drains.

Volumes of the service water, which was extracted, lost (evaporation of cooling towers, evaporation from surfaces, water blown with the wind, filtration into the ground), repeatedly used, reverse water, discharged (returned) into the Styr River, are accounted for and reflected in the statistic records as per the form 2TP (water services).

Data on the use of water at the Rivne NPP for the last 6 years are given in tables 1.6 and 1.7.

Table 1.6. Dynamics of volumes of water use of PE "Rivne NPP"

Name of the source of water supply	Used water, ths m^3					
	2012	2013	2014	2015	2016	2017
Technical	55066	48746	54547	55848,763	50145,260	58573,110
Artesian	1914/321*	1744/344*	1705/361*	1700/385*	1632/531*	1607/583*

* - water taken from a water supply source / used at the enterprise

In general, water use in the Rivne NPP is carried out in accordance with the established limits, special conditions of use and standards of the GDS. The volume of used river and artesian water in percentages to the limit is given in table 1.7.

Table 1.7. Volume of used river water

	% of the limit					
	2012	2013	2014	2015	2016	2017
Volume of used river water	75,26	66,74	75,01	76,8	68,84	80,05
Volume of used artesian water	53,22	53,56	55,87	59,87	82,62	44,68

1.8 List of environmental impact sources

The main types of possible impact onto the environment of Rivne NPP site during plant operation, based on the working proccess, are radiation, chemical and non-radiological physical impact. Under the normal operation conditions the significant ones are thermal (non-radiological physical impact), chemical and radiation impact (enumerated as per the order of significance). For low-probability but possible cases of maximum design-basis or beyond-design basis accident, the dominant one is the radiation impact.

1.8.1 Radiation impact

During plant operation, it is inevitable to have gaseous, solid and liquid materials, which contain radionuclides in their composition (radioactive isotopes of the chemical elements). The radiation impact of the power units is conditioned by the releases of these materials into the atmosphere.

Under the normal operation conditions, any release of radioactive nuclides (fission products) outside the fuel elements cladding will lead to radioactive contamination of the primary coolant.

Substantial amount of radioactive products enter the primary coolant as a result of neutron activation in the structural materials and processes of erosion and corrosion of these materials.

In addition, air activation processes, in the close vicinity to the reactor vessel, will cause generation of insignificant amount of gaseous radioactive particles including evaporation of tritium water and inert gases.

Radioactive fission and activation products are drawn from the coolant because of ion exchange processes, which leads to generation of contaminated ion exchange resins in the special water purification (SWP) installations. Periodic change of these resins result in formation of liquid and solid radioactive waste.

Treatment of the radioactive medium at the SWP installations located in the special building will lead to generation of radioactive waste: solid, liquid and gaseous.

The circulation of coolant, flowing in the steam generator from the primary into secondary circuit, lead to formation of the contaminated water in this circuit.

Gases accumulated in the primary side generate the flow of gaseous release. Releases into atmosphere can also occur as a result of ventilation of the volatile matters of the primary coolant, which occur in the event of small leaks, controlled and uncontrolled leakages. As a rule, such types of releases have tritium water vapor, inert gases, aerosols and other gaseous particles.

During the annual reactor shutdown, the pressure is reduced using the cooling system, the reactor head is removed and one third of the fuel assemblies is withdrawn and moved to the spent fuel pit (SFP) for further cooling and storage. The other two third of the fuel assemblies are rearranged to support the optimal leak-tightness of the neutron flow density, and then the reactor core is loaded with the fresh fuel. The refueling operations can lead to increase of the liquid radioactive waste (LRW) releases and releases to the air from the spent fuel pit, reactor inspection shaft and guide tubes shaft. These releases by the nature are similar to the releases generated from the coolant in the primary side.

Besides, the repair and maintenance activities conducted during the reactor shutdown can be also a potential source for radioactive waste, which occurs as a result of opening and repairing of the equipment. Individual components of the primary circuit, which are contaminated due to neutron irradiation, as well as elements of the equipment of reactor hall and special building imposed to radioactive contamination, can be replaces, which leads to additional amount of solid radwaste.

LRW and SRW treatment and storage is accomplished in accordance with the requirements of "Sanitary rules of plant design and operation" [12]. Release of this type of waste into the environment during plant normal operation, design-basis accidents and probable beyond design-basis accidents is practically excluded.

Designing of the nuclear reactors involves one of the main safety principles, which is defense in depth concept. According to this concept, several layers of security are placed to prevent or limit adverse consequences from the equipment failures and plant personnel errors.

The main important requirement of the defense in depth principle is establishment of the safety barriers. Due to a potential of fission fragments spreading from the nuclear fuel and their release into the environment, the modern reactors incorporate three barriers, which can be considered as safety barriers based on their functions and significance. The first safety barrier is the nuclear fuel itself and fuel elements cladding. If the radioactive products get into the coolant, their spreading is blocked by the reactor coolant system (RCS), pipelines and RCS vessel structures (the second safety barrier). Also, radioactive fission products are restrained either by the system of hermetically sealed compartments or containment (the third barrier).

During normal plant operation, these barriers ensure safety of the personnel, public and environment.

1.8.1.1 Radiation state of Rivne NPP location during the pre-commissioning period

From 1976 to 1979, the radiation state of the environement was studied in the area of the construction activities for Rivne NPP prior to the plant commissioning. This refers to as studying of "zero background". The results of this research were used for assessment of the radiological impact of RNPP power units onto the environment during the entire period of plant operation.

According to the data of "zero background":

- specific activity of aerosols in the atmospheric air was in the range: ^{137}Cs – 1.11E-05÷5.92E-05 Bq/m^3; ^{90}Sr – 1.48E-05÷1.11E-04 Bq/m^3;

- total beta-activity of the atmospheric precipitations was in the range: 7.4E+00÷3.29E+02 (Bq/m^3)/month;

- content of ^{137}Cs in the pines was in the range: 7.2E+00÷1.7E+01 Bq/kg; ^{90}Sr – 2.96E+01÷1.05E+02 Bq/kg;

- content of ^{137}Cs in the plants was in the range: 2.55E+00÷9.55E+01 Bq/kg;

- ground surface contamination with ^{137}Cs prior to RNPP commissioning was in the range: 4.44E+02÷5.07E+03 Bq/m^2; ^{90}Sr – 1.85E+02÷2.92E+03 Bq/m^2;
- specific activity of ^{137}Cs in the milk prior to RNPP commissioning was in the range: 6.3E-01÷6.6E+00 Bq/l;
- specific activity of ^{137}Cs in the vegetables prior to RNPP commissioning was in the range: 1.5E-02÷2.0E+00 Bq/kg;
- specific activity of ^{137}Cs in the grain crops prior to RNPP commissioning was in the range: 8.1E-01÷1.18E+00 Bq/kg.

1.8.1.2 Radiation impact on surface and ground waters

Three points are established to conduct monitoring of impact of liquid discharges from Rivne NPP into the Styr River:

- Mayunychi Village – 10 km up the river stream;
- below the drain point of industrial and storm sewage system;
- Sopachiv village – 10 km down the river stream.

The sampling is performed once per a decade and then the specific activity of natural and man-made radionuclides is determined using semi-conductive γ-spectrometers. The tritium activity is determined by the liquid scintillation radiometer Tri-Carb 3170 TR/SL.

The concentration of radionuclides is thousand times lower in the Styr River than the allowed radionuclides concentration in portable water [6].

The bottom sediments, weed and fish of the Styr River are sampled in August every year. The samples go through preliminary verification and γ-spectrometric analysis. The objects of the Styr River have no man-made radionuclides except for ^{137}Cs of Chernobyl origin. The specific activity of ^{137}Cs in the fresh fish is 100 times less than the established allowed level [13].

To control non-spreading of the radioactive materials into the ground waters, the radiation monitoring of underground waters is conducted on the territory of Rivne NPP site. To control the underground water supply sources, the content of radionuclides is measured in the artesian wellholes.

There are 35 check-wellholes, and water is sampled from the bottom layer at a depth of 10÷14 meters from the surface. The frequency of water sampling from the check and artesian wellholes is once per quarter [“Technical Specification for radiation monitoring of Rivne NPP”]. Each sample is measured in terms of Σβ-activity using α/β radiometer MPC-9604 and specific activity of tritium is measured using liquid scintillational radiometer Tri-Carb 3170 TR/SL. The samples of check-wellholes are averaged and are subject to γ-spectrometeric analysis. The activity of man-made isotopes in the groundwaters is thousand times less than the level of allowed concentration in the portable water.

The network of artesian well-holes consists of nine wells, organized on the territory of the water withdrawal point “Ostriv”. The samples of water are taken from the special collector, and go through γ-spectrometry and measurement of tritium activity. The water of artesian wellholes has no isotopes of manmade nature.

1.8.1.3 Radiation impact on the air environment

Radionuclides content in the surface atmospheric layer.

Sampling and monitoring of the aerosol content in the surface atmospheric layer is performed in accordance with “Technical Specification of radiation monitoring of Rivne NPP” once per a decade at 16 monitoring points. The specific activity of manmade radionuclides in the atmospheric air for 37 years of observations did not exceed the regulatory values established by NRBU-97 [6]. For radionuclides ^{137}Cs and ^{90}Sr the specific activity is within the margins of “zero background” (see item 1.8.1.1 “Radiological state of SS “Rivne NPP” location during the pre-commissioning period”).

Radionuclides content in the atmospheric precipitations.

Gaseous and aerosol releases of radioactive substances, which entered into the atmosphere from the ventilation stacks, are spread in the atmosphere thus forming so-called “release cloud”. The aerosol particles fall from the cloud, deposit on the ground and migrate in the elements that adjoin the ecological systems of NPP.

The atmospheric precipitations are collected by the Radiological Monitoring Laboratory with the help of stainless steel tanks with the area of 0.25 m^2. The bottom of tanks is covered with the filtering paper as per DST 12026-76 [14].

The collecting tanks are located at 22 surveillance stations. The location was established based on the area tie-in design, and multi-year pre-commissioning meteorological observations of Rivne NPP construction area (according to the wind diagram), which is mostly in the residential area of the surveillance region. The frequency of taking samples of the atmospheric precipitations is once per month according to the requirements of the technical specification.

The results of multi-year observations show that Σβ-activity of the precipitations and the content of ^{137}Cs and ^{90}Sr for the observation period is within the margins of “zero background” and does not depend on the distance of the surveillance station from Rivne NPP.

1.8.1.4 Radiation impact on soil and vegetation

Sampling of the soil is conducted in the continuous monitoring stations together with the sampling of vegetation layer. Samples are taken from April to May in 22 points/stations from the layer of 0÷5 cm and are measured by γ-spectrometers. The radionuclides content in the soil and vegetation was detected to be the radionuclides of natural and “Chornobyl” origin (^{137}Cs).

1.8.1.5 Radiation impact on agricultural products

The controlled area of Rivne NPP is subject to monitoring of the main local food products like milk, vegetables, and crops. The samples are taken during ripening period and go through measurements using γ-spectrometry in order to establish possible presence of radionuclides of manmade origin.

During the surveillance period, the agricultural products were identified to be free from the manmade radionuclides except for ^{137}Cs of “Chornobyl” origin. The increased content of this radionuclide in the food products is conditioned by a large value of transition coefficients in the chain “soil-solution-plants” for the soil of this region.

1.8.2 Chemical impact

The chemical impact of Rivne NPP site on the environment comprises the contaminant effluents into the Styr River, contaminant releases into the atmospheric air (separate: from plant and from mobile sources) and possible impact on the atmospheric air, soil and underwaters due to placing of waste in the locations of waste treatment. The sources of chemical releases from the NPP into the environment are:

- evaporation of the additional source river water in the circulating water systems (increased concentration of chemical substances in water) and catching of contaminants by filtering materials and purification installations;
- combustion of diesel oil, fuel oil residue, gasoline and other kinds of fossil fuel;
- evaporation and loss of reagents during receipt and usage (acids, alkalis, oils, fuel);
- dust emissions during mechanic processing of metals and wood;
- aerosol emissions during metal welding and cutting;
- painting of equipment and building structures, erosion;
- corrosion and scraping of equipment surfaces;
- waste formation from used, unserviceable, replaced equipment.

The design and production documentation take into account the chemical impact on the environment during normal, abnormal plant operation and emergencies/accidents.

1.8.2.1 Chemical impact on the air environment

Rivne NPP is an entity with a large number of necessary additional production facilities. The entity is under the state accounting in the field of atmospheric air protection. It has 290 automobiles, among them 142 diesel items, 148 gasoline items, and 7 items belong to railway transport. Two certified check and adjusting stations operate for the automobile diagnosis and measurement of toxicity and smokiness of exhaust gases.

The site of Rivne NPP comprises 164 stationary sources of releases into the atmosphere, 40 contaminating non-radioactive substances. The post probable release source is the auxiliary boiler station, designed for sulphur oil burning. From 1994, there was no need in using the auxiliary boiler station; its boilers are started one per year with the minimum capacity and only for the purposes of personnel training and verification of the equipment. The stationary sources of releases into the atmospheric air are located in seven production sites of Rivne NPP. The contaminant releases into the atmospheric air from the stationary sources of every site are made on the basis of special permissions, issued in particular by:

- rehabilitation and recreation center “White Lake” near the village Bilska Volya of Volodymyrets region, the permission duration period is not limited;
- car fleet of transport facility in the industrial area No2 (northern) of the town of Varash, the duration period is 5 years;
- site of power units in the industrial area No1 (southern) of the town Varash, the duration period is 5 years;
- vocational technical school and sport complex in the district of Peremogy of the town Varash, the duration period is not limited;
- divisions, automatic radiation monitoring center, the cold-storage warehouse on the streets Teplychna, Rynkova, Komunalna, Energetykiv of the town Varash, the duration period is not limited;
- divisions, asphalt factory on the construction base of the town of Varash, the duration period is 10 years;

- treatment facilities of domestic sewerage division on the street Dachna of the town of Varash, the duration period is not limited.

The requirements and conditions of permissions are specified in the inspection time schedule, agreed with the Rivne Oblast State Administration. This schedule is developed and accomplished to verify compliance with the established allowable release limits of the contaminants, as well as conditions of permits for releases into the atmospheric air from the stationary sources.

Fourteen atmospheric release points are equipped with the gas treatment installations (GTIs). All gas treatment installations have passports. The gas treatment equipment is operated in accordance with “Rules for operation of gas treatment facilities”. By the order of General Director of Rivne NPP, the people are assigned who are responsible for GTIs operation. According to the design documentation and operation conditions, the operating instructions were developed for each GTI The body of installations have applied registration numbers as per their passports. The accounting records are maintained with regard to operation time for each gas treatment installation.

Rivne Oblast State Administration submits the annual reports of Form 2-TP (air) in a timely manner to the Department of Ecology and Natural Resources. Reports are prepared using the quantitative method based on the data regarding the used raw products, fuel, materials and time of facilities operation. The stationary sources of Rivne NPP release from 33 to 37 tonnes of contaminant substances into the atmosphere for a year. Among them:

- nonmethane volatile organic compounds – 18-25 t;
- nitrogen compounds – 5-9 t;
- substances in the form of suspended solids (microparticles and fibers) – 1.4-2.7 t;
- sulphur compounds – 1.2-2.7 t.

Releases of the polluting substances into the atmosphere from the plant is 2-3 thousand times less than from the coal thermal power plant with the similar installed capacity.

1.8.2.2 Impact on surface and ground waters

The water from the cooling system returns back continuously to the river through one discharge point of the industrial storm water sewerage system, which is located 30 m below the river stream from the river (additional) water intake facility. The industrial storm sewerage system receives the blowdown water from the circulation systems continuously and other debalancing waters from the power unit sites periodically after calculation of non-exceedance of normative effluents of contaminating substances. In accordance with the permission on special water use, the allowed effluents are in the volume of up to 18409.0 thousand m^3 of water for a year ($0.7 m^3$/sec).

Monitoring of the chemical composition of sewerage water and river water discharged to the water intake station of Rivne NPP and after the discharge point is conduced by the certified laboratories of the NPP. The laboratory of heat and ground communications take samples and performs analysis of the discharge water not less than six times a day (oil products and pH).

The ecological and chemical laboratory of environmental protection service (EPS) performs analysis of the surface and sewerage (discharge) waters three times a week using 25 indicators. The analysis of monitored indicators prove that the values of the maximum allowed effluents (in tons) were not exceeded, the sewerage water is within the purity limits, and contains the same natural impurities like the source river water, and operation of Rivne NPP does not input the significant changes into the quality of surface waters.

From the hydrogeological point of view, the site of Rivne NPP is located on the planned ridge with grade elevation of 188.5 m. The absolute elevation of the landscape before the plant construction was

185.00÷189.00 m in the central part of the site, and it achieved 190.00÷193.00 m in some particular areas. The grade elevation is 188.50 m in the area of main structures location. The following water bearing formations and complexes underlie here, from the top to the bottom:

- fill-up ground (in some particular areas) and natural quaternary deposits: sands, then sandy clay, often argil sand ground. The subface of stratum is traced at a depth of 15.00÷25.00 m on the average from the grade elevation; the oriented absolute elevations are mainly 166.00÷168.00 m. The water-bearing free-flow complex (groundwaters), which is fed by atmospheric precipitations, and partially from water flows from other aquifers. The formation depth of ground waters level is 7.00÷15.00 m, and greater in some places. The amplitude of seasonal fluctuations of ground water level is 1.00÷2.00 m. The main unloading of water bearing complex is to the south of the plant site, i.e. to the valley of the River Styr. The horizon is controlled by three drill holes of the stationary surveillance hydrogeological network to the "perched water" and by 123 ones to other ground waters;
- horizon of deposits of Upper Cretaceous. The dominant position in the cross section is taken by the fractured chalk-stone, with developed karst-suffosion processes (hollow spacing, macrocracks, filled with chalk suspension or "healed" with particles of stones, which are deposited higher: sand, sand clay, sometimes even with clay, often in suspended state). The total thickness of deposits achieves 15.00 m, the subface of stratum at the absolute elevations is 148.00÷151.00 m. In the upper part of loamy cretaceous layer, there is an area of aquiclude clay mud of 25.00÷40.00 m at the plant site. The horizon is controlled by 54 drill holes of the stationary surveillance hydrogeological network;
- water-bearing horizon of Berestovets strata deposits of the upper Proterozoic eon is widely spread, suspended in extension and thickness. The aqueous rocks are fractured basalts and different grainy fractured tuffs. The aquiclude layer contains solid tuff deposited in the upper part of section. The separating layer between the upper Proterozoic eon upper-chalk water-bearing horizons is the massive chalk, but because of the little spreading of this rock, there is a hydraulic connection of horizons. The horizon is artesian aquifer. The depth of the horizon bedding is 40.00÷45.00 m on the plant site. The horizon is controlled by 13 drill holes of the stationary surveillance hydrogeological network.

The hydrogeological analysis includes the following activities:

- measurement of water level and temperature in the drill holes;
- measurement of water temperature along the entire length of the shaft in the drill holes - temperature log;
- water pumping from the drill holes;
- sampling of water from the drill holes for determination of the chemical composition of the groundwaters.

The controlled area of the first ring of the Artesian wells of the village Ostriv are subtracted and enclosed. The analysis is conducted by the ecological and chemical laboratory certified for making measurements of chemical composition of groundwaters (drill holes/wells) in the area of sludge collector and landfill for construction and industrial waste from Rivne NPP. The analysis of monitored characteristics prove that Rivne NPP operation does not input significant changes into the quality of ground waters.

1.8.2.3 Impact on soils

The area of sludge collector and landfill for construction and industrial waste from Rivne NPP is subject to the analysis by the ecological and chemical laboratory certified for making measurements of chemical composition of the soil.

The analysis of monitored characteristics prove that Rivne NPP operation does not input significant changes into the quality of soils.

1.8.3 Non-radiological physical impact (thermal impact)

Nuclear power plants are the sources of heat release into the atmosphere. The thermal impact of Rivne NPP on the environment should be considered in the context of microclimate impact. The microclimate in the area of Rivne NPP is formed under the influence of additional heat and humidity, which come into the atmosphere with the releases from cooling towers and spray ponds.

About 70% of thermal power generated in the reactors is not used for electricity production in the steam turbines, and it goes through the cooling systems to the environment. This released low-potential heat is transferred to the service water. This water transports the heat to the cooling towers and spray ponds, where it is transferred to the ultimate heat absorber, atmospheric air, due to convectional heat exchange and evaporated water cooling.

Part of the heat, removed by the service water of the cooling system, is transferred to the River Styr through the permanently open blowdown line of the circulation systems. A small amount of heat produced from the heated walls of equipment, pipelines and cables in the processing areas and then ventilation systems and air conditioning is released to the atmosphere.

The impact of cooling towers and spray ponds onto the microclimate is analyzed for the Rivne NPP site in general, since the cooling system for all power units is geographically grouped in one place and induce a combined impact on the microclimates of near-surface layer of air by cappilary transport of humidity. It can be mostly intense during strong winds and only in close vicinity to the ponds (100-500 m). During a cold season of the year, the sprays in the ponds are turned off and the impact of the ponds during this period of time reduces to zero.

Heat and humidity releases from the spray ponds do not exceed 3% of the similar releases of the cooling towers, which accordingly make the same amount of heat in formation of the entire microclimate of Rivne NPP site.

The main contribution in measuring the plant region microclimate belongs to the cooling towers. Increase of the air temperature and humidity due to steam and drops release from the towers occurs mostly in the near-surface layer of the atmosphere, at the height of 200-500 m.

Increase of the air temperature for about 0.5-1.0 ^{0}C in winter as per January background indicators, measured at the distance of 1 km from the cooling towers, and increase of the yearly amount of precipitations for 2-3 % due to releases from steam-dropping flares of towers are subtle: in winter there can be glaze and rime.

Each power unit operates three cooling systems:

- circulation systems of service water supply;
- Group A service water cooling system (three independent trains with cooling of the spray ponds);
- Group B service water cooling system with cooling of two-section spray pond.

Table 1.8 presents the values of heat releases of Rivne NPP into atmosphere.

Table 1.8. Amount of heat removed by the cooling water from the plant components and released into atmosphere.

Plant equipment	Heat release, Gcal/year
Circulation systems of service water supply	5220
Group A service water supply system	60
Group B service water supply system	100

The existing regulatory documents do not have requirements to the allowed limits of heat releases. Monitoring of heat releases is performed by measuring the consumed water, which is collected from the River Styr for service needs and consumed water that returns to the river.

Taking into account that impact of the plant cooling systems is quite insignificant on the climate parameters, and that impact of the cooling towers and spray ponds is practically implicit on the microclimate and environment outside the sanitary protection zone within the radius of 2.5 km, no special activities are foreseen with regard to limitation of these influences during NPP operation.

1.9 Comprehensive activities on establishment of regulatory basis for environment protection

1.9.1 Resource-saving activities

Land resources.

The land plot with an area of 217.895 ha, which is intended for usage by the facilities of electricity production and distribution, is assigned for the permanent use by NNEGC Energoatom and certified with the state act on the right of continuous management of the land plot - series ЯЯ No252110 as of 01.07.2006, issued upon the Decision No 433 as of 28.04.2005 by the Kuznetsovsk Town Council.

In addition to the land plot used by Rivne NPP power units, NNEGC Energoatom also holds the right of continuous use of the land plots for servicing the production and social objects with the total area of 262,3 ha on the territory of Varash town council and Volodymyrets and Manevytskiy regions.

Preservation and rational use of the land resources is ensured by the maximum effective use of the assigned territory. The territory is arranged, the land plot used for the power units has a developed infrastructure and landscape. No additional land allocation for extended lifetime of Rivne NPP power units operation is required.

Water resources.

The four- units Rivne NPP is the largest consumer of water from natural sources. According to the permit conditions, the plant has the right to use water from the Styr River, without loss to the nature, in the amount of 73.164 mln m^3 per year. In fact, the plant takes in less volume of water.

Every cubic meter of the river water is used by the cooling system of Rivne NPP for up to one hundred times. Water consumption by RNPP is accomplished upon the permission on special use УКР No1/Рвн as of 06.08.2015 with the validity date until 06.08.2020. Losses in the reverse water supply system (evaporation in the cooling towers and from the water surface of the channels, removal and filtration, system blowdown) are covered by the service water, which is pumped from the Styr River at the auxiliary water pump station (water intake limit is 73164 thousand m^3/year, 267 840 m^3/day, 2.32 m^3/sec).

Due to the special acitivities (water catching devices, inclination of the territory to the cooling tower side) the water loss is insignificant. With the average wind speed of 3.9 m/sec, the water loss from the cooling towers is 0.15% of the reverse water, from the spray ponds – 2% (totally 0.23% of the consumed reverse water). The facility and drinking water supply to Rivne NPP is made from the underground water point Rafalivske-1 (the Ostriv village), which comprises nine wells (water intake limit is 3386 thousand m^3/year, 9277 m^3/day).

The facility has “Norms of annual average water consumption and water discharge per item of product”.

The cooling water supply system of Rivne NPP consists of the reverse circulation systems, reverse essential cooling water system (which ensures safety of the plant) and non-essential cooling water system (normal operation equipment).

The blowdown of cooling towers takes 0.42% of reverse water. At present, sox one-type cooling towers are in operation. Consumption of circulation water to power units 1 and 2 is 91000 m^3/year for each unit, and power units 3 and 4 –188920 m^3/year for each unit.

Water reuse is foreseen through purification of the sewage water contaminated with oil products and rain run-off for the purpose of rational use of natural resources.

The volume of service water that was pumped, used, lost (evaporated in the cooling towers, evaporated from the surfaces, blown with the wind, ground filtration), reused, reversely supplied, discharged (returned) into the Styr River is subject to accounting and recording in the statistical reports as per Form 2-TP (water sector).

Use of surface water from the Styr River, discharge of sewage water depending on the electricity produced, reverse water supply, reused water during the period from 2010 to 2017 is presented in Table 1.9.

Table 1.9. Data on the use of surface water of the River Styr for the last seven years.

Year	Electricity output, mln. kWt×year	Water intake from the Styr River, thous. m^3	Discharge of sewage water into the Styr River, thous. m^3	Reverse water supply, thous. m^3	Reused water, thous. m^3
2010	16841.2	51003.7	13838.6	3672402.4	981.438
2011	17551.7	55011.2	13061.9	4023911.9	1347.2
2012	17891.9	55066.5	12952.6	4131547.5	1846.3
2013	16158.8	48746.9	10875.8	3912077.3	1790.3
2014	18238.9	54547.3	13774.6	4160324.5	1744.3
2015	18932.0	55848.7	12512.0	4235410.4	1501.7
2016	17468.2	50063.0	11505.6	3853860.1	1495.3
2017	19792.8	58493.3	12788.3	4235537.0	1623.1

Rivne NPP makes portable ground fresh waters for the centralized and non-centralized water supply (except for production of packed drinking water) from the water deposit “Rafalivske-1”, located at the western periphery of the village Ostriv of Volodymyrets Region of Rivne Oblast. Usage of deposits is fulfilled upon the special permission No2263 as of 09.10.2000 with validity period of 20 years, which was reissued on 19.06.2015 due to change of the legal address of NNEGC Energoatom (renaming of the street).

The first upwelling area includes nine wells with the depth from 130 m to 350 m. Accounting is in place for the pumped water. At the station of the second upwelling area, two reservoirs of pure water are installed with the volume of 1000 m^3 each. The water intake limit of the ground water from the Artesian wells of the village Ostriv is 3386.0 thousand m^3 per year.

The Artesian water is used exclusively for the domestic and fresh water needs.

Fuel and power resources.

For the internal needs Rivne NPP consumes 8% of electricity of the total power output. To reduce these losses the specific measures are applied at the plant: installation of low-energy lamps, consideration of replacing the current equipment with more energy-saving one (pumps).

For the purpose of further reduction of energy consumption, the NPP also applies the measures on reduction of fuel consumption by the transport.

1.9.2 Emergency response measures

In accordance with the regulatory documentation, Rivne NPP has a developed and functioning system of emergency response actions. This system is an interrelated complex of technical means and resources, organizational, technical, radiation and health-related measures, which are implemented by NNEGC Energoatom to prevent or minimize radiation impact on the personnel, population and environment in case of nuclear or radiation accident at the plant, as well as to ensure civil protection.

The main activities of the emergency response system of Rivne NPP related to personnel protection are the following:

- administrative coordination and oversight of meeting the established radiation and sanitary provisions and limitation of personnel exposure;
- timely initiation of protective countermeasures;
- performance of radiation survey in the rooms and on site;
- provision of the personnel with individual protection means, preventative radiation-proof means (potassium iodide)
- announcement about the threat or occurrence of radiation accident or another emergency situation;
- sheltering and evacuation of the personnel;
- personnel dose control, decontamination
- medical help to the injured;
- personnel training on actions in the emergency situations.

The main activities of the emergency response system of Rivne NPP related to personnel protection are the following:

- enhanced monitoring of radiation indicators related to the external facilities and exposure of the personnel in the surveillance area of Rivne NPP;
- forecasting of personnel exposure dose rates in the surveillance area of Rivne NPP;
- informing of the central and local executive authorities and municipal authorities regarding the countermeasures on public protection.

1.9.3 Compensatory measures

Compensation of environmental damage.

For the last few years, the legal department of Rivne NPP did not receive materials, which would contain claims or requests for environmental damage compensation, or these claims were not recognized by the established legislation. There were no cases of paying penalties by the accounts department of Rivne NPP for violation of legislation on the environmental protection.

Until 2010, there were some cases of payment of penalty by Rivne NPP for violation of legislation on the environmental protection. This sum of money was paid out from the salaries of the plant employees in accordance with the Article 132 of the Code of Laws on Labor of Ukraine.

Social economic compensation of the risk to population that lives in the plant surveillance area.

Rivne NPP is not only the ecologically clean production of thermal and electrical energy but also the annual social guarantees in the form of state subventions, which go to the local budgets of the settlements of the observation zone (OZ) of the nuclear object. In accordance with the current legislation of Ukraine, the population that lives in the 30-km surveillance area has the right for social and economic compensation of the risk from their activity, which specifically includes:

- establishment and maintenance of the special social infrastructure in the operable state;
- allowances in the consumed electricity payment as per tariff, which is established in accordance with the Law of Ukraine “On Electrical Energy”.

According to the Directive of the Cabinet of Ministers of Ukraine, the correlation of state subvention breakdown among the local budgets of the settlements, located in the plant surveillance area, is the following: 30% to the oblast budget, 55% to the budgets of regions and towns of oblast subordination, 15% to the budgets of satellite towns. Usage of these budgets is implemented exclusively in the areas and order established by the Cabinet of Ministers of Ukraine.

The subvention is allocated primary for:

- construction, reconstruction, overhaul and periodic maintenance of the facilities of specific social infrastructure and civil protection installations;
- purchase of respiratory protection equipment and stable iodine medication;
- public training on how to use these means and civil protection installations.

Control of the targeted use of the budget by the local government and municipal authorities is implemented in accordance with the law.

Taking into account the size of subventions for the social and economic compensation of the risk to the population of the surveillance zone, Rivne NPP is the main budget formation entity in the region of its location, which promotes stable economic development.

In 2017, the government allocated more than 32 mln hrivnas (uah) of the state subvention for financing of the activities on social and economic compensation of the risk to the population of the surveillance zone. The subvention breakdown among the local budgets in 2017 was the following:

- Rivne oblast (regional contribution) – 7 mln. 18.3 thousand uah;
- Volyn oblast (regional contribution) – 2 mln. 757.9 thousand uah;
- Manevets region (Volyn oblast) – 7 mln. 227.6 thousand uah;
- Volodymyrets region (Rivne oblast) – 9 mln. 895,9 thousand uah;
- Sarny region (Rivne oblast) – 646 thousand uah;
- Kostopil region (Rivne oblast) – 153.6 thousand uah;
- Town of Varash (Rivne oblast) – 4 mln. 888.1 thousand uah.

1.9.4 Protective activities

Protective activities related to radioactive releases.

Prevention and mitigation of the radioactive release impact is ensured by the following Technical Solutions:

- purification of air that contains radioactive substances using filters;
- absorption and filtration of gases that contain radioactive components, most of which are isotopes of inert noble gases (xenon and krypton);
- installation of barriers on the way of radioactive materials spreading;
- usage of close-cycle circuits in order to prevent leakages of liquid substances that contain radioactive components;
- arrangement of special collection and storage system for SRW and LRW;
- establishment of CA and OZ;
- continuous monitoring of the releases into air, as well as level of radioactive contamination of soils and water in CA and OZ.

Protective activities related to non-radioactive impact.

To ensure stable operation of the power units of Rivne NPP, the following organizational activities are implemented:

- hydrological station is commissioned at the Styr River in the town Varash (down the river stream between the water intake and water discharge from Rivne NPP);
- parameter chart of power unit operation is developed, which takes into account condition of the Styr River;
- lightening is performed for 100% of added water used for feeding of the reverse water systems at the added water purification facility (AWPF);
- minimum sanitary consumption of water from the Styr River is ensured during low water months of the year;
- instrumental measurements are conducted by the certified laboratory: industrial releases into the atmosphere from the plant sources; reverse and surface waters; soils, ground waters and atmospheric air in the area of extracted waste location. The results are recorded in the primary accounting information documents;
- handover of dangerous waste is conducted, as well as realization of the secondary material;
- insurance of civil liability of Rivne NPP is provided in case of emergencies of ecological nature and insurance of transportation of hazardous cargo;
- primary accounting of releases, consumed water, waste is implemented by the plant’s subdivisions, reports on environmental protection are prepared by Rivne NPP, NNEGC Energoatom are and submitted to the Tax Administration, and State Statistics, Control and Oversight Authorities;
- maintenance, repair and reconstruction of the production funds intended for nature protection purposes are conducted;
- in-company monitoring is conducted, including instrumental and laboratory-based monitoring, as well as verifications conducted by regulatory authorities with regard to meeting of the nature protection legislation by Rivne NPP;
- ecological tax is calculated and paid, as well as rental payments for natural resoures (water) use are made.

The planned nature protection activities are accomplished within the established dates, the system of continuous progress control is established. The production activity of Rivne NPP does not cause any environmental changes, which would evidence worsening of the environment state.

1.9.5 Radiation monitoring of the environment

In 1978, two years prior to commissioning of the power unit of Rivne NPP, the external radiation monitoring laboratory was established at the plant with the main function of identification of radiation impact from plant operation on the population and environment. In 2001, the laboratory of automated radiation monitoring system (ARMS) was established.

Radiation monitoring is implemented in accordance with “Technical Specification on Radiation Monitoring” 132-1-Р-ЦРБ, agreed with the Main State sanitary doctor of the facility and State Nuclear Regulatory Inspectorate of Ukraine. According to the Technical Specification, about 2500 environmental samples in the territory of Rivne NPP location are taken and measured.

The monitoring process comprises monitoring of radioactive releases into the atmosphere, monitoring of atmospheric air, precipitations, flora, pine-needle, soil, agricultural products, dose rates, liquid effluents, water, bottom deposits, fish and weeds of the Styr River. In general, the radiation monitoring covers 43 out of 110 settlements of OZ of Rivne NPP.

The normative document NRBU-97 specifies the dose limits for the personnel that works with the sources of ionizing radiation (Category A for exposed persons) and population (Category B).

A dose limit is the main radiation and health-related standard, which aims at limitation of radiation influence on the personnel and population from all industrial ionizing radiation sources (IRS) in the situations of practical activity. The dose limit for industrial IRS is 1 mZv/year for the population, whish is several times less than radiation dose from the natural sources. The quota of 8% was set for NPP from this limit to fulfill operation of all power units, independent from their number.

Regulation and monitoring of the Category B exposure is conducted upon calculations of the annual radiation effective dose for the critical groups. The critical group is a population group, which can obtain the highest levels of radiation from the source based on their age and gender, social and professional conditions, place of living and other indicators.

Limitation of the Category B exposure is accomplished through regulation and control of the activity of environmental objects (water, air), gas and aerosol releases and liquid effluents during plant operation. For gaseous and aerosol releases and liquid effluents, the allowed radiation levels are established. At these levels, the total annual effective dose of a critical group representative, with regard to all radionuclides present in the releases and effluents, does not exceed the quota for the dose limit. The established levels are reviewed and agreed on a regular basis with the Ministry of Health Protection of Ukraine.

In order to reduce the personnel and population exposure limit below the dose limits, based on the actual achieved radiation adequacy level, the plant introduced the radiation monitoring levels. The monitoring levels are defined based on the analysis of actual releases and effluents for the last five years.

For the prompt response to the changed release and effluent activity, the operator NNEGC Energoatom introduced the additional indicators – administrative technological release levels. The release levels are defined for each power unit during at-power operation and during maintenance activities.

During operation, the plant conducts continuous monitoring of non-exceedance of administrative technological, reference and allowed levels of releases and effluents from Rivne NPP, as well as analysis of the manmade radionuclides activity in comparison with the values of “zero” background.

From 2000, the laboratory of external radiation monitoring was certified to conduct activities in the field of radiation monitoring of the environment. The next certification was performed in 2015. The certification covered verification of legitimacy and adequacy of equipment and methodological support; amount and qualification of the personnel, equipping of the working places, their compliance with the sanitary norms. The laboratory is equipped with the state-of-the-art measuring equipment by the advanced world manufactures. The work of the laboratory is subject to the regular inspections with participation of the representatives of the State Inspectorate for Technical Regulation and Consumer Policy (Derzhspozhivstandard) of Ukraine, State Oblast Administration for Ecology.

In addition to monitoring of the environmental radiation impact from Rivne NPP, the continuous monitoring is performed from April 2007 using automated radiation monitoring system (ARMS).

ARMS includes:

- 16 control and monitoring stations on the territory of Rivne NPP site:
  - ✓ 6 stations of gas and aerosol release monitoring, conduct measurements of the dose rate in the ventilation stacks; concentration of radioactive inert gases, iodine, aerosols; conduct sampling to determine tritium concentration in the releases;
  - ✓ 2 stations on the territory of the plant site, conduct measurement of the dose rate, iodine and aerosol concentration in the atmospheric air;

- ✓ 7 stations located on the roofs of main buildings of the site, conduct measurement of the dose rate.

- 13 stations of the territory of CA and OZ, conduct measurements of:
  - ✓ dose rate;
  - ✓ iodine and aerosol concentration in the atmospheric air during an emergency situation;
  - ✓ sampling of aerosols and atmospheric air, precipitations for lab monitoring;
  - ✓ ^{137}Cs, ^{60}Co activity in the stormwater sewage system, volume of discharged water, sampling of water to determine tritium concentration.

The ARMS system also includes two mobile monitoring stations, which conduct a complex of measurements similar to the scope of stationary monitoring stations. The stations are equipped with the additional equipment for identification of locations, carrying out of γ-spectrometry measurements, identification of meteorological parameters, sampling of the environment.

The mobile stations are equipped with the devices for information transfer via the satellite communication channels and mobile operator networks.

With the help of four meteorological complexes, more than 50 meteorological parameters are defined in the near-surface layer of the atmosphere, and meterological parameters are identified at the elevation up to 3000 m.

Radiation and meteorological information is used in the program complexes for calculation of the population doses from the actual releases and effluents (RNPP Doses) and doses for all settlements of observation zone in case of emergency situations. The program complexes are developed by “Institute of Radiation Protection” of the Academy of Technological Sciences of Ukraine.

The calculation methods are agreed with the Ministry of Health Protection of Ukraine. From 2017, the European system for forecasting of the radiation accident consequences RODOS is in place.

Information on the radiation and meteorological situation, in the real-time mode, is available for the personnel of Rivne NPP. It is also provided together with the technological parameters of Rivne NPP into the Crisis Centre of NNEGC Energoatom, Crisis Centre of State Nuclear Regulatory Inspectorate of Ukraine, Rivne State Administration, Oblast Administration of the State Emergencies Service.

The systematic measurements of radioactive material concentration in the atmospheric air, soil, flora and food in the controlled area and surveillance zone, confirm absence of significant impact of Rivne NPP on the population and environment.

During the entire period of NPP operation, the content of radionuclides in the air of Rivne NPP’s observation zone was at the level of annual average concentration, peculiar for the pre-commissioning period.

The indications of γ-radiation level in the surrounding settlements did not change after commissioning of Rivne NPP. And, it is not possible to point out the radiation impact of Rivne NPP, in comparison to the natural background, even with the help of state-of-the-art measuring equipment.

Information on correlation of release activity and allowed values, established by the Ministry of Health Protection of Ukraine is presented in the diagram below (Fig. 1.6)

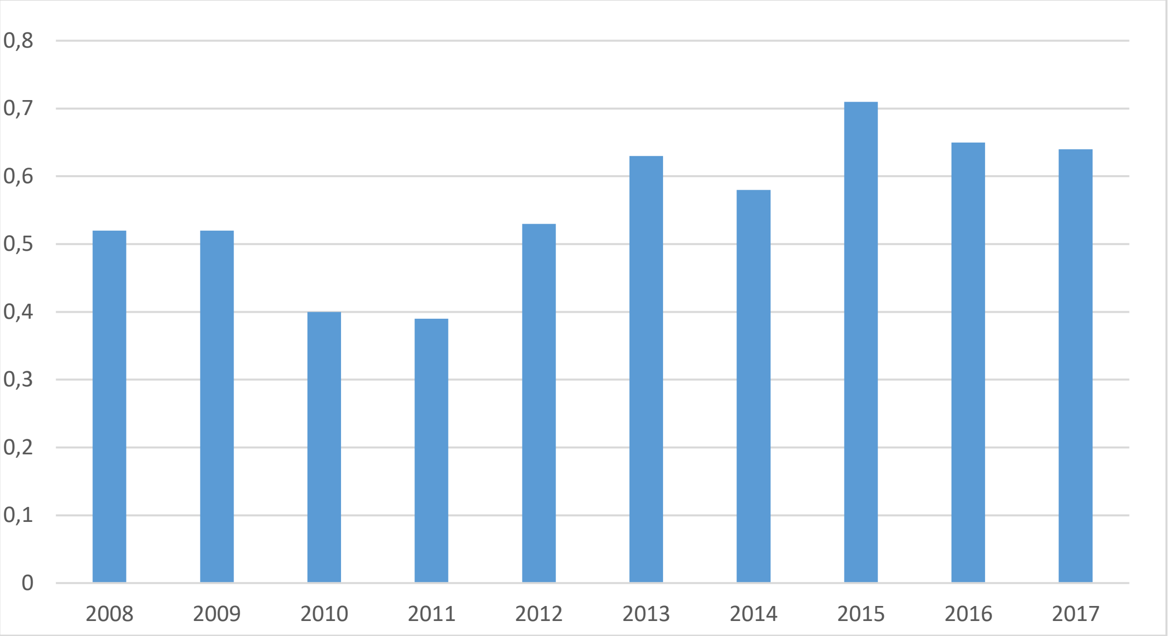

Fig. 1.6. Index of gaseous and aerosol releases of Rivne NPP as related to the allowed release.

The main indicator, which characterizes the plant impact on the population of the observation zone is a maximum possible dose on the border of CA (dose for the population critical group). The normative document NRBU-97 specifies the quota at the level of 80 mcZv/year – a limit of the yearly population radiation dose from the NPP release and effluents.

From January 2006, the plant applies a program on dose monitoring complex for the population critical groups, which is intended for calculation of the radiation dose, formed by actual gaseous and aerosol releases and liquid effluents on the CA border during a calendar year.

The calculation methodology is agreed with the Ministry of Health Protection of Ukraine. The calculation results, presented in the diagram (Fig. 1.7), show that the actual radiation impact of RNPP on the population for the last ten years did not exceed 0.5% from the quota of the dose limit, specified in NRBU-97, and is hundred of times less than the radiation from the natural sources.

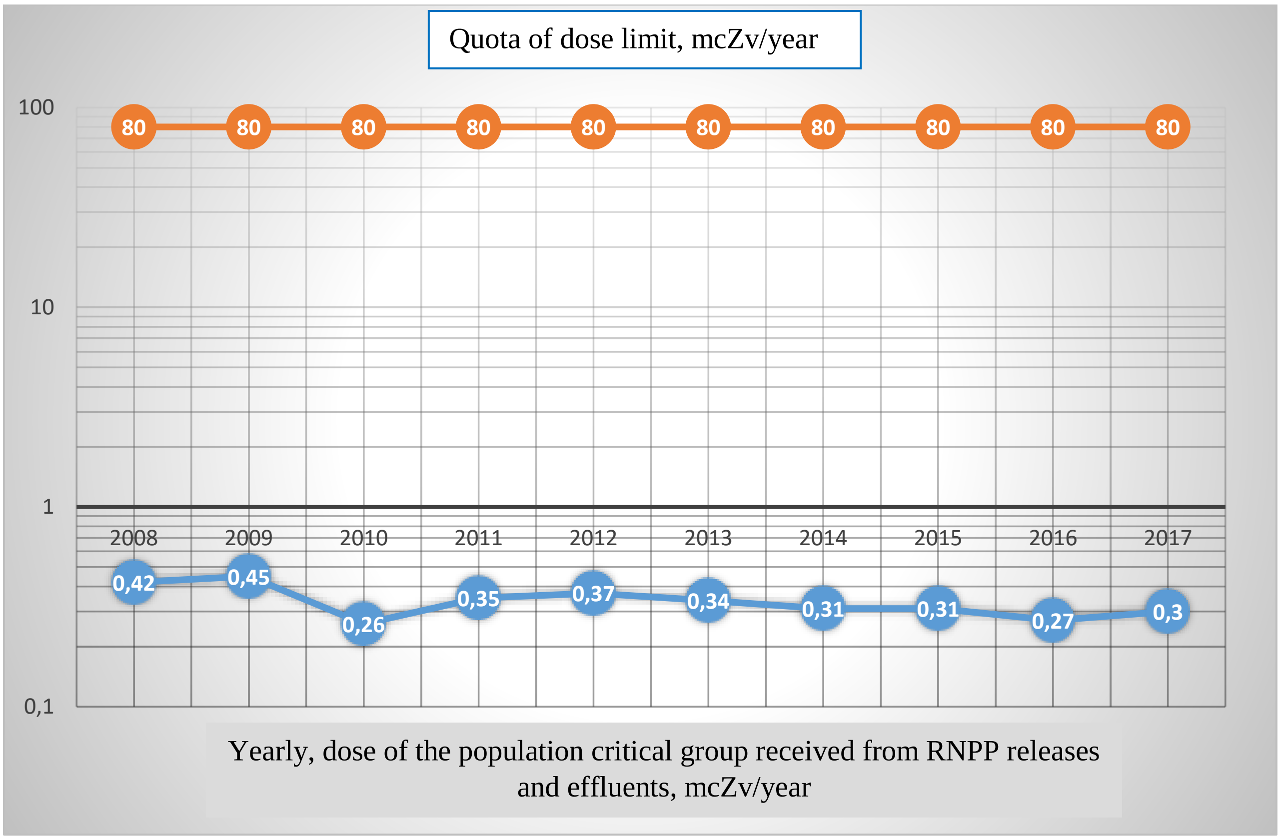

Fig. 1.7. Comparative characteristics of the quota of dose limit and dose of the population critical group from the releases and effluents of Rivne NPP, mcZv/year

1.9.6 Analysis of events based on INES scale

The international scale of nuclear and radiation events INES (International Nuclear Event Scale) is used to provide information to the public about the safety significance of events involving radiation sources.

The INES rates the events as “accidents”, “incidents” and “anomalies”. The events without safety significance are rated as “below scale/level 0 events”. The general criteria applied for classification of events as per INES scale are presented in Table 1.10.

In terms of impact, the events are divided into three different classes: impact on people and the environment; impact on radiological barriers and control; impact on defense in depth.

The radiological purpose is not to exceed the limits established by the sanitary norms with regard to radiation impact on the personnel, population and environment during normal plant operation and design-basis accidents. With that, the conditions should be ensured to keep the indicated radiation impact at the minimum possible level considering the economic and social factors.

Defense in depth is a number of consequent physical barriers on the way of radioactive material and ionizing radiation spreading, in conjunction with the technical means and organizational activities aimed at prevention of deviation from the normal operation conditions, prevention of accidents and limitation of their consequences.

Table 1.10. General criteria of events rating as per INES scale.

Event description and INES level	People and environment	Radiological barriers and control	Defense in depth
Major accident Level 7	Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.		
Serious accident Level 6	Significant release of radioactive material likely to require implementation of planned countermeasures.		
Accident with wider consequences Level 5	Limited release of radioactive material likely to require implementation of some planned countermeasures. Several deaths from radiation.	Severe damage to reactor core. Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.	
Accident with local consequences Level 4	Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. At least one death from radiation.	Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.	
Serious incident Level 3	Exposure in excess of ten times the statutory annual limit for workers. Non-lethal deterministic health effect (e.g., burns) from radiation.	Exposure rates of more than 1 Sv/h in an operating area. Severe contamination in an area not expected by design, with a low probability of significant public exposure.	Near-accident at a nuclear power plant with no safety provisions remaining. Lost or stolen highly radioactive sealed source. Misdelivered highly radioactive sealed source without adequate procedures in place to handle it.
Incident Level 2	Exposure of a member of the public in excess of 10 mSv.	Radiation levels in an operating area of more than 50 mSv/h.	Significant failures in safety provisions but with no actual consequences.

	Exposure of a worker in excess of the statutory annual limits.	Significant contamination within the facility into an area not expected by design.	Found highly radioactive sealed orphan source, device or transport package with safety provisions intact. Inadequate packaging of a highly radioactive sealed source.
Anomaly Level 1			Overexposure of a member of the public in excess of statutory annual limits. Minor problems with safety components with significant defence-in-depth remaining. Low activity lost or stolen radioactive source, device or transport package.
	No safety significance (below scale/level 0)		

1.10 Possible emergency situations

Nuclear power industry makes quite an insignificant input into changing of radiation background of the environment during normal operation of power units. An NPP is just a part of nuclear fuel cycle, which starts from mining and enrichment of uranium ore.

An accident that may occur at the nuclear power plant can result in the releases of a large amount of radionuclides into the atmosphere. There can be accidents with local contamination only of the technological rooms. There can be also accidents accompanied with releases of the radioactive substances into the atmosphere in the amount exceeding the statutory limits. The biggest danger is represented by the releases into the atmosphere.

At Rivne NPP, possible accidents and emergencies are divided into:

- general emergency (“communal”) – a radiation accident at the plant, which leads to the consequences not limited by the plant rooms and plant site, but spread over the adjacent territory, where people live. When this type of an emergency is announced, measures must be taken immediately on minimization of accident consequences and protection of the personnel and population;

- site area emergency – a radiation accident at the plant, which leads to the significantly reduced protection of the personnel and public, who were near the plant. When this type of an emergency is announced, measures must be taken immediately on minimization of accident consequences, protection of personnel and preparation of activities on protection of the population and territories outside the plant site, if required;

- “industrial” emergency – a radiation accident at the plant with the forecasted consequences that cannot not spread outside the territory of production facilities and plant site, and the personnel can be only exposed. When this type of an emergency is announced, measures must be taken immediately on minimization of accident consequences and protection of the personnel;

- emergency preparedness – a dangerous event at the plant associated with the significant or non-identified reduction of protection level of the personnel or population. When this type of an accident is announced, measures must be taken immediately on evaluation and minimization of dangerous event consequences, increase the level of preparedness on the site and level of the preparedness of organizations responsible for response actions outside the plant site.

When the plant announces emergency preparedness, industrial emergency, site area emergency or general emergency (“communal”), the Emergency response Plan (ERP) is initiated in the relevant functioning mode: emergency preparedness, industrial emergency, site area emergency, general emergency.

Analysis of the design-basis accidents (DBA) and beyond design-basis accidents (BDBA) at Rivne NPP is accomplished in accordance with the requirements of RD-95 “Regulatory document. Requirements on the content of safety analysis report for operating nuclear power plants with VVER reactor type in Ukraine” [15].

Based on the DBA analysis results, it was confirmed that the main safety principles, introduced in the plant and plant systems design, are met with consideration of the nuclear safety requirements, which relate to the reactor and reactor safety systems, and normal operation systems.

Based on the BDBA analysis results, the methods for prevention of severe core damage for each BDBA were identified, i.e. the operator actions, targeted at placing the reactor into safe end state, were defined.

During the DBA and BDBA analyses, the values of equivalent individual dose were determined, which were calculated for the worst weather conditions at the plant territory, on the border of CA and beyond the border. And it was shown that these values do not exceed the criteria specified in the normative document НРБУ-97/Д-2000 [16].

To analyze the radiation consequences of the design-basis accident at Rivne NPP, the following initiating events were considered:

- maximum design-basis accident (MDBA) – an accident caused by the double-ended break of one out of the four pipelines of the reactor cooling system (loss of coolant accident) at the nominal power level;
- primary-to-secondary leak – an accident caused by the steam generator collector head rupture (loss of coolant accident) at the nominal power level;
- accidents caused by the leaks in the spend fuel pool (accidents during transportation or process operations with the fuel);
- accidents caused by dropping of the fuel assembly into the fresh fuel pool (accidents during transportation or process operations with the fuel);
- accidents caused by dropping of hydraulic gate into the spent fuel pool (accidents during transportation or process operations with the fuel);
- accidents during radioactive waste handling.

Analysis of the radiation consequences during the beyond design-basis accidents was performed during BDBA materials update in the framework of the periodic safety review and during development of the severe accident guidelines.

During development of the severe accident guidelines, analysis of the radiation consequences was performed for the following severe accidents:

- Loss of coolant accident (LOCA), Dn2×850 mm, with combination of loss of all ac power;
- LOCA, Dn×850 mm, with combination of loss of all ac power , not considering the “failure” of ionizing chambers with filtered releases from the containment;
- Loss of all ac power;
- Primary-to-secondary leak, Dn2×13 mm, with combination of loss of all 6kV busses of emergency power supply system;

- Primary-to-secondary leak, Dn100 mm, with loss of all 6kV busses of emergency power supply system.

Besides, clarification of the observation zone was made for Rivne NPP as per “Requirements to determination of the observation zone size and boundaries of Rivne NPP” in case of occurrence of the maximum accident release.

The results of this clarification confirm that the primarily designed surveillance size of 30 km is adequate.

The plant safety is ensured by consequent use of the physical barriers on the way of ionizing radiation and radioactive materials release into the atmosphere, use of the systems of technical and organizational measures aimed to protection of the barriers and preserving of their effectiveness for the purpose of protection of the personnel, population and environment.

During plant operation, the integrity of barriers is controlled on the entire way of radioactive materials spreading. Under the normal operation conditions, all barriers and means of their protection are in the operable state. In case of identified inoperability of any of the designed barriers or means of its protection, the at-power plant operation is forbidden in accordance with the safe operation conditions.

The plant applies the following basic safety principles:

- establishment of the physical barriers on the way of radioactive material release (fuel matrix, fuel element cladding, reactor coolant boundaries, containment of the reactor facility, biological shielding);
- availability of special safety systems, which are designed on the principle of parallel trains that perform one and the same function;
- introduction of the principles of independence, redundancy, physical division and consideration of every incident during establishment of the safety system;
- high technical characteristics of localization system that prevents of radioactive releases into the environment;
- high level of process control and automation system, including elimination of emergencies during the most responsible phase (primary) of the accident without personnel actions;
- safety provision under the conditions of external impacts, specific for the sites under consideration, including natural and manmade impacts;
- safety provision for the wide spectrum of initiating events with consideration of postulated possible personnel errors and additional impacts;
- application of the conservative approach to selection of the technical solutions that influence the safety;
- introduction of measures and technical solutions aimed at protection of the localization systems during design-basis accidents; prevention of the initiating event transition into the design-basis accident, mitigation of accident consequences which were not prevented.
- possibility to verify and test the safety related equipment and systems to maintain them in the operable state;
- arrangement of the controlled area and surveillance zone;
- ensure the quality as per requirements of relevant regulatory documentation.

The system of technical and organizational activities, implemented in the plant design, has five levels:

Level 1: Establishment of conditions that prevent violation of plant normal operation;

Level 2: Prevention of design-basis accidents using normal operation systems;

Level 3: Prevention of accidents using safety systems;

Level 4: Management of beyond design-basis accidents;

Level 5: Planning of activities for personnel and public protection.

The plant design includes the following basic safety principles:

- establishment of the physical barriers on the way of radioactive material release (fuel matrix, fuel element cladding, reactor coolant boundaries, containment of the reactor facility, biological shielding);
- availability of special safety systems, which are designed on the principle of parallel trains that perform one and the same function;
- introduction of the principles of independence, redundancy, physical division and consideration of every incident during establishment of the safety system;
- high technical characteristics of localization system that prevents of radioactive releases into the environment;
- high level of process control and automation system, including elimination of emergencies during the most responsible phase (primary) of the accident without personnel actions;
- safety provision under the conditions of external impacts, specific for the sites under consideration, including natural and manmade impacts
- application of the conservative approach to selection of the technical solutions that influence the safety;
- introduction of measures and technical solutions aimed at:
  - protection of the isolation systems during design-basis accidents;
  - prevention of the initiating event transition into the design-basis accident;
  - mititgation of accident consequences which were not prevented;
- possibility to verify and test the safety related equipment and systems to maintain them in the operable state;
- arrangement of the controlled area and surveillance zone;
- ensure the quality as per requirements of the relevant regulatory documentation.

In accordance with the requirements of the document “НП 306.2.141-2008. General safety provisions for nuclear power plants” [18], Rivne NPP developed the emergency plan [19]. The plan was approved by the General Director of Rivne NPP and put into force with the Order No2059 as of 03.12.2013. The emergency plan contains the organizational structure of Rivne NPP, distribution of responsibility regarding emergency response, list of means applied for emergency response, list of external organizations involved in the emergency response, the plan defines the list and procedure for emergency response activities at the site of Rivne NPP and in CA.

The activities accomplished by the plant, except for the public and environment protection activities, are bounded by the NPP site and CA. The activities on public and environment protection implemented by the NPP are bounded by the surveillance zone.

Rivne NPP has “Program for Improvement of Radiation Safety and Radiation Protection at SE RNPP” [20], which is accepted and in effect at the plant. The program covers main tasks of radiation safety of the personnel, population and environment. The program is intended for all subdivisions and organizations, implementing their activity at the plant, and is mandatory for execution.

Based on the results of periodic safety review by NNEGC Energoatom (stress-tests) as per “Action Plan for unscheduled target assessment and further safety improvement of Ukrainian NPPs taking into account events at Fukusima-1” [21], which was conducted at the request by the State Nuclear Regulatory Inspectorate of Ukraine and European Nuclear Safety Regulators Group (ENSREG), it was concluded that:

- design of operating Ukrainian NPPs consider all possible external extreme natural impacts. The plant safety, with all considered external extreme natural impacts in the design, is justified in the Safety Analysis Report. The results of additional reviews and walkdowns did not indicate presence of any additional factors, which influence the operability of the equipment that ensures safety of the plant;

- operating Ukrainian NPPs have a safety margin with respect to external extreme natural impact. The conducted equipment qualification confirmed that the external hazards characteristics are above the design values;

- to ensure long-term heat removal in the conditions of extreme hazards, the NPPs apply addition options of power supply in case of loss of power and implement special activities for long-term emergency heat removal.

1.11 list of other environmentally-dangerous facilities located in the area of impact of Rivne NPP

Most part of 30-km area of Rivne NPP is occupied by the territories of two regions: Manevytskiy (Volyn Oblast) and Volodymyrets (Rivne Oblast). The activity profile of the local agriculture in the regions are crop farming and livestock farming of dairy and meat production. The farm lands of both regions are located mainly on the sod-podzolic and peat-bog soils.

At average the products are sold for 18.4 milliards of hrivnas without VAT in Volyn Oblast annually (6.0 milliards of hrivnas – outside of Ukraine), including the products of processing industry sold for 15.6 milliards of hrivnas. In the total turnover, the biggest share includes production of foods, drinks, machinery (except for repair and mounting of equipment and machines), production of wood, paper goods, and polygraphic activity, supply of electricity, gas, steam and conditioning air, which was indicated in the Regional Report on the environment state in Volyn Oblast for 2015.

Reduction of volumes of the industrial production is observed in the following areas for the last few years in Volyn Oblast:

– production of chemical material and goods (-2.7%). Reduced production of paints, varnish and similar goods, other chemical goods (pastes for molding);

– metallurgical production, production of finished metal products, except for machines and equipment (-15.3%). Reduction occurred, mostly, due to reduced scope of forging, pressing, stamping, profiling, other products of primary steel treatment;

– production of food and beverage (-3.9%). Reduced scope of production of dairy goods, oil and animal fat, other food products (milk-containing products, spreads, fat blend, ketchups, sugar), bread, bakery and pastries for 51.7–7.9 %;

– production of wood goods, production of paper and polygraphic activity (-0.7%), including production of paper and cardboard goods for 22.5 %.

Increase of industrial production volume is ensured in the following areas:

– mining industry and quarry development (+13.8%);

- textile manufacture, production of clothes, leather and other materials (+14.7%). Volumes increased in the textile production – for 18.4 % and clothes production – for 17.5 %;

- machinery, except for repair and mounting of machines and equipment (+8.4%). Volume build-up occurs in the companies that produce electrical equipment, motor vehicles, trailers, semi-trailers and other transport means, and machines and equipment not related to other groups (for 15.6-0.4%).

– production of rubber and plastic goods, other non-metal mineral products (+2.2%), mainly due to increase of volumes in production of goods made of concrete, alabaster, cement, plastic goods.

In Manevytskiy region of Volyn Oblast, the observation zone contains 17 collective farms of different property forms. At present, due to changes in the property forms for lands, restructuring of the collective farms takes place. The area of bankrupted/destroyed farmlands has the tendency of reduction due to severe deficiencies in resources. Soils applied for agricultural activity are poor. Yield enhancement for several times is possible with fertilizers treatment, and funds for required agronomic measures are absent. In the area of meat and dairy productions, there is a tendency in reduction of the cattle number in the collective farms more than four times and reduction of average indicators of milk yield per one cow.

Among the Ukrainian oblasts, Rivne Oblast is specific for electricity production (20.8% of total national electricity output of the nuclear power plants), mineral fertilizers (11.4%), wood chipboard (24%), high quality plywood (63.4%), and cement (11%). In the industrial complex of Ukraine, part of the oblast makes 1.5% in the complex, which is indicated in the Report on the environment state of Rivne Oblast in 2014.

Volodymyrets region in the OZ of Rivne NPP comprises 23 collective farms, which occupy 51500 ha of agricultural lands, where about 30000 ha are croplands, cultivation area is about 18000 ha. The cattle stock was 27700 animals in 1995, 5700 animals in 1997, indicators of average milk yield reduced per one cow.

Analyzing the current status of the agriculture in the 30-km area of Rivne NPP, the conclusion can be made about the need to contribute large investments into increasing the soils fertility, improvement of food reserves and implementation of breeding activities in the livestock farming. Thus, the state of the agricultural and industrial complex depends on the state of economy in the country in general.

The industry in the 30-km area of Rivne NPP is presented with the entities of food production (bread making factories, dairy factories), construction materials, opencast mines and peat factory, motor transport companies, roads construction facilities. At a distance of 150 km to the south from the plant site, there is a section of railway main line “Kyiv-Kovel”. The nearest railway station Rafalivka is situates 5 km to the east from the plant. At the distance of about 20 km to the south from the plant site, there is an automobile road of state significance “Kyiv-Kovel”. Within the OZ of Rivne NPP there are also some gas stations, “Rafalivskiy opencast mine” for mining of sand, gravel, clay and kaolin, Polytskiy basalt opencast mine. Totally, Rivne NPP OZ incorporates 28 industrial entities: 13 in Volyn Oblast and 15 in Rivne Oblast.

The public significance facilities are concentrated mainly in the town Varash. The residential settlements in the 30 km territory (except for the town of Varash) are one- storied houses with bigger degree of deterioration. The residential housing is not provided with networks of centralized water supply, sewage systems and heating even in the regional centers (Manevychi and Volodymyrets).

The public significance facilities located in this area (except for the town Varash) do not also have engineering support.

The stationary sources of releases into the atmospheric air at RNPP are concentrated at seven production sites. The contaminant releases into the atmospheric air from the stationary sources of every site are made upon the special permissions, issued by:

- rehabilitation and recreation center “White Lake” near the village Bilska Volya of Volodymyrets region, the permission duration period is not limited;
- the car fleet of transport facility in the industrial area No2 (northern) of the town of Varash, the duration period is 5 years;
- the site of power units in the industrial area No1 (southern) of the town Varash, the duration period is 5 years;

- the vocational technical school and sport complex in the district of Peremogy, the town of Varash, the duration period is not limited;
- divisions, automatic radiation monitoring center, the cold-storage warehouse on the streets Teplychna, Rynkova, Komunalna, Energetykiv of the town Varash, the duration period is not limited;
- divisions, asphalt factory on the construction base of the town of Varash, the duration period is 10 years;
- treatment facilities of domestic sewerage division on the street Dachna of the town of Varash, the duration period is not limited.

Operation of Rivne NPP does not make a negative impact on the existing agricultural, industrial and residential facilities.

2 PRODUCTION WASTE

During the plant operation, it is inevitable to have the production waste: solid, liquid and gaseous.

Radioactive waste are the material objects and substances with the activity of radionuclides or radiation contamination exceeding the limits, established by the existing norms, with the condition that these objects and substances are not used. Radioactive waste is a special type of radioactive materials (in any physical form), in relation to which:

- it is determined that neither now or later they will be used, or
- the final decision is not yet taken with regard to how these materials can be used in the framework of modern or further developed technological processes [11]. Classification of radioactive waste is defined by the State Sanitary Rules DSP 6.177-2005-09-02 “Main sanitary rules for radiation safety of Ukraine (OSPU-2005)” [11].

Production of the electricity at the nuclear power plants comes along with generation of radioactive waste in the course of the main technological process, as well as during routine and maintenance operations. The stable development of the nuclear energy field in the country requires safe management of the radioactive waste at all phases of waste formation and existence. The radwaste management system is an important component in the entire safety systems while using nuclear energy.

The main principles of the radwaste management at the NPP is minimization of waste formation and interaction between all phases – from formation to disposal [22].

The strategy on radwaste management in Ukraine, approved by the Cabinet of Ministers of Ukraine and National Target Environmental Program for Radioactive Waste Management approved by the Law of Ukraine, specifies withdrawal and processing of radioactive waste accumulated during plant operation. It should be done through establishment of the infrastructure for radioactive waste specification, conditioning and packaging using the method applicable for its further transportation for storage and/or disposal.

Emptying of the volumes in the NPP radwaste storage facilities by reprocessing/conditioning is a required condition for lifetime extension of the plant.

Radioactive waste management at Rivne NPP is accomplished in line with:

- Law of Ukraine “On radioative Waste Management”, dated 30.06.1995 No 256/95 –BP [23];
- Law of Ukraine “On Usage of Nuclear Energy and Radiation Safety” as of 08.02.1995 No 40/95 –BP [2];
- Law of Ukraine “On National Target Environmental Program for Radioactive Waste Management” as of 17.09.2008 No516-VI [24];
- Radioactive Waste Management Strategy in Ukraine, approved by the directive of the Cabinet of Ministers of Ukraine, as of 08.2009 No516- VI [25];
- Integrated Program for Radioactive Waste Management in NNEGC Energoatom ПМ-Д.0.18.174-16, put into force with the order as of 12.10.2016 No927-р. [26]

The national regulatory authorities for radioactive waste management are the State Nuclear Regulatory Inspectorate of Ukraine and the Ministry of Health Protection of Ukraine, the national governing body is the Ministry of Energy and Coal Industry of Ukraine.

The State Special Enterprise “Central Radioactive Waste Management Enterprise” (CRWME), the storage facilities operator, within the State Agency of Ukraine on Exclusion Zone Management (SAUMEZ) is responsible for acceptance and storage (if required, long-term storage) of the conditioned radwaste. Currently, NPP radwaste shipping for the long-term storage or disposal at the facilities is not accomplished, but activities were initiated on radwaste preparation for shipping to the special enterprise.

Planning of the activities on radioactive waste management at RNPP is accomplished in accordance with “Integrated Program for Radioactive Waste Management in NNEGC Energoatom” ПМ-Д.0.18.174-16 [26]. The program specifies main areas and a list of activities related to radioactive waste management in NNEGC Energoatom. These activities are: minimization of radwaste generation, improvement of the current radwaste management systems at NPPs sites, construction of complex lines on radwaste processing for its preparation to transference to the ownership of the state, provision the plant with the equipment for radwaste storage, harmonization and improvement of the regulatory framework in the area of radwaste management.

During planning the activities in the field of radioactive waste management, NNEGC Energoatom applies the following main principles:

– ensure corresponding safety level in the field of radioactive waste management;

– minimization of generated radwaste volumes during plant operation;

– selection of optimal radwaste treatment technologies considering such factors as:

- ✓ individual and collective radiation doses of the personnel;
- ✓ cost of radwaste processing;
- ✓ amount of generated radwaste;
- ✓ duration and cost of short-term radwaste storage;
- ✓ requirements to the end product accepted for disposal;
- ✓ capability of using selected methods of radwaste processing both during plant operation and its decommissioning;

– ensure capability of processing, immobilization, and temporary storage of radwaste generated during extended lifetime of the plant;

– application of the advanced technologies during radwaste processing and immobilization to provide for radwaste safe transportation and disposal;

– ensure quality of all processes and works related to the radioactive waste management at the plant.

The main activity on improvement of the radioactive waste management system at Rivne NPP is construction of a complex for the radioactive waste processing (CRWP). The Program ПМ- Д.0.18.174-16 indicates commissioning of CRWP in 2018. A separate permission was obtained from the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) for operation of the new facility of the infrastructure - radioactive waste processing complex.

SNRIU ensured regulatory follow-up of the activity, review and agreement of the complex testing programs and corresponding technical solutions regarding putting of CRWP into trial operaiton at Rivne NPP within other process facilities:

- extraction of SRW from the SRW storage compartments;
- SRW sorting and fragmentation;
- SRW supepressing;
- SRW cementation;
- SRW activity measurement;
- metal decontamination;
- spent oil treatment.

Implementation of the radwaste complex will allow for:

- reduce the amount of accumulated SRW and waste generated during operation;

- condition the solid radioactive waste (SRW) to ensure its safe long-term storage and disposal;
- obtain additional free volumes in the existing storage facilities for the short-term storage of the containers with SRW under the ownership of the state.

Radwaste management at Rivne NPP is accomplished like at any other operating NPP in compliance with the principle flow chart presented below at Fig. 2.1.

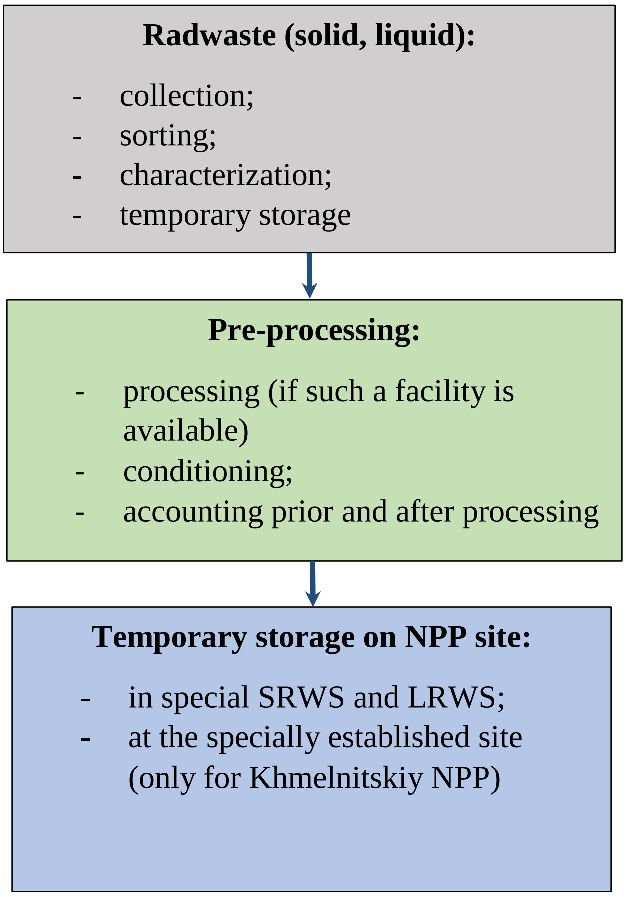

Fig. 2.1. Principal flow chart for radioactive waste management at NPP

The condition of radwaste management at Ukrainian NPPs is characterized with absence of completed technological cycle from the processing to obtaining of the end-product, acceptable for further long-term storage or disposal.

At present, due to unreadiness of the Operator of CRWME storages, which is under subordination to the State Agency of Ukraine for the of Exclusion Zone Management, with regard to receiving the NPP radwaste for its long-term storage and disposal, radwaste transfer to this specialized enterprise is not accomplished.

2.1 Solid radioactive waste management during plant operation

The solid radioactive waste (SRW) generates in the process of normal plant operation, during maintenance and repair activities and during accidents [27].

The main source of SRW generation is maintenance and repair activities at the power units, which include:

- operation of the plant components, buildings and facilities;
- reconstruction and modernization of equipment;
- decommissioning of components, including replacement of steam generators;
- decontamination of equipment, rooms, buildings and facilities of NPP;
- equipment maintenance and repair;
- activities on mounting, dismantling and replacement of thermal insulation;
- construction and reconstruction works;
- replacement of worn and spent part of equipment, consumables;
- replacement of worn work clothes, personnel protection means;
- implementation of sanitary and health protection measures in the controlled area.

The solid radioactive waste usually is:

- metal formed during replacement of the equipment and as a result of maintenance activities;
- woodware (stage, spacer, scaffolding);
- used individual protection means;
- rubber technical goods, cable products;
- filters of ventilation systems in auxiliary building and reactor hall;
- thermal insulation materials;
- construction waste (concrete chips, plaster);
- wipers, dusters;
- ash after radwaste processing at the burning facility;
- reactor internal devices and elements of reactor hall systems.

Transportation of SRW containers to the SRW storage located in the special building of Rivne NPP site is performed using special transport, as shown on Fig 2.2.

Fig.2.2. Special vehicle OT-20 on the chassis ISUZU

SRW distribution by types of treatment is presented on Fig. 2.2.

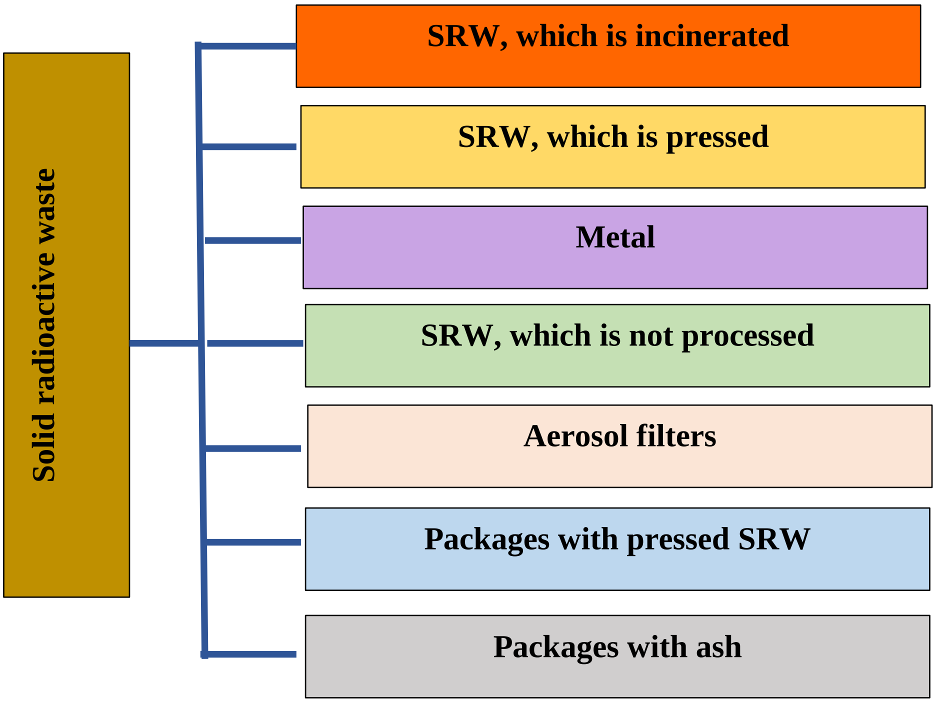

Fig.2.3. SRW distribution by types of treatment

Solid radwaste are classified by the following types:

- Short-lived ($T_{1/2}$ – to 10 years);
- Medium-lived ($T_{1/2}$ - to 100 years);
- Long-lived ($T_{1/2}$ – over 100 years).

SRW management at RNPP includes:

- waste collection into plastic bags at the places of waste formation;
- primary sorting of waste with fragmentation (is necessary);
- waste transportation from the places of temporary collection;
- SRW sorting by its activity to low-level, intermediate-level and high-level activity;
- SRW transportation by special vehicle OT-20 from the places of temporary collection into special building No2 (for power units 3, 4);
- SRW acceptance by the personnel of the decontamination and radwaste processing departments for temporary storage;
- SRW loading by the personnel of the decontamination and radwaste processing departments into cells of special building No1 of SRW storage (for power units 1, 2) and special building No2 of SRW storage (for power units 3, 4).

According to СП АС-88 [28] all SRW, sorted by types and classification, are allocated for temporary storage in the SRW storage in the special building at Rivne NPP site.

The diagram of the SRW management at Rivne NPP is provided on Fig. 2.4.

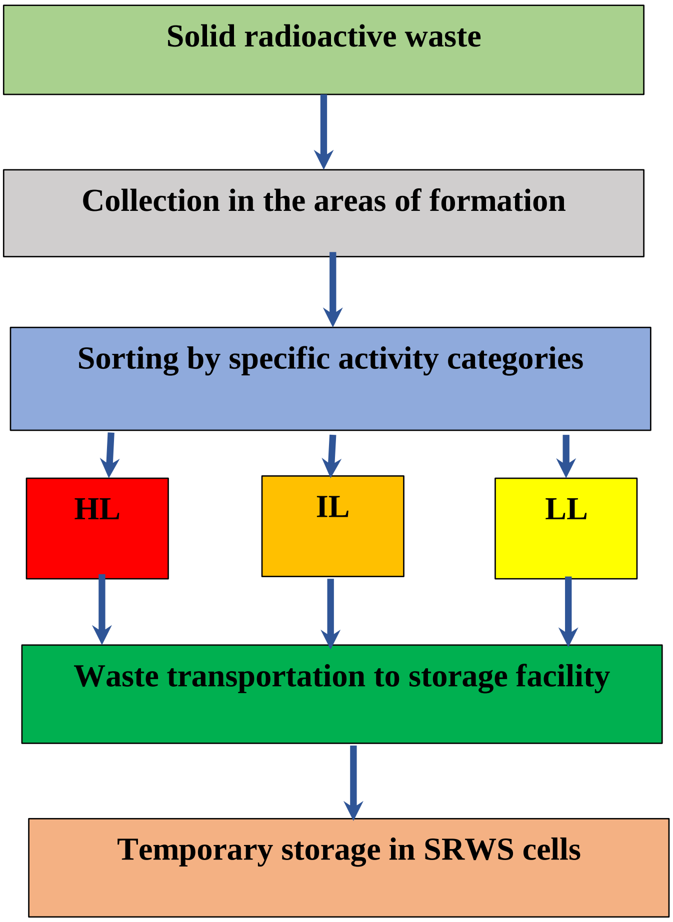

Fig.2.4. Diagram of the SRW management at Rivne NPP

According to [28] all SRW, sorted by types and classified by activity, are allocated for temporary storage in the SRW storages in the special building at Rivne NPP site.

Radwaste classification by groups, which is defined based on the extraction level, for different radionuclide groups, is presented in Table 2.1

Table 2.1. Radwaste classification by groups [11].

Radwaste group	Solid radwaste	Extraction level $kBq \times kg^{-1}$
1	Transuranium alpha-emitting radionuclides	0.1
2	Alpha-emitting radionuclides (except for transuranium radionuclides)	1
3	Beta, gamma-emitting radionuclides (except for those related to group 4)	10
4	H-3 C-14 Cl-36 Ca-45 Mn-53 Fe-55 Ni-59 Ni-63 Nb- 93m Tc-99 Cd-109 Cs-135 Pm-147 Sm-151 Tm-171 Tl-204	100

Classification of SRW categories by SRW specific level activity is provided in Table 2.2

Table 2.2. Classification of SRW categories by SRW specific level activity [11].

SRW category	Interval of values of SRW specific activity, kBq/kg			
	Group 1	Group 2	Group 3	Group 4
Low-level	$>10^{-1}<10^{1}$	$>10^{0}<10^{2}$	$>10^{1}<10^{3}$	$>10^{2}<10^{4}$
Intermediate-level	$\geq 0^{1}<10^{5}$	$\geq 10^{2}<10^{6}$	$\geq 10^{3}<10^{7}$	$\geq 10^{4}<10^{8}$
High-level	$\geq 10^{5}$	$\geq 10^{6}$	$\geq 10^{7}$	$\geq 10^{8}$

The radwaste classification with unknown radionuclide composition (URC) and unknown specific activity based on the criteria of air absorbed dose rate at the distance of 0.1 m from the surface of the object (container) is presented in Table 2.3.

Table 2.3. Radwaste classification by the criteria of air absorbed dose rate [11].

SRW category		Air absorbed dose rate, mcG/year
1.	Low-level URC	>1; ≥100
2.	Intermediate-level URC	>100; ≥10000
3.	High-level URC	>10000

At the RNPP’s Complex for radioactive waste processing (CRWP), which was jointly constructed with the European Commission under the framework of TACIS International Technical Assistance Program, the first phase of complex testing has been completed. Next in turn is the second phase, so called “hot” tests with the actual radioactive waste. The successful completion of these tests will become the beginning of operation of the first radwaste processing complex at the operating nuclear power plants of Ukraine.

This complex consists of seven installations. Four of them: extraction (ONET, France); SRD sorting and fragmentation (Nukem, Germany); superpressing Megane 15 (Nukem, Germany) and activity measurement HS 541 (Envinet, Check Republic) were provided within the TACIS project. The rest three installations: cementing (Envitek, Ukraine), oil purification and metal decontamination (Consortium Specenergetikos, Lithuania-Ukraine) were implemented by NNEGC Energoatom’s funds. In May, “cold” tests were successfully conducted on the radwaste simulators at CRWP.

Fig.2.5. Exterior of CRWP building

Implementation of the CRWP will increase the safety level at Rivne NPP by application of the advanced innovative technologies on radioactive waste treatment, thus promoting the radwaste management system of Rivne NPP to the new, modern international level.

Fig.2.6. CRWP equipment

In February of this year, the first stage of complex (“cold”) tests of the additional systems and all seven installations of CRWP were completed at Rivne NPP. The tests were conducted with participation of the plant personnel and representatives of the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU). The testing results were documented in the report, which was submitted to the SNRIU. In addition, the Special Permit was obtained for the second phase of “hot” tests.

The successful results of “hot” tests will transfer the facility gradually to the commercial operation. “The complex is intended for processing of “historical” low-level radwaste, which accumulated in the solid radwaste storage at the Rivne NPP site”, the current waste, which formed during plant operation and the waste, which will accumulate during decommissioning of the power units of the NPP. The end product of processing will comply with the requirements of waste acceptance for disposal at the special radwaste treatment facilities.

Before the radioactive waste was shipped to the CRWP, the Rivne NPP personnel and guests had a chance to see the unique installation, its process line, obtain answers from the experts who will further operate the equipment of the radwaste processing complex.

The modern process equipment meets the high European standards. The activity implemented at CRWP of Rivne NPP will allow not only reduce the volumes of waste generated during plant operation but also increase safety and environmental compatibility of the nuclear power industry in general and preserve the environment.

The permission was issued on June 1, 2018 with duration period until the end of the lifetime of “Power Unit 4 of Rivne NPP”. The decision on its issuing was taken by SNRIU based on the results of the state expert review of the safety justification documents related to implementation of the declared activity, and inspection conducted by SNRIU commission to study the capability of the operator (NNEGC Energoatom) to accomplish works related to commissioning of the Complex for radwaste processing at Rivne NPP.

2.2 Liquid radioactive waste management during operation of power units

During plant operation, the liquid radioactive waste are generated in the process systems of the reactor department and auxiliary building as a result of the contact of water with fuel elements, contamination of oil systems, and operation of special water purification systems.

LRW are mainly met in the form:

- primary coolant uncontrolled leakages;
- contaminated oils;
- spent ion-exchange resins of the SWP system;
- waters that generate after decontamination;
- sewage waters from laundry hot shower drains;
- waters from hydraulic discharge of the filters;
- bottoms/residue;
- spent filtering materials of SWP system;
- SWP sludge.

Rivne NPP operates the transport bridge, which allows transmission of the drain waters and decantate of bottoms/residue from the auxiliary building 1 into auxiliary building 2. The spent filtering materials (SFM) are transported by the hydro-transportation system into the tanks of radwaste storage (RWS), where they are stored under the layer of water.

The diagram of LRW management system is presented on Figure 2.7.

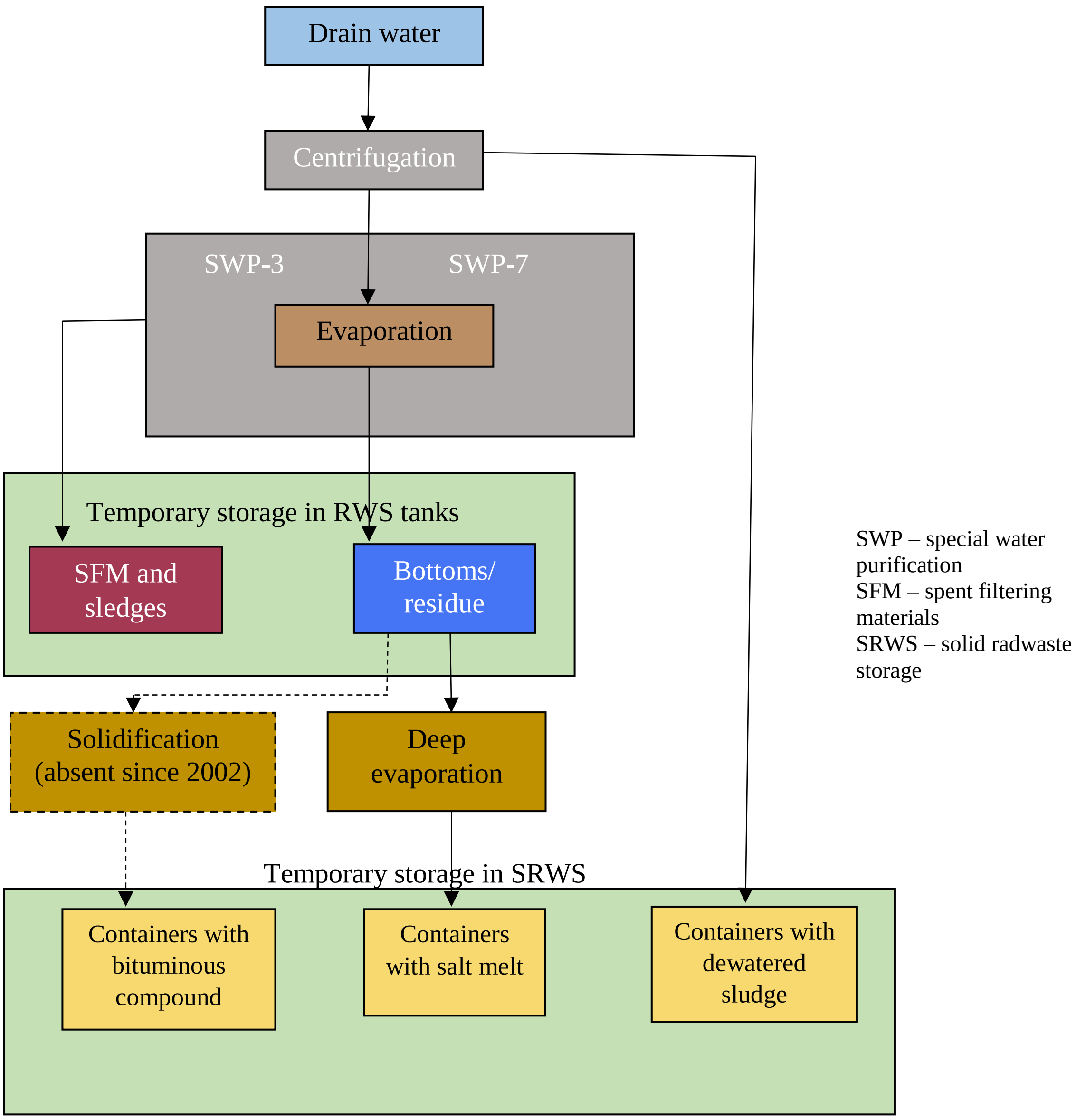

Fig.2.7. Diagram of LRW management system at Rivne NPP.

The analysis of the sources and amount of generated drains was conducted. Based on the analysis results, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, “Measures on minimization of liquid radioactive waste at Rivne NPP” were developed, which result in significant reduction of drain waters.

According to ДСП 6.177-2005-09-02 the liquid radioactive waste include:

- solutions of non-organic substances;
- pulps of filter materials;
- salt melt;
- organic liquids (oils, solvents), which have the following radiation characteristics:

- content of particular radionuclides that exceeds the allowed concentration established for water consumed by the population for drinking and household;
- content of radionuclide mixture is such that the total of ratio of specifi activity of each individual radionuclide to the corresponding value is greater than one.

Table 2.4 presents characteristics of the main types of liquid radioactive waste.

Table 2.4. Characteristics of the main types of liquid radioactive waste (LRW).

LRW characteristics	Bottoms /residue	SFM*	Sludge (in RWS)	Spent oil	Dewatered sludge	Salt melt
Mina isotopic composition	^{134}Cs, ^{137}Cs, ^{60}Co, ^{58}Co, ^{54}Mn	^{134}Cs, ^{137}Cs, ^{60}Co, ^{58}Co, ^{54}Mn	^{134}Cs, ^{137}Cs, ^{60}Co, ^{58}Co, ^{54}Mn	^{134}Cs, ^{137}Cs, ^{60}Co,	^{134}Cs, ^{137}Cs, ^{60}Co,	^{134}Cs, ^{137}Cs, ^{60}Co,
Activity category	Low and intermediate-level activity	Low and intermediate-level activity	Low and intermediate-level activity	Low-level activity	Intermediate-level activity	Intermediate-level activity
Chemical composition, g/dm³	Na^+ - 13÷89; K^+ - 1.3÷7.8; Fe^{2+}- 0.005÷0.023; NH_3 - 0.0095 ÷0.104; H_3BO_3 – 26.6÷148.4; Cl- - 0.0048÷0.55 7; NO_3- - 0.36÷ 35.9	Na+ - 0.014÷0.7; K+ - 0.001÷0.1; Fe2+ - 0.0008÷ 0.0029; NH_3 – 0.00005÷ 0.11; Cl- - 0.00004÷ 0.0285; NO_3- - 0.012÷0.8	Na+ - 0.014÷0.72; K+ - 0.001÷0.1; Fe^{2+} - 0.0008÷0.0029 NH_3 – 0.00005÷0.1; Cl- - 0.00004÷0.02 85; NO_3- - 0.012÷0.84	n/i	n/i	H_3BO_3 310; Na^+180÷220; K^+ - 55; Cl^- - 5; Fe^{3+} - 0,02; SO_4^{2-} - 25÷ 95
pH	10÷13	4÷9	4÷9	n/i	n/i	n/i
Density, kg/m³	1100-1450	990-1010	995-1005	n/i	793	2000-2100
Salt content, kg/dm³	0.2÷0.6	3.2÷7.9	3.2÷7.9	n/i	n/i	n/i

*SFM-spent filtering materials, RWS – radwaste storage, n/i – not identified

During normal plant operation, the equipment is collected and stored in the special tanks of contaminated environment (effluents) – drain waters. Radioactive liquids and drains are obtained from the equipment of the reactor departments, and are generated as a result of operation of the special water purification system (SWP), decontamination of equipment and special protection clothes, sanitary and household discharge, laboratory discharge etc.

Following the procedure of treatment and evaporation at the SWP drain water evaporators, the liquid concentrate of salts is generated – evaporator residue/bottoms. The residue is stored in the special storage of liquid radioactive waste in the metal leak-tight tanks made on corrosion resistant steel, equipped with automated system indicating the LRW level and alarm system in case of a leakage. To exclude accidental LRW leakage into the environment, all tanks are placed in the reinforced-concrete rooms, encased with the sheets made of corrosion resistant steel up to the elevation of accidental spillage of tanks.

From the RWS the residue/bottom is sent to the deep evaporation facility (DEF) for processing, where more concentrated product is formed, which is placed to the container (with volume of 200 dm^3) and it gets into a solid phase during the cooling process. The containers with the salt melt (the product of the residue processing at the deep evaporation facility) is transported for the temporary storage to the solid radioactive waste storage facility (SRWS).

The photo of 200-litre containers with the salt melt (SM) is presented on Fig. 2.8.

Fig.2.8. Containers with the salt melt

The analysis of the sources and amount of generated drains was conducted. Based on the analysis results, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, “Measures on minimization of liquid radioactive waste at Rivne NPP” were developed, which result in significant reduction of drain waters.

Centrifugation facility.

Rivne NPP operates the centrifugation facility (CF). This facility is intended for preliminary purification of drain waters from mechanic residues through centrifugation in the cycle of CWP system, as well as clearing of tanks, intended for collection and settling of drains, from accumulated sludge. The dewatered sludge, generated as a result of drains purification at the CF, is placed into the container (volume of 200 dm^3) with further transportation to SRWS for temporary storage.

Deep evaporation facility.

The solid salt concentrate is formed due to fixation of 5÷25% residual free water of the solution into crystalline hydrates with formation of salt melt (SM).

Two lines of the facility УГУ-1-500М were in operation for 2508 hours in 2015. As a result of operation of the deep evaporation facilities, in 2015 Rivne NPP processed 1084 м^3 of the residue/bottoms and obtained 480 containers (96.0 m^3) with salt melt. The total volume of residue/bottoms in RWS 1,2 was 3217 m^3 in 2015.

Rivne NPP (back in 2011) performed the activities on washing-out of SM salt deposits in the tanks ЕКО-71 (in the auxiliary building-1) and РЕКО-1 (in the auxiliary building-2). The tanks for SM storage were emptied (tank ЕНС-78 that was used as the emergency tank for acceptance of the salt melt, and tanks for storage of the salt melt ЕА-79 and ЕР-76) and their design functions were restored (decision 171-247-

ТР-ХЦ рег. ПТС №Тр-13/2011, approved on 21.01.11). Accordingly, the design volume of the tanks for SM storage reduced, and volumes of the SFM tanks increased (shown on Fig 6.2.2 – 6.2.3).

Formation of the salt melt reduced to 379 m^3 at Rivne NPP in 2015; it was 35 m^3 less compared to 2014 (414 $м^3$) and not greater than the annual controlled level of SM formation, established at Rivne NPP. Decrease of the salt melt formation was the result of:

– stopping of “double” accounting of the medias that are repeatedly processed at the evaporation facilities (residue decantate, washing-out of salts, transportation of residue/bottoms to auxiliary building-2), and that were recorded as repeatedly formed residue;

– reduction of amount of drain waters (regenerative, spray and cleaning water of SWP, special laundry water, water after purification and cleaning), which happened due to increase in control of compliance with “Norms of received drain waters, resulting from technological process, maintenance and repair activities at Rivne NPP” [29]

At Rivne NPP the amount of accumulated drain waters in 2015 at power units 1,2 was 12200.5 m^3 (10408.5 m^3 in 2014), at power units 3,4 – 11210.0 m^3 (2014 -11535 m^3), which does not exceed the control levels. Fluctuation of the amount of the received drain waters from the power units in 2015 versus 2014 is due to corresponding increase/decrease of the received spray waters and filter cleaning waters, water from the special laundries, equipment of the reactor hall, equipment decontamination, cleaning of equipment during repairs, sanitary-household discharge and cleaning of the rooms of the chemical department.

Also, in accordance with the ПМ-Д.0of “Measures on minimization of LRW generation at RNPP” the report was developed – “Report for 2013 on quantitative analysis of boron containing waters, drained into special sewerage system of Units 1, 2 from different sources.” [30]. The analysis showed that owing to the continuous control over the received drain waters in the special sewage system, as well as conducted minimization measures, the tendency of the reduced annual drain formation was observed. The biggest input into residue formation is made by the non-returnable losses of the boron acid. That is why it is necessary to consider the possibility of implementing the drain returning approach (boron-containing waters) when taking the equipment out of service with the help of the mobile drainage systems.

For purification of the technological media from the corrosion products and chemical mixtures, it SWP facilities are used, which contain ion-exchange filters. When the filters are in operation, the SFM are formed – ion exchange resins. The SFM are collected and stored in the RWS tanks under the layer of water.

Solidification facility.

At Rivne NPP the solidification facility (SF) was in operation till 2002, which was deactivated due to mounting of DEI (deep evaporation installation). At SF the residue/bottoms was evaporated in the bituminizer. Then it was added into the bitum, heated up to the specific temperature. The received processing product, a salt-bitum compound (SBC), was placed in the container and further transported to the SRWS for storage.

The solidification facility is intended for processing of the residue/bottoms. The design capacity is 150 dm^3 /hour. The principle of action of the facility is evaporation of the residue/bottoms to the state with 5% humidity with simultaneous addition of salts into the bitum matrix. The facility was deactivated on 31.12.2002, and has not been in operation since that time.

According to the classification given in ОСПУ-2005 [11], the bitum compound does not relate to LRW.

Starting from 2013, the activity started with respect to transition of containers from SBC, which are stored in the RNPP’s storage, to the CRWME for disposal.

The SNRIU, in general, agreed "Technical Solution on disposal of radioactive waste of Rivne NPP (in containers with salt-bitum compounds) at the production complex "Vector", which was prepared by the CRWME in 2014 [31].

With the Directive No60-p of NNEGC Energoatom as of 21.01.2015, the working group (WG) on the NPP Radwaste Optimization Strategy was established at the interdepartmental level. In the course of its activity, the working group developed the Extended Plan on Primary Actions for NPP Radwaste Optimization System and agreed it with NNEGC Energoatom. The action plan included activities for further treatment of the RNPP's SBC:

– analysis of the maps of SBC casks transportation and immobilization at the radwaste facilities of ChNPP and at CTRW of RNPP. As a result of the map analysis, the Technical Solution was updated with regard to shipment of Rivne NPP's SBC into Lot 3 for disposal;

– characterization of RNPP's SBC: analysis of shipment conditions for identification of the SBC radiation and chemical characteristics, preparation of the SBC characterization program, laboratory studies;

– preparation of SBC to transportation for disposal into the Lot 3 storage of CRWME: taking a decision on immobilization of casks with CBS, preparation of the Technical Specification for SBC packing, review, agreement as per the procedure and implementation of the Technical Solution on acceptance of the SBC for disposal in Lot 3 storage of CRWME. All specified activities are planned to be completed in 2018.

The bitum compound accumulated at Rivne NPP is in the amount of 147.8 m^3 (739 packages).

As of today, the complex of implemented activities include the SBC preparation to transporation to the CRWME.

The general diagram of the drain water and LRW treatment is presented on Fig. 2.9.

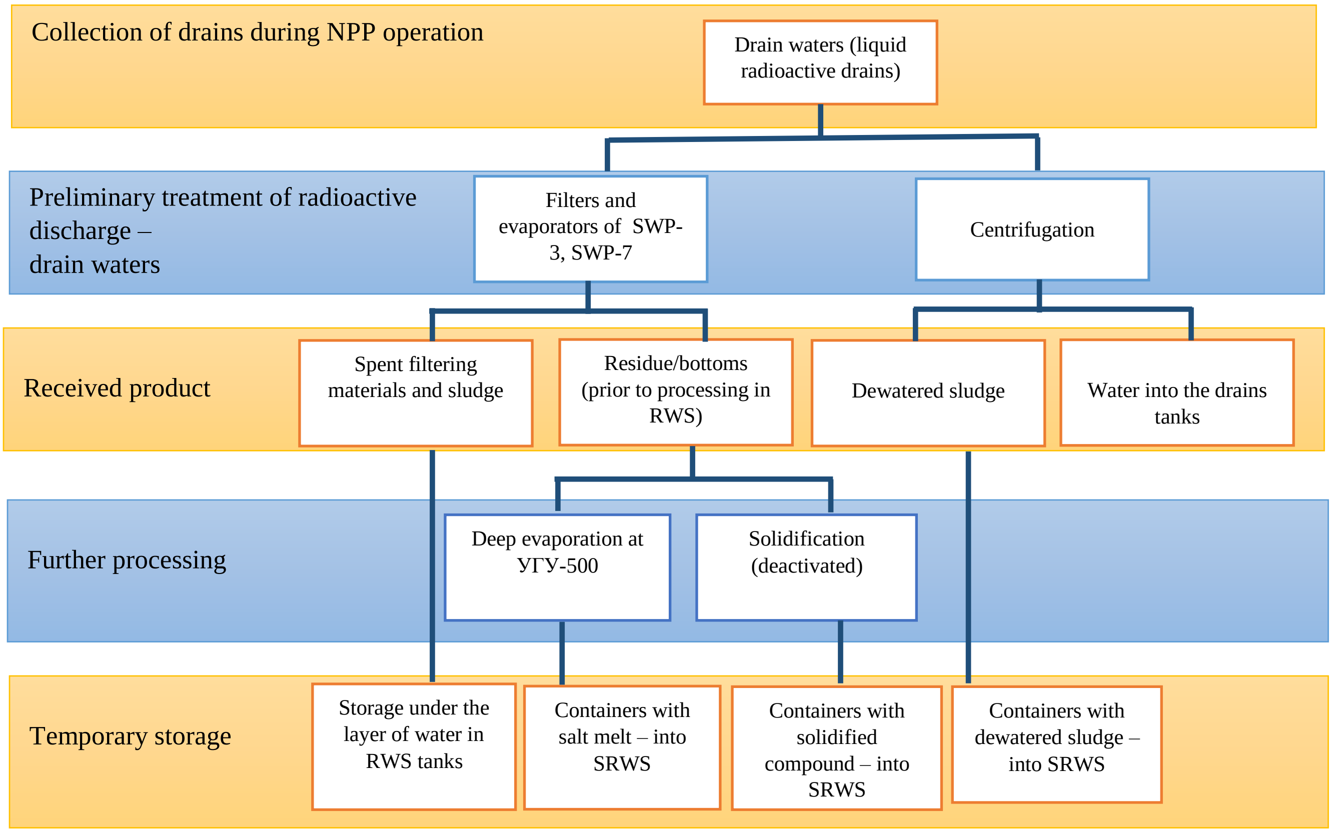

Fig.2.9. Diagram of drain waters and LRW treatment at Rivne NPP

List of available facilities/installations for LRW treatment at Rivne NPP are presented in Table 2.5.

Table 2.5. LRW treatment facilities at Rivne NPP.

Facility/installation	Main function	Design capacity
Evaporators of the drains treatment system of SWP-3, 7	Evaporation of drain waters	6 m^3/year
Deep evaporation facility (УГУ1-500М)	Deep evaporation of drain waters	500 dm^3/year
Solidification facility (with rotor film solidifier РБ-800)	Solidification of residue/bottoms	150 dm^3/year
Centrifugation facility	Purification of drain waters from mechanic residues	1.5 – 7 m^3/year

Accumulation of the liquid radioactive waste in the storage facilities at Rivne NPP as of 31.12.2017 is presented on Fig. 2.10.

During 2017, the following volumes were accumulated at Rivne NPP:
- 380 m^3 residue/bottoms;
- 3.6 m^3 of spent filtering materials;
- 5.0 m^3 of dewatered sludge (25 containers);
- 77. 6 m^3 of salt melt (388 containers).

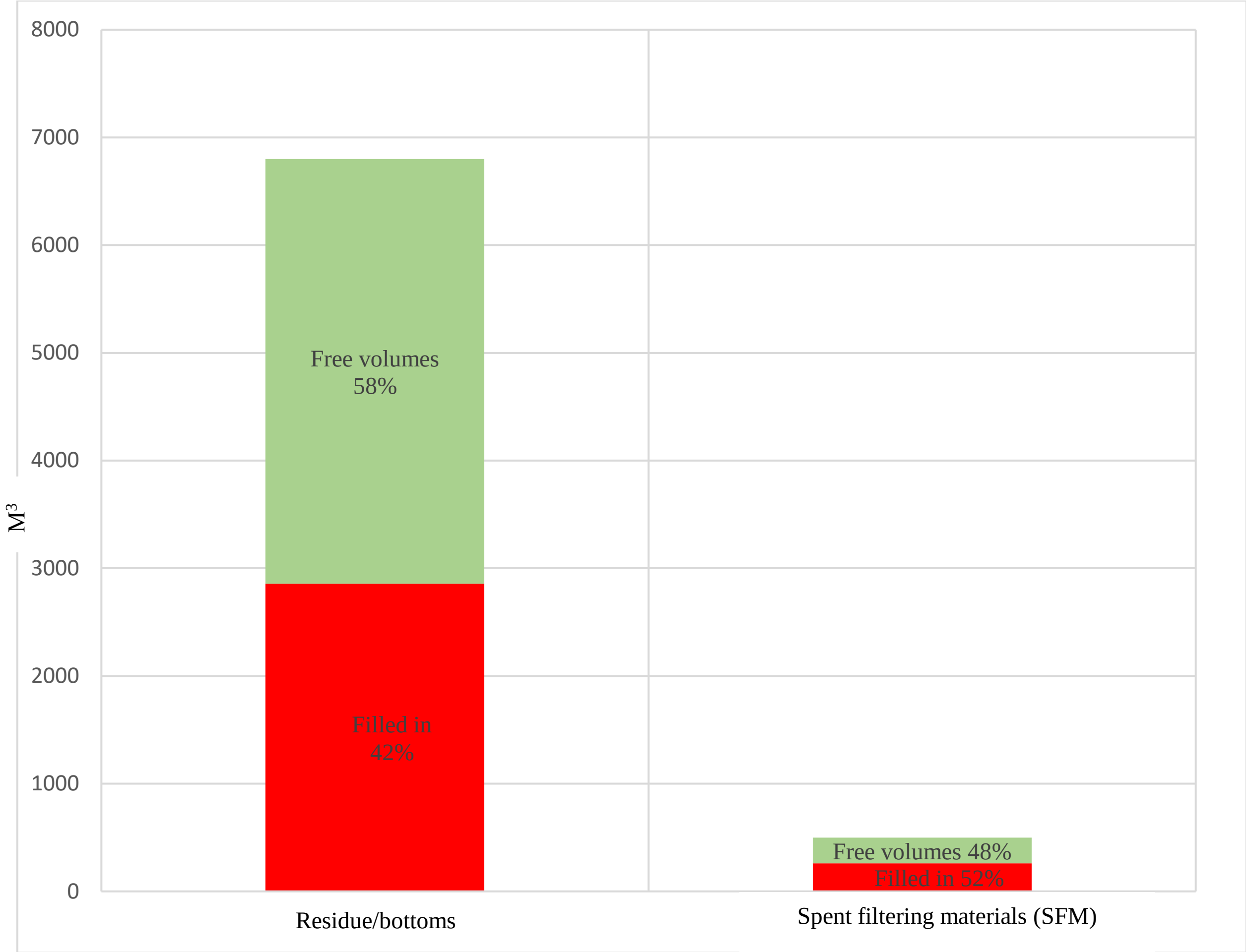

Fig. 2.10. LRW accumulation in RWS at Rivne NPP

The radioactive waste management at Ukrainian NPPs is characterized with absence of the completed technological cycle from the radwaste processing to receiving of the end-product, suitable for further long-term storage or disposal. For this reason, the interdepartmental working group was created for solving the issues on radwaste optimization strategy in Ukraine, which included the representatives from NNEGC Energoatom, NPPs, STC, SNRIU, Ministry of Energy and Coal Industry of Ukraine, KIEP, Ministry of Health Protection of Ukraine, SAUMEZ, ChNPP (Directive by NNEGC Energoatom as of 21.01.2015 No60-p. It was agreed that at the first phase of the working group's work it is reasonable to focus efforts on the improvement of the radioactive waste management system in Ukraine. To resolve the existing issues, the group developed "Extended Plan on Primary Actions for NPP Radwaste Optimization System" and got its approval on 09.03.2016. The issues related to further treatment of the SFM, salt melt, dewatered sludge are resolved with the efforts of the specified working group.

The following measures are in place: control of meeting the LRW formation and drain waters controlled levels, established in "Technical Specifications for radioactive waste formation and shipment to the storage facilities of Rivne NPP" 175-7-Р-ЦД, continuous control of LRW shipment to RWS, implementation of the minimization measures related to residue/bottoms accumulation, that reduce due to residue processing at the deep evaporation facilities. Implementation and development of the SRW management system at Rivne NPP and its detailed description is provided in Attachment C.

Having stable operation of the deep evaporation facilities and activities implemented as per the schedule of “Comprehensive program for radioactive waste management at NNEGC Energoatom” ПМ-Д.0.18.174-16 [26], there will be sufficient free volumes in the RWS to ensure safe operation of power units of Rivne NPP, both during design and extended lifetime of the plant.

2.3 Design data on formation of non-radioactive waste and waste management

The generic data on formation and placing of the non-radioactive waste at Rivne NPP for 2017 are provided in Table 2.6 [40]. The information, received from all the plant divisions with regard to volumes and types of non-radioactive waste in 2016 to be transmitted to the specialized utilization (extraction) facility, was provided to SE “Storage Facilities” (SE SF) of NNEGC Energoatom for development of the plans. Transportation of the secondary material to SE SF during the reporting period was made on the basis of “Provisions on arrangement of work with the secondary material” ПЛ-Д.045.541-15.

In 2017, the ecological and chemical laboratory of the environmental protection service of Rivne NPP (according to the registration certificate NoR-4/12-59-4 as of 11.05.2015) performed monitoring of the state of groundwaters and soils in the waste extraction locations. Monitoring was performed in line with the approved schedule of analytical control of the environmental state around the sludge collector and landfill of industrial and construction waste.

The facility has “Instruction on non-radioactive waste management at Rivne NPP” 083-1-І-СОНС. The persons, responsible for waste management issues, were designated in the order No436 as of 31.05.2017.

On a yearly basis, according to the paragraph 15 of “Procedure for keeping records on the locations of waste formation, treatment and utilization” approved by the Directive of the Cabinet of Ministers No1360 as of 31.08.1998, the information is submitted to the Rivne Oblast Administration with regard to the changes in the registration card and changes in the passports of waste extraction locations: sludge collector and landfill of industrial and construction waste.

According to the paragraph 19 of “Procedure for keeping records on the waste extraction locations” approved by the Directive of the Cabinet of Ministers No1216 as of 03.08.1998, based on the results of surveillance and control measurements, the passports of the sludge collector and landfill of industrial and construction waste are reviewed annually. To control the waste extraction location (WEL) at Rivne NPP, the State entity “Rivne Oblast Laboratory Center” of the Ministry of Health Protection of Ukraine conducted the instrumentation and laboratory measurements of the atmospheric air pollution in the third quarter of 2017 in the waste extraction locations. The analysis of water, soil and air indicators show that WEC operation is performed in accordance with the requirements of the environmental legislation and does not cause damage to the environment.

Changes in the passports are agreed with the Department of Ecology and Natural Resources of Rivne Oblast Administration, which are recorded in the relevant documentation.

Waste management is accomplished by the entity in compliance with the regulatory documents and production instructions.

In the reporting period, the solid household waste was transferred to the landfill of the municipal company of the town. During the year, in accordance with the document ПЛ-Д.0.45.551-13 “Provision on interrelation of SE “Storage Facility” with NPPs, SE “Atom Complekt”, SE “Atomproerkengineering” and In-service Inspection Department of NNEGC Energoatom”, the waste of used luminescent lamps, monitors, used batteries and tires were transmitted through SE SF to other specialized entities.

The used oils and lubricants (motor, turbine, industrial, transformer), used storage batteries, broken glass, metal scrap and waste paper (except for the technical documentation, accounting and other documents that must be destructed/shredded) were transmitted to Rivne department of SE “Storage Facility”, as secondary materials. Transmission of waste, as secondary materials, was accomplished on the basis of “Provisions on arrangement of work with the secondary material” ПЛ-Д.0.45.541-15.

Due to putting into force the law of Ukraine No1193-VII “On introducing changes into some legal acts of Ukraine regarding reduction of number of documents of permissive character” as of 09.04.2014, issuing of permits for activities and operations in the waste management field shall be accomplished in accordance with the requirements of associated Orders (Directives) following their approval by the Cabinet of Ministers of Ukraine. Currently, the corresponding Order has not been approved (clarification letter of the Department of Ecology and Natural Resources of Rivne Oblast Administration No2560/02/2-07/15 as of 09.12.2015).

Table 2.6. Non-radioactive waste formation and location at Rivne NPP

Safety class	Name and physical state of the waste	Storage location	Amount of waste as of 01.01.17	Waste formation limit	Wate movement for the reporting quarter (from the beginning of year)				
					Amount of generated waste items/tons; (beg. of year)	Amount of waste used	Waste transported to extraction place: ММВ	Waste transmitted to other pl. items/t;	Waste left as of 01.12.17
I	Luminescent lamps and waste that contain mercury, other broken or used (used materials)	Individual room at the facility territory, metal containers	0 items/ 0 т	40000/ 12.0 t	16789/ 5.037	-	-	16789/ 5.037	0
I	Leaded batteries wasted or used (used materials)	Individual rooms at the facility territory	0.641	5t	9.080	-	-	9.188	0.533
Total for Class 1:			**0.641**	**17.0**	**14.0**	**-**	**-**	**14.104**	**0.533**
II	Used transformer oils (oils)	Metal tanks	0	100	0	-	-	0	0
II	Turbine, industrial, synthetic used oils (oils)	Metal tanks	18.780	400	20,730	-	-	22.980	16.530
II	Oils and used motor lubricants (oils)	Metal tanks	34.177	40	5,526	0.362	-	-	39.341
Total for Class 2:			**52.957**	**540**	**26.256**	**0.362**	-	**22.980**	**55.871**
III	Oil sludge (sludge)	Sludge collector	12.664	20	4.324	-	4.374	0	16.988
III	Wasted filtering materials, spent or dirty (used materials)	Polygon/Landfill of Rivne NPP	20.941	8	0.530	-	0.430	0.100	21.371
III	Wasted wiping/cleaning materials, spoiled, used or dirty (solid)	Landfill of Rivne NP	15.256	7	1.134	-	1.080	0.054	16.336
III	Used absorbents (solid)	Landfill of Rivne NP	7.090	2	0.400	-	0.400	0	7.490
III	Wasted used batteries	Individual rooms at the facility territory	0		0.255	-	-	0.255	0
Total for Class 3:			**55.951**	**37**	**6.643**	**-**	**6.284**	**0.409**	**62.185**
IV	Sludge generated from water clearing (sludge)	Sludge collector	116978.920	40000	22516.85	-	22516.85	5866.0	133629.770

Safety class	Name and physical state of the waste	Storage location	Amount of waste as of 01.01.17	Waste formation limit	Wate movement for the reporting quarter (from the beginning of year)				
					Amount of generated waste items/tons; (beg. of year)	Amount of waste used	Waste transported to extraction place: MMB	Waste transmitted to other pl. items/t;	Waste left as of 01.12.17
IV	Used ion-exchange resins (solid)	Landfill of Rivne NP	197.73	120	8.000	-	8.000	-	205.730
IV	Construction waste (solid)	Landfill of Rivne NP	25667.772	5000	4190.2	-	4190.2	-	29857.972
IV	Used filtration materials (solid)	Landfill of Rivne NP	116.60	55	0	-	0	-	116.600
IV	Lime green coke (solid)	Landfill of Rivne NP	10284.66	6000	1136.340	-	1136.340	-	11421.000
IV	Waste from purification of sewage water (residue from sludge beds)	Landfill of Rivne NP	178.0	40	50.0	-	50.0	-	228.000
IV	Residues left in the process of sand extraction (solid)	Landfill of Rivne NP	19.18	30	20.5	-	20.5	-	39.680
IV	Residues from tanks (solid)	Landfill of Rivne NP	11.271	-	0	-	0	-	11.271
IV	Wood dust (solid)	Landfill of Rivne NP	5.53	50	10.58	10.580		-	5.530
IV	Used wood cases (trays, drums)	Landfill of Rivne NP	2.0	5	0.7	-	0.700	-	2.700
IV	Mixed packing materials, including wood or metal, damaged, used or dirty (solid)	Landfill of Rivne NP		-	0	-	0	-	0
	Total waste at Rivne NPP landfill (safety class 4)								
IV	Plastic small packing (PET bottle)	Dedicated places in subdivisions			0.129			0.129	0
IV	Mixture of waste, materials and products from plastic, which are not subject to special treatment (plastic waste, hats etc.)	Dedicated places in subdivisions	0.122		0.782			0.782	0
IV	Plastic packing materials (plastic barrels, boxes)	Dedicated places in subdivisions			0.165			0.165	0
IV	Waste paper and cardboard (solid)	Dedicated places in subdivisions	0	20	11.620			11.620	
IV	Damaged or used wood pieces and products made of wood (lump waste)	Dedicated places in subdivisions	0	300	16.277			11.219	5.058
IV	Clinker (solid)	Dedicated places in subdivisions	6.316	5	0.232	0.232			6.316
IV	Other equipment (including for scientific studies, polygraphic,	Dedicated places in subdivisions	0	-	0,052			0.052	0

Safety class	Name and physical state of the waste	Storage location	Amount of waste as of 01.01.17	Waste formation limit	Wate movement for the reporting quarter (from the beginning of year)				
					Amount of generated waste items/tons; (beg. of year)	Amount of waste used	Waste transported to extraction place: MMB	Waste transmitted to other pl. items/t;	Waste left as of 01.12.17
	office), damaged, used or not repairable								
IV	Damaged, used, dirty tires (solid)	Storage - hangar	0.015	30	5.849			5.854	0.010
IV	Broken glass (solid)	SF metal containers	0	35	9.800			9.701	0.099
IV	Municipal (mixed) waste, including waste from litter-boxes (solid)	Landfill of household waste of the town	0	1000	529.460			529.460	0
Total for Class 4:			**153468**	**52699**	**28502.8**	**10.8**	**25996.0**	**6428**	**175532**

The dynamics of the non-radioactive waste accumulation in the sludge collector and polygon/landfill of Rivne NPP is presented in Table 2.7.

Table 2.7. Dynamics of the non-radioactive waste accumulation in the sludge collector and polygon/landfill of Rivne NPP

	2011	2012	2013	2014	2015	2016	2017
Sludge collector, thous. tons	139.154	161.746	184.227	161.683	132.664	116.978	133.636
Polygon/landfill, thous. tons	14.164	19.727	25.133	29.113	32.794	36.789	42.193

Environmental costs of Rivne NPP are provided in Table 2.8.

Table 2.8 Environmental costs of Rivne NPP

NPP	Charged for water and mineral resources use, thous. uah	Actually paid for water use, thous. uah	Environmental impact for a reporting / previous period											
			Charged amount, uah					Including above-limit payment, uah					Всього нараховано з початку року, грн. (4+9)	Фактично оплачено, тис.грн
			Total (5+7+8)	Including for releases from stationary sources	Including for releases from mobile sources	Including for releases to waters	Including for waste location	Total	Including for releases from stationary resources	including for releases from mobile sources	Including for releases to waters	Including for waste location		
RNPP	7178.330 168.066	27205.507	-	28 869.87	-	484 385.62	377 481.73	-	-	-	-	-	890737.22	-

* - not considering the costs for environmental protection activities

As a result of production activity, the non-radioactive waste of hazard classes 1-4 is generated at Rivne NPP:

- **Hazard Class I:** used luminescent lamps, used standard elements, used thermometers, which contain mercury.

- **Hazard Class II**: waste generated as a result of production processes and distribution of electrical, gas, steam and hot water energy, not indicated by any other way (packaging from chemically dangerous substances); batteries and other damaged or used storage batteries; damaged or used nickel-cadmium batteries (including the lantern); waste from additional materials and substances used in the nuclear energy field (expired chemical reagents).

- **Hazard Class III**: used oil products (sludge- and paste-like), used oil, used lubricants (paste-like), oily sand, used oily automobile filters, waste generated as a result of production processes and distribution of electrical, gas, steam and hot water energy, not indicated by any other way (packaging from diisopropylamine).

- **Hazard Class IV**: photo development solution for and solution of water-base substances, which speed up the development process - non-revertible, photographic film and paper that contain silver or silver compounds - non-revertible (used radiographic film), used oily cloth, cans for paints (solid – barrels and cans), cans for lubricants (solid – barrels and cans), used tires with metal cord (solid), black metal scrap, colored metal scrap, waste paper, pharmaceutical products and substances (including veterinary), medical drugs and goods (including aerosols), their remnants - damaged or used, expired or unidentified (expired potassium iodide pills), protection means from chemical or bacterial aerosols – damaged or used (respirators), used, damaged or dirty protection clothes (water suits), broken glass, worn out, damaged shoes (special protection shoes), used filtering material “Sipron”, used organic-silicon material, remnants of the other film (printer film), used steel wire with oils, used medical waste – needles, syringes, ampullas, paints, enamels, lacquers, ink, damaged or used claying materials, their remnants, which cannot be used as intended, office and computer machines - non-revertible, plastic waste, non-revertible fixative solutions (fixers), construction waste (solid), food, sludge generated from water clearing, eye solutions, sawn or chipped wood, broken porcelain isolators (solid), mixed household waste (solid), used ion exchange resins (solid), waste after lime slaking, used thermal insulation material, sand-like abrasive material, used coal sorbent, used filtering material, abrasive metal dust, non-revertible abrasive products, slime after automobile transport washing, used sulphate slime mud, used wax, ozocerit, grease waste after cleaning of sewerage pipes.

About forty types of non-radioactive waste is formed or separately accumulated at Rivne NPP. The biggest amount of waste comes to the sludge formed after clearing of water, which is accumulated in sections C-1, C-3, C-4, C-6 of water-isolated sludge collector, a facility with open water surface, banked with the embankment. In general, the sludge collecting system includes six sections (sections C-2 and C-5 for oil sludge of the purification facilities of sewage water containing oil products) and pump station for returning of settled water to the plant reverse systems. The characteristics of sludge collector are provided in Table 2.9.

Table 2.9. Characteristics of sludge collector.

Area of sludge collector	0.6 ha
Number of sections	6
Capacity (design)	226 thous. tons
Volume of allocated waste as of 01.01.2018	133.636 thous. tons
Number of operating surveillance wells/bores	4

The waste, that may be utilized and processes in Ukraine using relevant technologies and technical and/or economical prerequisites, are partially processed by the structural plant subdivisions. The waste is mainly taxable as the secondary products and transferred to the separate subdivision “Storage household” of NNEGC Energoatom, other entities and physical persons. This is a sludge formed as a result of water clearing, scrap of black and colored metals, used oils, paper and cardboard, polymers, glass, wood, textile, rubber (used automobile tires), photo materials containing silver compounds, spare details containing precious metal and stones.

The hazardous waste are collected separately by its type and transferred also through the separate subdivision “Storage household”, but for decontamination and extraction - to the specialized facilities. The waste includes luminescent lamps and devices containing mercury, lead-acid storage batteries, oil sludges of the purification facilities of sewage water containing oil products, monitors, used batteries, unused drugs. Rivne NPP has a copy of license for collection, transportation, storage and extraction of: used oil products, including oils and mixtures; used luminescent lamps and used lead-acid storage batteries. Under the contract, the solid waste containing organic compound, which easily rotten, is transferred to the local municipal entity for extraction and sent to the polygon of the town of Varash.

The construction and industrial waste of Rivne NPP are extracted and shipped to the polygon, located 3 km from the town of Varash, at the location of the sand quarry. The drive way has a solid road. The perimeter of the polygon is surrounded with reinforced concrete plates. The first section of the polygon was operated from the beginning of RNPP commissioning and is recultivated at present; the second section has been closed since 2008. At the beginning of 2009, the waste is disposed at the third section of the polygon, which was accepted into operation in December 2007 with the act of the working commission. The place for the forth section is in standby. The waste of the hazard class 3, polluted with oil products (used absorbents, used filtering materials and used washing materials) are shipped to the polygon in the polyethylene packages.

Compacting and buildup of the construction and industrial waste at the polygon of Rivne NPP are performed using the bulldozer on the base of T-170 truck. The day watch is in place. Characteristics of the polygon/landfill of industrial waste at Rivne NPPs is presented in Table 2.10.

Table 2.10. Characteristics of the polygon/landfill of industrial waste at Rivne NPPs.

Landfill area	5 ha
Number of maps	4
Capacity (design)	204.6 thous. tons
Volume of allocated waste as of 01.01.2018	42.193 thous. tons
Number of operating surveillance wells/bores	2

Non-radioactive waste management is implemented in accordance with the requirements of the environmental legislation, which are specified in “Instructions of non-radioactive waste management at Rivne NPP” [32] and the Order with assignment of the responsible people. The accounting is accomplished in accordance with the generic form of primary accounting documents No1-BT “Accounting of waste and packing materials” [33]; reports are prepared in accordance with the form of state statistic surveillance No1 – Waste (yearly) “Waste formation and management” [34].

According to the data of laboratory studies conducted by the licensed laboratories, no negative impact was identified with regard to the state of atmospheric air, soils and ground waters at the waste extraction locations (sludge collector and polygon/ landfill of the construction and industrial waste).

2.4 Spent nuclear fuel handling facilities

In the process cycle of the nuclear power plant, one of the most important elements is the spent nuclear fuel (SNF), which generates as a result of the energy produced in the nuclear reactors.

The time of using the nuclear fuel in the reactors is defined by the value of allowed burn-up of the fissionable isotopes. After the planned burn-up is achieved, the nuclear fuel is unloaded from the reactor and considered to be spent fuel, since it cannot be used any longer for energy generation [22].

After unloaded from the reactor, the spent nuclear fuel is loaded to the near-reactor spent fuel pit (SFP). The SNF is stored in the pits for the limited time, necessary for reduction of energy release, due to decay of fission products, to the allowed values. After SNF storage in the SFP during limited time, the spent fuel assemblies (SFAs) should be transported from the power unit and shipped for storage (disposal) or processing. This is done because the capacity of SFP is limited and it should always have free volume for loading of the nuclear fuel from the reactor core or periodic inspections of the reactor vessel and in-vessel internals of VVER reactors.

During SNF management, it is also necessary to consider the factors, which relate to the specifics of this material: high radioactivity level and presence of valuable elements in SNF (uranium, plutonium, germanium, erbium, palladium, zirconium etc.), which in the perspective can be used in other fuel cycles (nuclear fuel for the fast-neutron reactors, MOX-fuel for light-water reactors). Taking into account the above mentioned, the SNF does not refer to radioactive waste.

The current state of the nuclear energy field in the world shows that, given the modern level of technologies, the final conclusions cannot be made as for the economic viability of SNF processing or disposal, i.e. the final phase of the nuclear fuel cycle (NFC). In light of this, Ukraine like most other countries that develop nuclear energy, took for themselves the so-called “deferred decision”, which implies long-term storage of the spent nuclear fuel. The “deferred decision” allows the country to take a decision later on the final phase of NFC, considering the technologies development in the world and economic benefit for the country.

At present, Ukraine has two storage facilities in operation, designed for temporary storage of the spent nuclear fuel: wet type interim spent fuel storage facility (ISF-1) at Chernobyl NPP and dry-type spent fuel storage facility (DSNFF) at Zaporizhzhya NPP. Besides, Ukraine is constructing two more storage facilities: ISF-2 at Chernobyl NPP and centralized spent fuel storage facility (CSFSF) for the SNF of VVER reactors.

2.4.1 Handling of spent nuclear fuel of VVER reactor type

SNF from Rivne, Khmelnitskiy and South Ukraine nuclear power plants is currently transported to the Russian Federation. SNF from VVER-1000 reactors is shipped for storage, and SNF from VVER-440 (power units 1, 2 of Rivne NPP) is shipped for reprocessing.

To accomplish “Action Plan for 2006-2010 with regard to implementation of the Energy Strategy of Ukraine for the period up to 2030” (approved by the Decree of the Cabinet of Ministers of Ukraine No427 as of July 27, 2006), the operator SE “NNEGC Energoatom” signed the contract with the American Company “Holtec International” for construction of the centralized spent fuel storage facility (CSFSF) in Ukraine. The SCFSF will be used for storing the spent nuclear fuel of Rivne, Khmelnitskiy and South Ukraine NPPs based on the dry-type storage technology applied at Zaporizhzhya NPP.

In accordance with the legislative provisions, the operator NNEGC “Energoatom” developed “Feasibility Study for construction of the CSFSF for VVER reactors types”. Following the complex state expert review, the document was approved by the Cabinet of Ministers with the Decree No131-p as of 04.02.2009.

The specified Feasibility Study justified the economic viability for the long-term storage of SNF in Ukraine, compared to SNF shipment to the Russian Federation, and construction of one centralized storage facility was substantiated compared to any other option of SNF storage.

The CSFSF is designed to store 12500 SFAs (spent fuel assemblies) from VVER-1000 reactors and 4000 SFAs from VVER-440 reactors for the period of 100 years.

On 09.02.2012 by the Law of Ukraine No4383-VI “On Spent Nuclear Fuel Handling with regard to Location, Design and Construction of the Centralized Spent Fuel Storage Facility for VVER reactors” [35], the Verkhovna Rada of Ukraine took a decision with regard to CSFSF siting on the territory of the Exclusion Zone, as well as CSFSF design and construction.

On 30.04.2013, the State Nuclear Regulatory Committee of Ukraine agreed the document of NNEGC Energoatom “Task Order for modification of the SNF shipment technology from VVER-1000 reactor (B-320) to ensure its transportation to the CSFSF” [36].

On 23.04.2014, with the Decree No399-p of the Cabinet of Ministers, NNEGC “Energoatom” received a permission for development of the land survey project with regard to siting of lands with the total area of 45.2 ha, located between the former villages Stara Krasnytsya, Buryakivka, Chystogolivka and Stechanka of Kyiv Oblast in the exclusion Zone, that were contaminated due to the Chernobyl catastrophe. The lands shall be allocated to the specified enterprise for the permanent usage and the target application will be changed for construction of the CSFSF and railway access road.

On 22.07.2015, the State Nuclear Regulatory Committee of Ukraine agreed the updated “Licensing plan for establishment of the centralized spent nuclear fuel storage facility” (PN-Д.0.46.527-15), developed to replace PN-Д.0.46.527-11 [37].

On 23.07.2015, the State Nuclear Regulatory Committee of Ukraine agreed the proposals of the operating company with regard to the content and scope of the Explanatory Note “Construction Plan for the Centralized Spent Fuel Storage Facility for VVER reactors of Ukrainian NPPs” and provided recommendations as for the CSFSF construction.

On 12.10.2015, with the Order No926 of NNEGC Energoatom, the Steering Committee was established with regard to implementation of the Holtec technology for SNF handling at Rivne, Khmelnitskiy and South Ukraine nuclear power plants, which included the representative from the State Nuclear Regulatory Committee of Ukraine and State Scientific and Technical Center.

On 05.10.2016, by the Directive No721-p of the Cabinet of Ministers, the land plot with the area of 45.2 ha was extracted from the permanent use of the State Agency on Exclusion Zone Management and assigned to the permanent use by NNEGC Energoatom for construction and operaiton of the Centralized Spent Fuel Storage Facility.

On 03.11.2016, by the Directive No08 of the SNRCU Board, the Conclusion was agreed with regard to the state review of the preliminary safety analysis report for CSFSF.

On 07.12.2016, NNEGC Energoatom received registration of declaration No ІУ030163421149 for beginning of preliminary works.

On 07.06.2017, the Cabinet of Ministers by Decree No380-p approved the project “Construction of the centralized storage facility for spent nuclear fuel of VVER reactor type”.

On 29.06.2017, the State Nuclear Regulatory Inspectorate of Ukraine issued NNEGC “Energoatom” with the license for implementation of activity at the phases of lifecycle of “construction and commissioning of the nuclear facility (centralized spent fuel storage facility for VVER reactor type)” [38].

On 09.11.2017, the special ceremony was held with regard to the beginning of CSFSF construction in the urban-type village Buryakivka (Exclusion Zone)

In addition, the following tasks were accomplished by SNRIU in 2017:

- review of 15 packages of the technical specifications for safety important equipment, with the preliminary comments provided to “Energoatom”;
- preliminary agreement was made, following the state review of nuclear and radiation safety of three technical specifications (TS);
- state review and submittal of the preliminary comments to three programs on acceptance tests at the manufacturer’s factory;
- review of series of Technical Solutions related to the Holtec technology on SNF preparation for storage in CSFSF to be implemented at the Ukrainian NPPs;
- participation in the meetings of the Steering Committee with regard to the Holtec technology on SNF preparation for storage in CSFSF to be implemented at the power units of Rivne, Khmelnitskiy, South Ukraine NPPs.

2.4.2 Management of HLW after reprocessing of SNF from Rivne NPP

According to the Agreement between the Government of Ukraine and the Government of the Russian Federation (RF) on the scientific and economic cooperation in the nuclear energy field as of 14.01.1993 and contractual obligations of NNEGC "Energoatom", the spent nuclear fuel of VVER reactors is transported for the technological storage and reprocessing to the entities of the Russian Federation (Federal State Unitary Enterprise (FSUE) Mayak Production Association and Federal State Unitary Enterprise "Mining and Chemical Plant"). To Ukraine, the products of reprocessing are expected to be returned in the form of vetrified high-level waste (HLW)[1], obtained after SNF reprocessing. The waste will be returned to Ukraine in compliance with the conditions and terms specified in the relevant contracts between the entities of the Parties.

2.4.2.1 High-level radioactive waste after reprocessing of SNF from VVER-440

Starting from 1993, the SNF of Rivne NPP VVER-440 is transported to the FSUE "Mayak" for storage and reprocessing.

Amount of the vetrified HLW that returns to Ukraine is calculated on the agreement by the regulatory authorities of Ukraine and Russia in accordance with the document СОУ-Н ЯЕК 1.027:2010 "Methodology for calculation of high level radioactive waste that returns to Ukraine after storage and reprocessing of SFAs of VVER-440" (put into effect by the Order of the Ministry of Fuel and Energy of Ukraine as of 25.08.2010 No 332) [39].

At present, the parties are in the process of agreement of the Technical Conditions for the vitrified HLW from the reprocessed SNF of Rivne NPP VVER-440, that will be returned to Ukraine, and the passportization procedure and Quality Assurance Program for SNF processing.

Construction of the storage facility at the site of "Vector" Complex, for interim long-term storage (100 years) of the vetrified HLW from the reprocessed SNF of VVER-440, is planned in Task 3 of "National Target Environmental Program on Radioactive Waste Management" approved by the Law of Ukraine No516-VI as of 17.09.2008.

In 2012, the Feasibility Study (FS) was developed with regard to construction of the storage facility for the interim storage of the vetrified HLW that are returned from the Russian Federation after processing of the spent nuclear fuel from VVER-400 reactors of the Ukrainian NPPs. The FS received a positive expert report after the State Construction Review. The state review showed that the Technical Solutions accepted in the FS are in compliance with the current construction norms and design rules applied in Ukraine, as well as in compliance with the requirements to the nuclear and radiation safety. Since the FS, due to some objective reasons, was not approved in the corresponding ministries and government departments, the activities are being performed now with respect to its repeated state review.

In addition, a full package of the design and estimates documentation ("draft" stage) was developed, which is also submitted for the state construction review.

According to the design, the lifetime of the storage facility is 15 years for the mode of acceptance and HLW preparation to storage and 100 years for the mode of interim storage and off-loading of HLW (for disposal). The capability of reverse HLW uploading is considered when the interim storage finishes in the facility.

The construction will be conducted in two queues (it is planned to have two commissioning complexes, the first one for 350 m^3, and the second one for 200 m^3).

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[1] After reprocessing of the SNF from the VVERs, the valuable products of processing also have to be returned (oxides of uranium, plutonium and neptunium), solid HLW (structural elements of SFAs, residues of cladding of heavy and light fraction) and cemented intermediate-level waste.

The decision on locating the HLW at the site of “Vector” Complex has several advantages:

- a closely situated operating railway;
- a quite developed network of roads;
- availability of labor resources;
- possibility to use an existing infrastructure of the first queue of the “Vector” Complex, engineering and telecommunication systems, systems of radiation control and environmental monitoring.

2.4.2.2 High-level radioactive waste after reprocessing of SNF from VVER-1000

The spent nucler fuel of Khmelnitskiy, Rivne and South Ukraine NPPs with VVER-1000 (until 2001 Zaporizhzhya NPP as well) is transported for the temporary storage with further reprocessing to the Federal State Unitary Enterprise "Mining and Chemical Plant” (Krasnoyarsk, Russian Federation). At present, reprocessing of the SNF from VVER-1000 of Ukrainian NPPs is not performed in the Russian Federation. Returning of the products of reprocessing to Ukraine, including HLW, can start from 2025.

Two documents agreed and approved by the Russian Federation and Ukraine must define the amount and nomenclature of the products after reprocessing of SFAs from VVER-1000. They are Methodology for defining the amount of high-level waste and products of reprocessing, which return to Ukraine after technological storage and reprocessing of the batch of SFAs from VVER-1000, and Technical Conditions for products after reprocessing of SFAs from VVER-1000.

The radioactive waste after reprocessing of SNF from VVER-1000 has to be shipped to the facilities for interim storage with further transition for disposal in the deep geological formations. At present, such facilities in the infrastructure of the operating radwaste management entities is absent in Ukraine.

Construction of the modern high-technology, centralized spent nuclear fuel storage facility, designed for storage of the SNF from South Ukraine, Rivne and Khmelnitskiy NPPs, will enable to resolve the problem with the spent nuclear fuel handling in the long-term perspective. This is confirmed by the positive experience of the dry spent nuclear fuel storage at Zaporizhzhya NPP.

The government of Ukraine issued the Directive No399-p as of 23.04.2014 on giving the permission to NNEGC Energoatom for development of the land survey project as for allocation of the land plot for storage of the spent nuclear fuel from the nuclear power plants of Ukraine. NNEGC Energoatom is assigned as the operator of the nuclear facility - centralized facility for storage of the spent nuclear fuel from VVER reactors of Ukrainian NPP (which is part of the complex for spent nuclear fuel handling at the specialized entity “Chernobyl NPP”).

According to the estimations, the expenses for construction and operation of the CSFSF will be almost four times less than the total costs spent by Ukraine today for transportation of SNF to Russia; investments into the CSFSF will be compensated in less than four years of the facility operation.

Design, production and supply of the SNF handling equipment will be accomplished in line with the contract with “Holtec International”.

Commissioning of the CSFSF will be performed by the stages, starting from 2018. This will allow Ukraine to refuse from the SNF shipment to the Russian Federation, which will significantly increase the energy safety of Ukraine and eliminate risks of shutting the power units down due to overloading of the spent fuel pits.

CONCLUSIONS

The main types of possible impact on the environment with the nuclear power plant in operation, based on the technological process, is radiation, chemical and physical impact. Under the normal operation conditions of the power units, the significant impact (in descending order) is thermal, chemical and radiation impact. In unlikely but possible cases of the maximum design-basis or beyond design-basis accidents, the dominant impact will be the radiation impact on the environment and people.

Analysis of the safety factors in this Book leads to a conclusion that the impact of RNPP site on the environment will stay at the same level, i.e. there are no prerequisites for worsening of the radiation conditions of the environment around the Rivne NPP.

In the normal operation conditions, the NPP does not impose danger to the personnel, population and environment.

To control non-spreading of the radioactive substances into the ground waters, the radiation monitoring of the ground waters is conducted on the territory of Rivne NPP site. To monitor the ground sources used for water supply, measurements of the radionuclide content are performed in the artesian wells.

There are 35 check-wellholes, and water is sampled from the bottom layer at a depth of 10÷14 meters from the surface. The frequency of water sampling from the check and artesian wellholes is once per quarter [7]. Each sample is measured in terms of Σβ-activity using α/β radiometer MPC-9604 and specific activity of tritium is measured using liquid scintillation radiometer Tri-Carb 3170 TR/SL. The samples of check-wellholes are averaged and are subject to γ-spectrometeric analysis. The activity of man-made isotopes in the groundwaters is thousand times less than the level of allowed concentration in the portable water.

The network of artesian well-holes consists of nine wells, organized on the territory of the water withdrawal point “Ostriv”. The samples of water are taken from the special collector, and go through γ-spectrometry and measurement of tritium activity. The water of artesian well-holes has no isotopes of manmade nature.

The results of multi-year observations show that Σβ-activity of the precipitations and the content of ^{137}Cs and ^{90}Sr for the observation period is within the margins of “zero background” and does not depend on the distance of the surveillance station from Rivne NPP.

During the surveillance period, the agricultural products were identified to be free from the manmade radionuclides except for ^{137}Cs of “Chernobyl” origin. The increased content of this radionuclide in the food products is conditioned by a large value of transition coefficients in the chain “soil-solution-plants” for the soil of this region.

Releases of the polluting substances into the atmosphere from the plant is 2-3 thousand times less than from the coal thermal power plant with the similar installed capacity.

The analysis of monitored indicators prove that the values of the maximum allowed effluents (in tons) were not exceeded, the sewerage water is within the purity limits, and contains the same natural impurities like the source river water, and operation of Rivne NPP does not input the significant changes into the quality of surface waters. The analysis of monitored characteristics prove that Rivne NPP operation does not input significant changes into the quality of ground waters and soils.

The systematic measurements of radioactive material concentration in the atmospheric air, soil, flora and food in the controlled area and surveillance zone, confirm absence of significant impact of Rivne NPP on the population and environment.

During the entire period of NPP operation, the content of radionuclides in the air of Rivne NPP's observation zone was at the level of annual average concentration, peculiar for the pre-commissioning period.

The indications of γ-radiation level in the surrounding settlements did not change after commissioning of Rivne NPP. And, it is not possible to point out the radiation impact of Rivne NPP, in comparison to the natural background, even with the help of state-of-the-art measuring equipment.

Based on the results of periodic safety review by NNEGC Energoatom (stress-tests) as per "Action Plan for unscheduled target assessment and further safety improvement of Ukrainian NPPs taking into account events at Fukusima-1" [21], which was conducted at the request by the State Nuclear Regulatory Inspectorate of Ukraine and European Nuclear Safety Regulators Group (ENSREG), it was concluded that:

- design of the operating Ukrainian NPPs consider all possible external extreme natural impacts. The plant safety, with all considered external extreme natural impacts in the design, is justified in the Safety Analysis Report. The results of additional reviews and walkdowns did not indicate presence of any additional factors, which influence the operability of the equipment that ensures safety of the plant;
- operating Ukrainian NPPs have a safety margin with respect to external extreme natural impact. The conducted equipment qualification confirmed that the external hazards characteristics are above the design values;
- to ensure long-term heat removal in the conditions of extreme hazards, the NPPs apply addition options of power supply in case of loss of power and implement special activities for long-term emergency heat removal.

According to the data of laboratory studies conducted by the licensed laboratories, no negative impact was identified with regard to the state of atmospheric air, soils and gound waters at the waste extraction locations (sludge collector and polygon/ landfill of the construction and industrial waste).

Based on the results of analysis of the sources and amount of generated drains, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, "Measures on minimization of liquid radioactive waste at Rivne NPP" were developed, which result in significant reduction of drain waters.

Also, according to the paragraph 5 of "Measures on minimization of LRW generation at RNPP" the report was developed, "Report for 2013 on quantitative analysis of boron containing waters, which flow into special sewerage system of Units 1, 2 from different sources."

The analysis showed that owing to the continuous control over the received drain waters in the special sewage system, as well as conducted minimization measures, the tendency of the reduced annual drain formation was observed. The biggest input into residue formation is made by the non-returnable losses of the boron acid. That is why it is necessary to consider the possibility of implementing the drain returning approach (boron-containing waters) when taking the equipment out of service with the help of the mobile drainage systems.

Having stable operation of the deep evaporation facilities and activities implemented as per the schedule of "Comprehensive program for radioactive waste management at NNEGC Energoatom" ПМ-Д.0.18.174-16 [26], there will be sufficient free volumes in the RWS to ensure safe operation of power units of Rivne NPP, both during design and extended lifetime of the plant.

In the normal operation conditions, the NPP does not impose danger to the personnel, population and environment.

LIST OF REFERENCES

1. “Nuclear Energy” / Ukrainian Soviet Encyclopedia (USE): in 12 volumes /chief editor M. P. Bazhan ; Editorial board: O. K. Antonov and others — 2nd edition. — K. : USE Chief editorial office, 1974–1985., “Nuclear energy” / Encyclopedia of Modern Ukraine: in 30 volumes./ Editorial board I. M. Dzyuba [and others]; National Academy of Ukraine, Coordination Bureau for Encyclopedia of Modern Ukraine, National Academy of Ukraine. — K., 2003–2016.
2. Law of Ukraine “On Usage of Nuclear Energy and Radiation Safety”, News of the Verkhovna Rada of Ukraine. 1995, No 12, page 81
3. Law of Ukraine “On Usage of Nuclear Energy and Radiation Safety”, Directive of the Cabinet of Ministers No 1268 as of 17.10.1996 “On Establishment of National Nuclear Energy Generating Company “Energoatom”
4. SNiP P-7-81 “Construction in seismic areas”
5. “Solution on the Size and Border of the Controlled Area and Observation zone of Rivne NPP”, No 132-1-P-11-ЦРБ
6. DGN 6.6.1-6.5.001-98 “Norms of Radiation Safety of Ukraine. State Hygienic Standards (НРБУ-97).
7. “Technical Specification on Radiation Monitoring at Rivne NPP” 132-1-P-ЦРБ, 2016.
8. Non-technical Summary. Materials on Justification of Safety for Lifetime Extension of Rivne NPP Unit 3 Beyond the Design Period. The Ministry of Energy and Coal Industry of Ukraine, State Enterprise “National Nuclear Energy Generating Company “Energoatom “Rivne NPP”, 58 pages, 2018
9. Energy Strategy of Ukraine for the Period up to 2030
10. Access regime: https://www.rnpp.rv.ua/assets/DocSite/czentr/Raes_1_23.pdf
11. DSP 6.177-2005-09-02. Main Sanitary Rules for Radiation Safety of Ukraine (OSPU-2005).
12. “Sanitary Rules for Design and Operation of NPPs”
13. “Allowed Levels of Content of Radionuclides ^{137}Cs and ^{90}Sr in Products and Portable Water”. Order No156 of the Ministry Of Health Protection of Ukraine as of 03.05.06.
14. DST 12026-76 “Intergovernmental Standard for Laboratory Filter Paper. Specifications
15. RD-95 “Regulatory Document. Requirements to the Content of Safety Analysis Report for Operating Nuclear Power Plants with VVER Reactor Type in Ukraine”
16. NRBU-97/Д-2000
17. “Requirements on the Size and Border of the Observation zone of Nuclear Power Plant” NP306.2.173-2011
18. “NP 306.2.141-2008. General Safety Provisions for Nuclear Power Plants”
19. “Emergency Plan for RNPP”
20. “Program on Improvement of Radiation Safety and Radiation Protection at Rivne NPP”
21. “Action Plan for Unscheduled Target Safety Review and Further Safety Improvement of Ukrainian NPPs taking into account Events at Fukusima-1”
22. Report on the Status of Nuclear and Radiation Safety of Ukraine 2017. State Nuclear Regulatory Inspectorate of Ukraine in 2017. SNRIU, 2018. -81 pages
23. Law of Ukraine “On Radioactive Waste Management”, No 256/95 –BP as of 30.06.1995

24. Law of Ukraine “On National Target Environmental Program for Radioactive Waste Management” No516-VI as of 17.09.2008
25. Program on Radioactive Waste Management in Ukraine Approved by the Directive of the Cabinet of Ministers of Ukraine No516-VI as of 19.08.2009
26. Integrated Program on Radioactive Waste Management in SE “NNEGC Energoatom”, No 927-p put into effect as of 12.10.2016
27. Radioactive Waste Management During Operation of NPPs of NNEGC Energoatom as of 31.12.2015, Ministry of Fuel and Coal Industry of Ukraine, NNEGC Energoatom, 2016 – 104 pages
28. Sanitary Rules for Design and Operation of Nuclear Power Plants (СП АС-88/93).
29. “Norms of Received Drain Waters, Resulting from Technological Process, Maintenance and Repair Activities at Rivne NPP”
30. “Report for 2013 on Quantitative Analysis of Boron-containing Waters, drained into Special Sewerage System of Units 1, 2 from Different Sources.”
31. Technical Solution on Disposal of the Radioactive Waste of Rivne NPP (containers with bitumen compound) at the “Vector” Production Complex, prepared by CRWME in 2014.
32. “Instructions on Non-radioactive Waste Management at Rivne NPP”
33. “Accounting of Waste and Packing materials”
34. “Waste Formation and Management”
35. Law of Ukraine No4383-VI “On Spent Nuclear Fuel Handling with regard to Location, Design and Construction of the Centralized Spent Fuel Storage Facility for VVER reactors”
36. “Task Order for Modification of the SNF Shipment Technology from VVER-1000 Reactor (B-320) to Ensure its Transportation to CSFSF”
37. “Licensing Plan for Establishment of Centralized Spent Nuclear Fuel Storage Facility” (PN-Д.0.46.527-15), developed in replacement of PN-Д.0.46.527-11
38. “License NoEO 001060 for Implementation of Activity at the Stages of Life Cycle “Construction and Commissioning” of the Nuclear Facility (Centralized Spent Nuclear Fuel Storage Facility for Nuclear Power Plants with VVER Reactor Type)”
39. СОУ-Н ЯЕК 1.027:2010 “Methodology for Calculation of High-level Radioactive Waste that is Returned to Ukraine after Storage and Reprocessing of SFAs from VVER-440” (put into effect by the Order of the Ministry of Fuel and Energy of Ukraine No 332 as of 25.08.2010)
40. “Report on Assessment of Environmental Impact from the Non-radioactive Factors of Rivne NPP, NNEGC “Energoatom” for 2017” - 2018. -25 pages

ATTACHMENTS

Attachment A

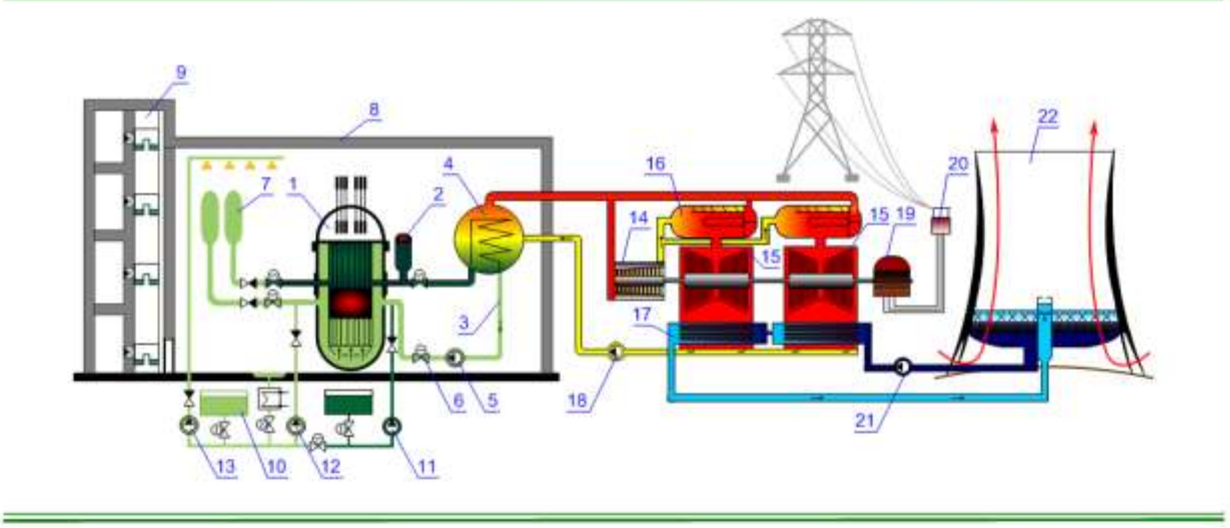
Flow chart of the power unit with VVER-440 reactor type.

The power units of Rivne NPP have a water-cooled water-moderated power reactor (VVER). The power units with VVER reactor type have a two-circuit system, primary and secondary circuits that do not mix with each other.

Rivne NPP is special for introduction of power units operated with the reactors of VVER-440 type. Two reactors of this type are operated at the plant, specifically reactor 1 and reactor 2.

Flow chart of the power units with VVER-440 reactor type is presented on the figure below.

Flow chart of the power unit with VVER-440 reactor type



1. Reactor
2. Pressurizer
3. Main circulation circuit
4. Steam generator
5. Main circulation pump
6. Main loop isolation valve
7. Hydroaccumulators
8. Containment
9. Accident localization vault
10. Boron concentration storage tank
11. Emergency feedwater pump
12. Core cooling pump
13. Spray pump
14. Turbine high pressure cylinder
15. Turbine low pressure cylinder
16. Moisture separator reheater
17. Condenser
18. Feedwater pump
19. Generator
20. Main transformer
21. Circulating pump
22. Cooling tower

The reactor primary circuit includes:

- reactor,
- steam generator,
- main circulation pumps,
- pressurizer,
- main loop isolation valves.

All components of the primary circuit are installed in the leak-tight boxes.

The coolant and neutron moderator is demineralized water.

The coolant removes heat generated during uranium fission in the operating reactor, and then it is pumped through the reactor core by the main circulation pumps and transfers heat to water of the secondary circuit in the steam generators.

The reactor core consists of hexagonal fuel assemblies (FAs), which contain fuel elements (FEs).

A fuel element is a rod made of zirconium alloy and filled with fuel pallets with uranium dioxide.

The water in the primary side heats up to 300 °C in the reactor, but it does not boil, since the pressure that is maintained by the pressurizer is 12 MPa for VVER-440 and 16 MPa for VVER-1000.

The secondary circuit is nonradioactive, it includes:

- steam generators,
- steamlines,
- steam turbines,
- moisture separator reheaters,
- feedwater pipelines with feedwater pumps, deaerators and regenerating heaters.

The saturated heat generated in the steam generators is supplied to the turbine, which activates electrical generator.

The electrical energy produced by RNPP is transmitted to the unified grid of Ukraine via the open switchgears of electrical transmission lines 110, 330 and 750 kV.

Attachment B

Flow chart of the power unit with VVER-1000 reactor type

Rivne NPP has two power units of VVER-1000 reactor type – Units 3 and 4.

VVER-1000 is a water-cooled and water-moderated reactor, where pressurized water is used as coolant and moderator. This is a second-generation light water reactor with high capacity. The electrical power is 1000 MWt, the thermal power is 3000 MWt. Nuclear reactors of this type are operated at Zaporizhzhya, Rivne, Khmelnitskiy, South Ukraine NPPs, as well as at the NPPs of Russia, Bulgaria, Check Republic and China.

Fig.1 presents the flow chart of the power unit with VVER-1000 reactor type.

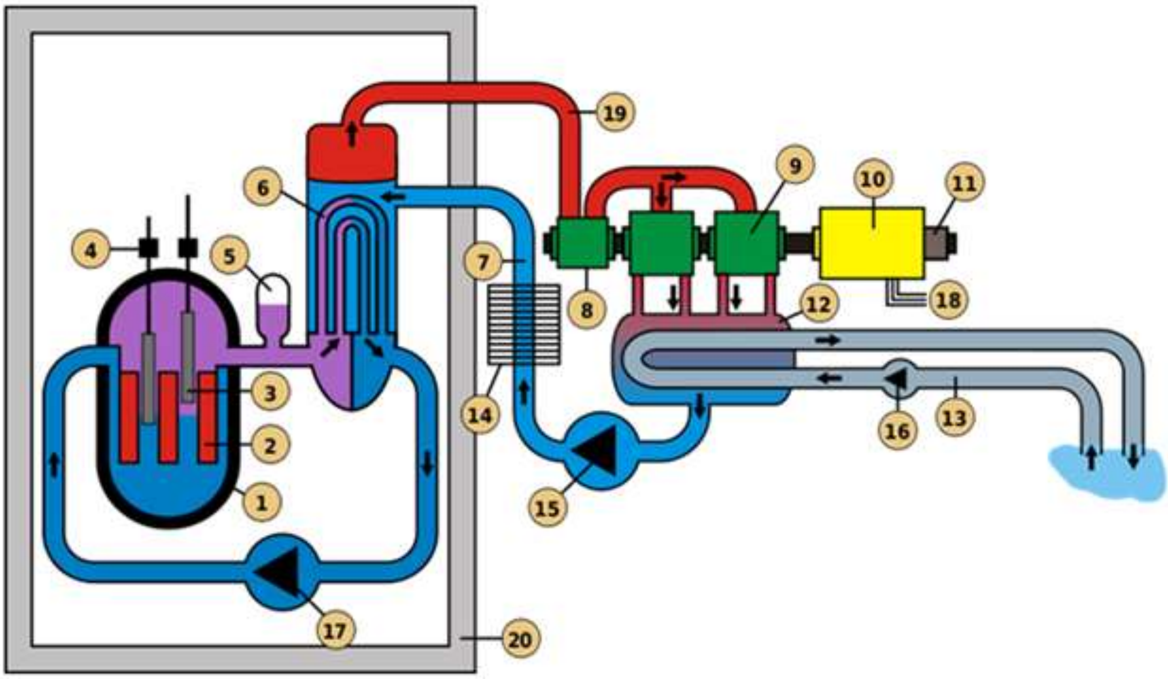


Fig. 1. Diagram of power unit with VVER reactor. 1- reactor, 2 – fuel, 3 – control rods, 4 – control rod driving mechanisms, 5 – pressurizer, 6 – steam generator heat exchange tubes, 7 – feedwater supply to steam generators, 8 – turbine high pressure cylinder, 9 - turbine low pressure cylinder, 10 – generator, 11 – exciter, 12 – condenser, 13 – turbine condenser cooling system, 14 – heaters, 15 – turbine driven feedwater pump, 16 – condensate pump, 17 – main circulation pump, 18 – generator connection to grid, 19 – steam supply to turbine, 20 – containment.

The regular demineralized water (heterogeneous reactor) is used as a neutron moderator and coolant in the energy reactors of VVER vessel-type. The core is placed in one common vessel, with water circulating through it. Two-circuit principle is applied to remove the heat. In the vessel-type unboiling reactor, the core is located in the high-strength, thick-walls steel vessel. The diameter of the core is 3.12 m, the height is 3.5 m, loading with natural uranium is 66 t, ^{235}U enrichment is 3-4%.

The reactor vessel is one of the most important structural elements and must ensure total reliability and complete leak-tightness both in normal operation conditions and in case of possible emergencies. The vessel is completely filled with pressurized water (15.7 MPa and greater).

The primary side of the reactor is fully isolated from the secondary side, which reduces radioactive releases into atmosphere. Water is pumped by the circulation pumps through the reactor and heat exchanger (the circulation pumps take suction from the turbine). Water of the reactor radioactive circuit is at the high pressure, thus regardless of its high temperature (320°C at the reactor exit, 289°C at the core inlet) it does not boil.

Water of the secondary side is at operating pressure of 6.4 MPa, that is why it is converted into steam at operating temperature of 280 °C in the heat exchanger (steam generator). In the heat exchanger – steam generator the coolant that circulates in the primary circuit transfers heat to the secondary circuit. The steam, generating in the steam generator, goes to the turbines via the main steamlines of the secondary side and gives away part of its energy to rotation of the turbine, and after that, it gets to the condenser. The condenser, which is cooled with water of the circulation circuit (so to say, the third circuit), ensures collection and condensation of the steam. The condensate, after going through the heaters system, goes back to the heat exchanger and the cycle repeats again.

For convenience of reloading and transportation, the fuel elements of the reactor are collected in the special assemblies – fuel assemblies (FAs). The assemblies have the hexagonal shape. The reactor consists of 163 fuel assemblies, which are located in the middle of the core with a pitch of 20-25 cm. All FAs in the core are assembled in the reactor core barrel (RCB). The bottom end of FAs is placed in the RCB's support tubes, and the top end (head) is supported by the guide tubes. The RCB's support tubes, the baffle and guide tubes hold the fuel assemblies in the required position.

Attachment C

Development and implementation of the solid radioactive waste management system at Rivne NPP.

The work is performed to resolve the issues associated with reprocessing and long-term storage/disposal of the solid radwaste waste, which has accumulated already, which are generated in the process of plant operation and will be generated during Rivne NPP decommissioning. This work started at the beginning of 2005 under the project of the international technical assistance program TACIS U1.01/01b “Establishment of the radioactive waste reprocessing complex at Rivne NPP” (further on – Complex). The general diagram of this complex is provided on Fig 1.

Under the Ukrainian part of commitment in the TACIS project, Rivne NPP developed the draft documents for radwaste reprocessing complex (RWRC) and cost estimate (contractor - Public Joint Stock Company “Kyiv Research and Design Institute Energoproject” (PJSC KIEP)).

The RWRC project was approved by the Cabinet of Ministers of Ukraine with the Directive of No 935–p as of 07.11.13.

In accordance with the Order of Rivne NPP No 120 as of 25.01.2016 “Organization of activities on CRWC commissioning”, the approximate dates for project completion, i.e. putting of the complex into commercial operation, was December 2017.

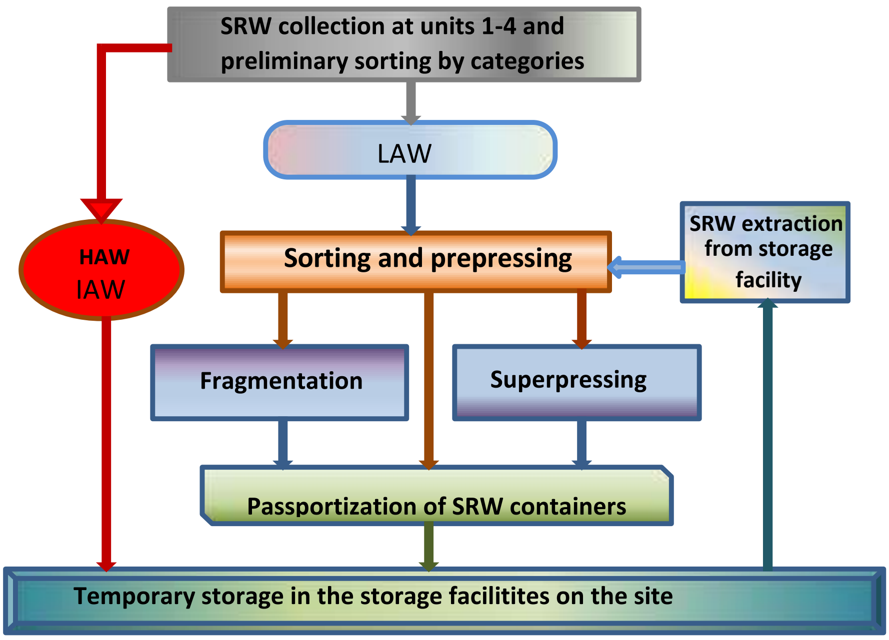


Fig. 1. Perspective diagram of SRW management system at Rivne NPP.

In accordance with the project, the following structure of the Complex was planned:

- Lot 1. Waste extraction intallation, supplier – “ONET” Company, France (Fig.2, Fig.3);
- Lot 2. Fragmentaiton and sorting intallation, supplier – “NUKEM” Company, Germany (Fig.4);
- Lot 3. Superpressing intallation, supplier - “NUKEM” Company, Germany (Fig. 5);
- Lot 4. Activity measurement intallation, supplier – “ENVINET” Company, Check Republic (Fig.6).

Intallation of solid radioactive extraction from the RNPP storage facilities

The SRW installation is a mobile steel structure, equipped with windows for observation of all performed processes (Fig. 2, Fig. 3). There is a lifting crane inside the installation, intended for extraction of the solid wadwaste from the storage cells and its loading into special containers for transportation and storage.

The control cabinet and operator are outside the installation. The video surveillance equipment is used to monitor the process of radioactive waste extraction both in the sectors of the storage cells and in the entire box, and enables to do the operations remotely.

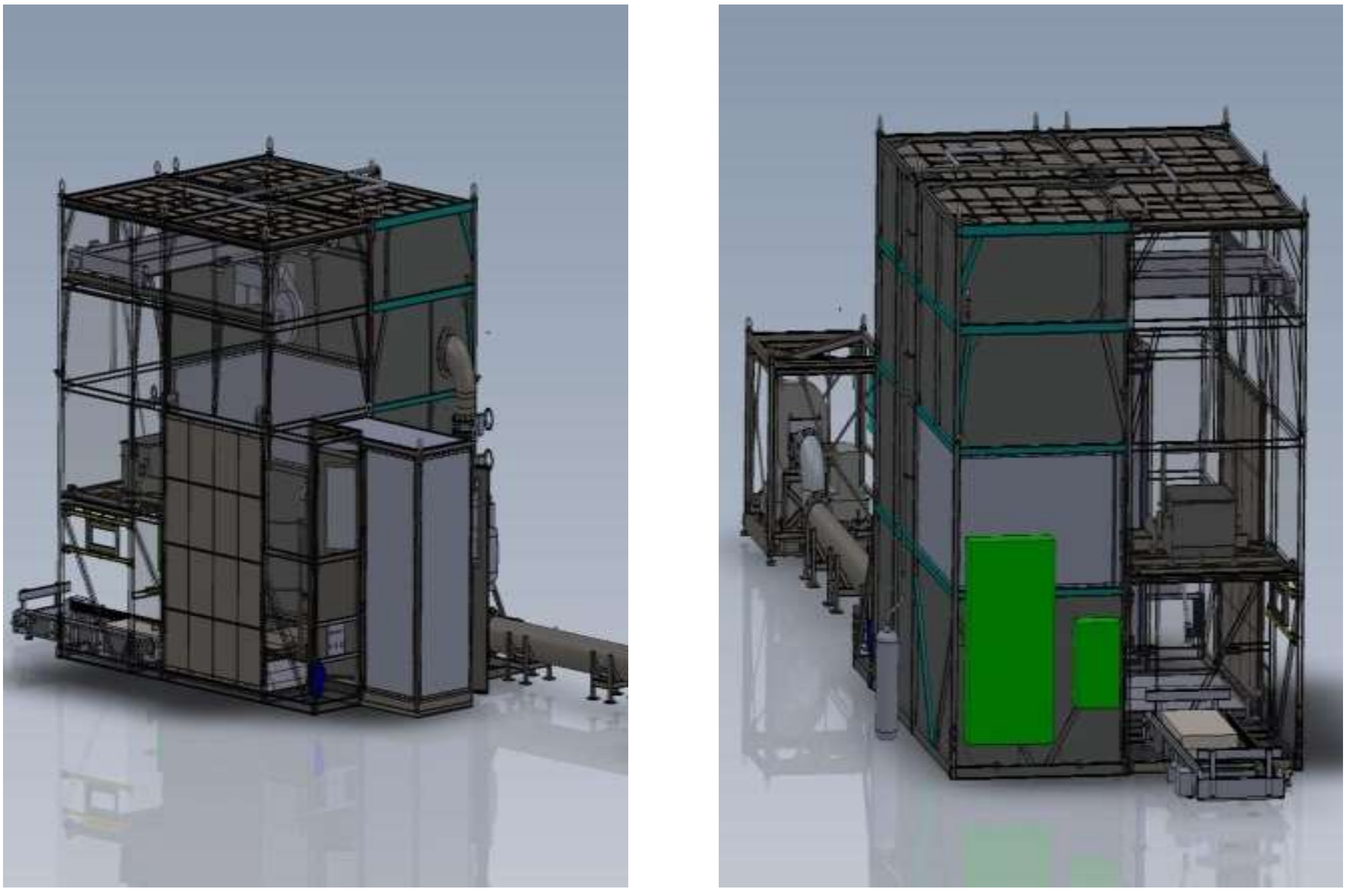


Fig.2. Solid radwaste extraction installation.

The acceptance tests of the extraction installation were conducted at Rivne NPP and the acceptance test report was approved.

The extraction installation was transported to the storage facility of auxiliary building-1, and installed in the compartment of SRW storage, the installation is adjusted and prepared for operation (Fig 3).

Fig. 3 Arrangment of the SRW extraction instllaiton in the storage facility of auxiliary building-1.

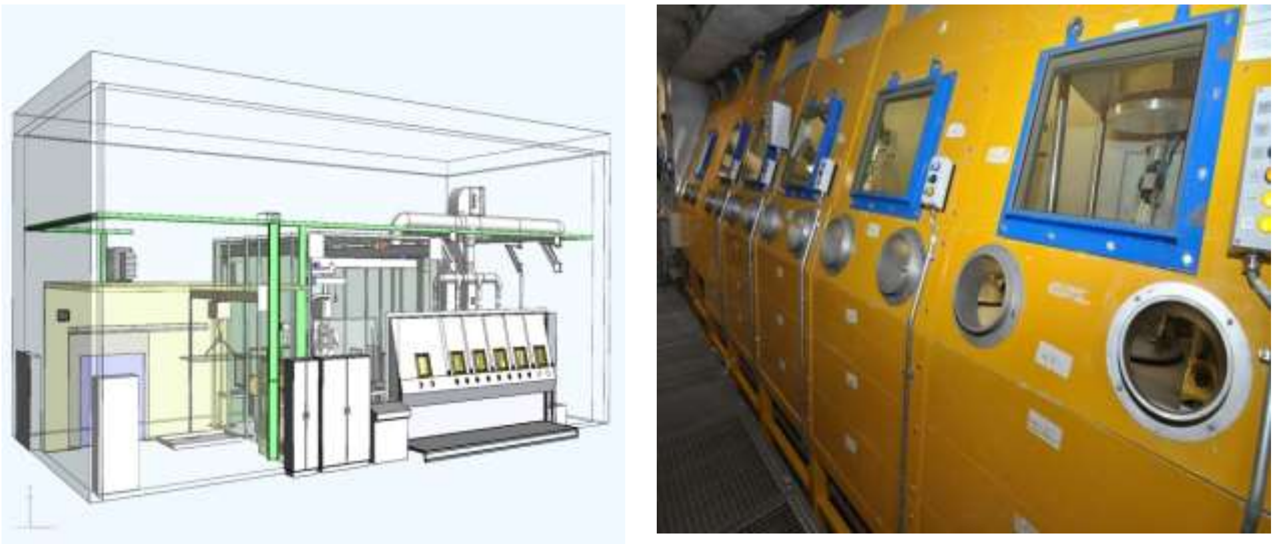


Fig. 4 Fragmentaiton and sorting intallation

The acceptance tests of the fragmentaiton and sorting installation were conducted at Rivne NPP and the acceptance test report was approved. The fragmentaiton and sorting installation is conservated and ready for operation after completion of all CRWP activites.


Fig.5 General view of superpressing installation.

The acceptance tests of the superpressing installation were conducted at Rivne NPP and the acceptance test report was approved. The superpressing installation is conservated and ready for operation after completion of all CRWP activites.

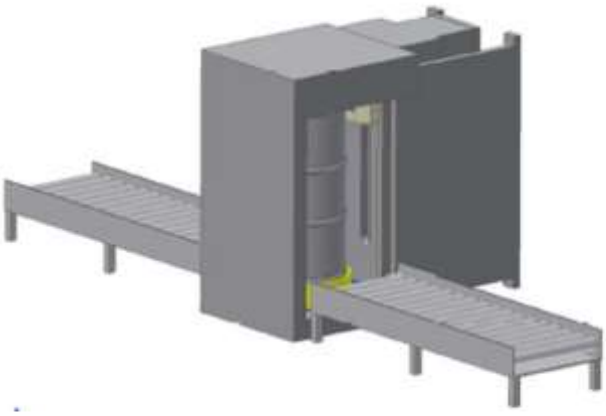



Fig. 6. Activity measurement intallation.

The acceptance test report for the activity measurement installatioin was approved. The activity measurement equipment is installed in the rooms in accordance with the project solutions.

Personnel training was conducted for all relevant lots.

The CRWP Complex is planned to be equipped with additional installaitons.

Metal decontamination installation (Fig. 7).

The equipment supply dates as per the contract between LLC “Promdezaktyvatsiya” and “Atomkomplext” were extended to 31.12.2015. LLC “Promdezaktyvatsiya” delivered the equipment for Stage 1 and partically for Stage 2:

- electrochemical decontamination module;
- manipulating crane;
- hydroabrasive decontamination installation;
- specialized bridge-type autooperator;
- module of ultrasonic decontamination in acid solution;
- interim rinsing module;
- safety fence of decontamination modules;
- servicing platform and frames for decontamination modules;
- baskets for metal transportation (5 items).

In accordance with the specification of the contract No AK11468122993 as of 13.12.12, the LLC "Promdezaktyvatsiya" is expected to supply more equipment to Rivne NPP in the amount of 9 840 000 uah with VAT.

With the decision of the Economic Court of Ukraine in Kyiv as of 08.12.15, the LLC "Promdezaktyvatsiya" recovered the penalty for the benefit of NNEGC Energoatom for breaching the contract conditions.

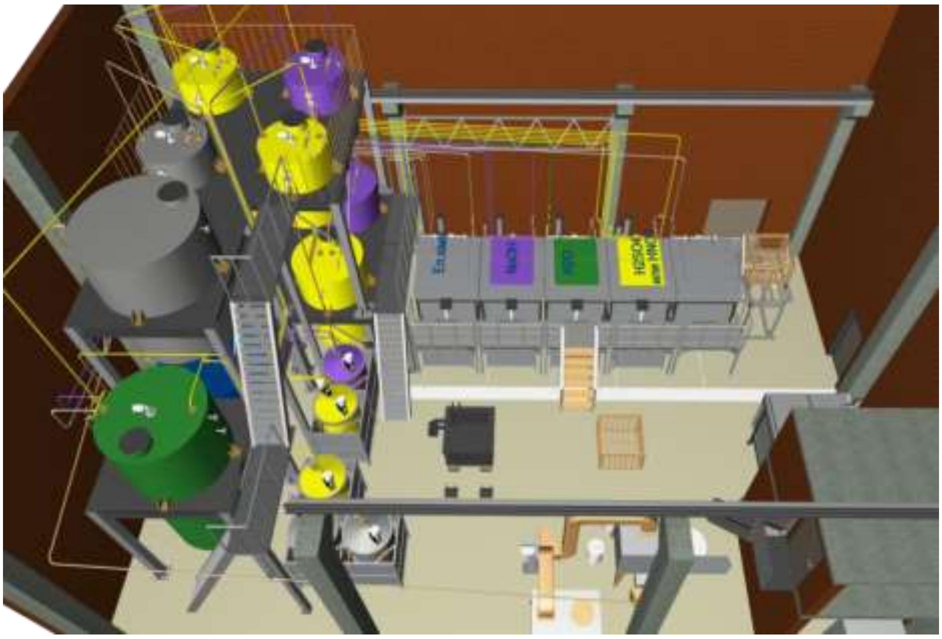


Fig. 7. Equipment layout of the metal decontamination installation (top view).

Oil purificatgiton installation (Fig. 8).

To identify the optimal scope of equipment for the oil purification installation, the experminatal works were conducted to determine the possibility to reduce the oil activity using the oil separation purification equipment of PSM type with futher oil purification using NFE-350 (Pall).

The Technical Requirements for procurement of the oil purification installation was developed and submitted to NNEGC “Energoatom” for agreement.

With the letter No6998 from NNEGC “Energoatom” No6998 as of 13.05.2015, Rivne NPP received comments to TTiUP for the oil purification facility. The comments are analyzed by Rivne NPP specialists and corresponding changes were introduced into TTiUP, which were submitted to NNEGC Energoatom for agreement. The Technical Requirements were agreed by the Company’s subdivision and they were sent back with the letter No10821/18 as of 27.07.2015 to Rivne NPP for preparation to the tender process.

Fig. 8. View of the oil purification installation

The tender did not take place since the price proposals were not submitted by the potential vendors. This tender was cancelled and will be reinitiated.

Cementation installation (Fig. 9, Fig.10).

The cementation installation is intended for putting the radwaste into the cementation matrix, which is performed by filling the radwaste container with the cement mixture and uniform distribution of the cement mixture along the container height.

Mounting of the main process equipment was completed. Setting up of the software and individual testing of the elements is in progress. The program on acceptance tests at Rivne NPP site was approved. The acceptance tests are scheduled for February 2016.

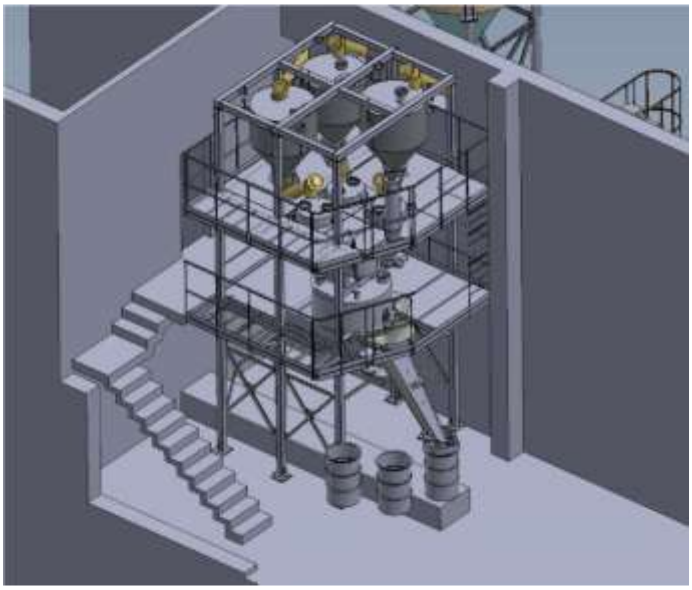


Fig. 9. Equipment layout of the cementation facility in the CRWP building

Fig. 10. Arrangement of the storage bunker for cementation facility outside the CRWP building

High-level software and hardware (Fig.11)

Tender procedures are in progress with regard to procurement of the high-level software and hardware equipment. The announcement No255110 was made in the "Bulletin of State Procurements No407 as of 24.12.15". Opening of the tender proposals took place at the beginning of 2016.

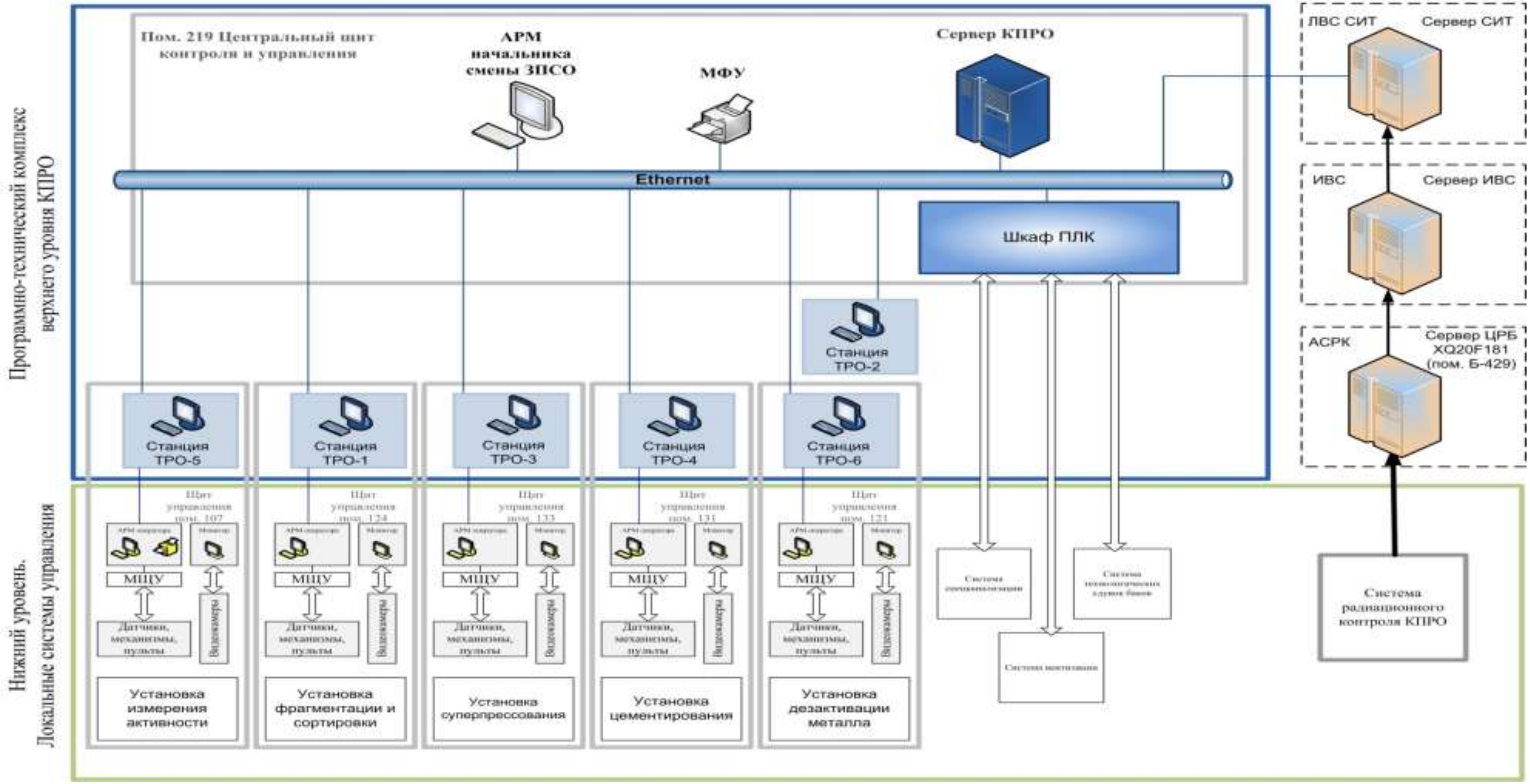


Fig.11. Flow chart of the software and hardware complex for managing CRWP activity (high-level equipment is highlighted).

The progress of construction and mounting works for low-activity waste (LAW) reprocessing facility, in accordance with the schedule, is the following:

- Special sewerage system is 70% assembled, fire and biological protection metal doors installed for Lots 2, 3; walls and ceiling painted; crane runway girder mounted; bunker for the sand and cement volume for cementation installation is cemented; the metal structures mounted; lining of the floor with stainless steel made; lightning protection on the CRWP roof installed; the emergency oil drain tank arranged; the frontage is coldproof; the gas and fire protection caisson in the auxiliary building -1 mounted; the portable water supply line mounted; the networks of external fire-resistant water pipe and production water pipe arranged; the external networks of the production rain sewerage arranged; the crane-manipulator of the decontamination facility mounted; the pipelines and air ducts of the heating and ventilation system mounted; the works are performed in line with the schedule.

The State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) issued a separate permission to NNEGC Energoatom on commissioning of the new infrastructure object – complex for radwaste processing (CRWP), which is a part of the technological complex of Rivne NPP.

The permission was issued on June 1, 2018 with the duration to the end of the life cycle "Operation of the nuclear facility of Rivne NPP Unit 4". The decision on its issuance was made by SNRIU upon the positive results of the state review of the documentation, which justify safety of the implementation of the declared type of activity, and the results of the inspection conducted by SNRIU commission in order to study the capabilities of NNEGC Energoatom to perform activities on commissioning of the CRWP at Rivne NPP.

The main objective of the project is to increase the operational safety level by implementing the advanced innovative technologies in radioactive waste reprocessing, which will enable to bring the radwaste management system of RNPP to the new and modern level.

nt engineering

APPROVED BY

_______________R.V. Maraikin

Director of NT-Engineering

«15» December 2018

REPORT

ON

SS "RIVNE NPP" ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

Book 3 Section 1

Climate and Microclimate. Air Environment.

Chemical Pollution of Air Environment.

Version 2

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2018

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ABSTRACT

Book 3 Section 1 of this report consists of 145 text pages, 39 figures, 84 tables.

The operating power units, buildings and construction facilities that form part of the complex of "Rivne NPP" site of SE "NNEGC Energoatom", as well as their impact on the environment in the area of Rivne NPP are the subjects of examination in this book.

The object of examination is the operating complex of the Rivne NPP that includes power units, buildings and auxiliary facilities, as well as the environment in the area of the Rivne NPP.

The sections of Environmental Impact Assessment (EIA) were developed in order to provide evaluation of impact of the SS "Rivne NPP" on "Climate and Microclimate" and "Air Environment" in the process of the VVER-440 (2 units) and VVER-1000 (2 units) reactors operation. They are based on the results of environment protection measures, multi-year research, monitoring and comparison of the NPP environment conditions before and during operation of the power units.

Section 1 Book 3 presents the general characteristics of climate indicators in the area of Rivne NPP and analysis of multi-year monitoring of climate and microclimate situation. The evaluation of air chemical pollution in the area of the Rivne NPP is based on the results of air monitoring before, during the Rivne NPP operation and in the future.

The report is prepared in line with the requirements to the scope and content of the documents on the assessment of environmental impact.

The outcome of this report is an environmental justification of the acceptance of the economic activity performed by the operating facilities of the Rivne NPP and identification of safety conditions for social and manmade environment in the future.

KEY WORDS: SS "RIVNE NPP", CLIMATE, MICROCLIMATE, AIR, EMISSION SOURCES, ENVIRONMENT, POLLUTING SUBSTANCES, IMPACT.

Conditions of the report distribution: according to the contract.

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LIST OF DESIGNATIONS, SYMBOLS, UNITS, ABBREVIATIONS AND TERMS

ADSFSF	At-reactor dry storage facility of spent fuel
ARI	Acute respiratory infection
ARMS	Automated radiation monitoring system
CCR	Construction codes and regulations
ChNPP	Chornobyl Nuclear Power Plant
CRWME	State Special Enterprise “Central Radioactive Waste Management Enterprise”
CRWP	Complex for radioactive waste processing
CSRWP	Complex for solid radioactive waste processing
CSFSF	Centralized waste fuel storage facility
DBA	Design-basis accident
DEI	Deep evaporation installation
DL	Dose limit
E	East
EDR	Exposure dose rate
EIA	Environmental Impact Assessment
EI	Earthquake index
ENSREG	European Nuclear Safety Regulators Group
EPS	Environmental Protection Service
ERS	Emergency response system
ES	Evaporator sludge
GTU	Gas treatment unit
HAW	High activity waste
HD	Head department
HPP	Heat power plant
IAEA	International Atomic Energy Agency
IAW	Intermediate activity waste
INES	International Nuclear Event Scale
IRS	Ionizing radiation sources
ISF	Interim Spent Fuel Storage Facility (Wet Type)
ITF	Interagency task force
LAW	Low activity waste
LLR	Long-lived radionuclide
LRW	Liquid radioactive waste
MA	Monitoring area
MDA	Minimum detecting activity
MDBA	Maximum design-basis accident
MHU	Ministry of Health of Ukraine
MIPH	O.M. Marzeiev Institute for Public Health NAMSU
MM	Mass media
MPC	Maximal permissible concentration
MPD	Maximum permissible discharge
N	North

n/i	Not identified
NFC	Nuclear fuel cycle
NNEGC “Energoatom”	National Nuclear Energy Generating Company “Energoatom”
NPP	Nuclear power plant
NRS	Nuclear and Radiation Safety
NT-Engineering	Limited liability company “NT-Engineering”
OSA	Oblast State Administration
PC “Vector”	Production Complex “Vector”
PD	Permissible discharges
PE “STC”	Production Enterprise “Scientific and Technical Centre”
PJSC KIEP	Public Joint Stock Company “Kyiv Research and Design Institute Energoproject”
PL	Power line
PL-97	Permissible level of 137Cs and 90Sr concentration in food and water
PPE	Personal protective equipment
PSAR	Provisional safety analysis report
PUF	Plant utilization factor
“Radon”	Ukrainian State Corporation “Radon”
RCS	Reactor coolant system
RIG	Radioactive inert gas
RW	Radioactive wastes
RNPP	Rivne nuclear power plant
RNPP Doses	Dose calculation software for population from actual emissions and discharges
RRCA	Restrictions on radionuclide concentration in air
RRCW	Restrictions on radionuclide concentration in domestic use water
RRIRS	Restrictions on radionuclide intake through respiratory system
RRIDS	Restrictions on radionuclide intake through digestive system
RODOS	European system for forecasting of radiation accident consequences
RWS	Radioactive waste storage
S	South
SAUMEZ	State Agency of Ukraine on Exclusion Zone Management
SCP	Security check point
SEA	Sanitary and epidemiological authorities
SF	Solidification facility
SFA	Spent fuel assembly
SG	Steam generator
SM	Scheduled maintenance
SNF	Spent nuclear fuel
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine

SOARS	Dose calculation software for all residential settlements of the surveillance zone in the emergency case
SRSU	Safety radiation standards of Ukraine 1997
SRW	Solid radioactive waste
SRWS	Solid radioactive waste storage
SSE "ChNPP"	State specialized enterprise "Chernobyl nuclear power plant"
SSE "CRWPE"	State specialized enterprise "Central Radioactive Waste Processing Enterprise"
SS "Rivne NPP"	Separate subdivision "Rivne nuclear power plant"
SSTC NRS	State Enterprise "State Scientific and Technical Centre for Nuclear and Radiation Safety"
SWP	Special water purification
SZ	Surveillance zone
TC	Technical specifications
TS	Technical support
TVS	Technical vocational school
VVER-440	Water-cooled water-moderated power reactor with nominal capacity of 440 MWt
VVER-1000	Water-cooled water-moderated power reactor with nominal capacity of 1000 MWt
WWTF	Waterwaste treatment facilities
^{235}U	Uranium 235
UE	Ultrasound examination
URS	Unidentified radionuclide spectrum
US	Urban settlement
W	West
WANO	World Association of Nuclear Operators
WBC	Whole-body counter
WEL	Waste extraction location

INTRODUCTION

The Environmental Impact Assessment (EIA) in the area of the SS “Rivne NPP” location was conducted in accordance with the Contract № 347 of March 27, 2018 between the State Enterprise SE “National Nuclear Generating Company “Energoatom” (SE NNEGC Energoatom), it’s Separate Subdivision SS “Rivne Nuclear Power Plant” and Limited Liability Company “NT-Engineering”.

The sections of the Environmental Impact Assessment (EIA) were developed in order to provide evaluation of SS “Rivne NPP” impact on the environment. They are based on the results of environmental protection measures, multi-year research, monitoring and comparison of the NPP environment conditions before and during operation of power units.

The outcome of this report is an environmental justification of the acceptance of the economic activity of the Rivne NPP site and identification of safety conditions for social and manmade environment in the future.

The data used in the development of the EIA include background materials, monitoring results, operational experience of power units, implemented and scheduled environmental measures, etc., on the basis of which estimations and studies were carried out to evaluate the impact of the Rivne NPP site on the environment and population, including a transboundary impact. This document is developed after the analysis, systematization and unification of the collected data.

The EIA was conducted in accordance with the Law of Ukraine "On Environmental Impact Assessment" [1], which stipulates the legal and organizational principles for environmental impact assessment, aimed to prevent environmental damage, to ensure environmental safety, environmental protection, rational use and reproduction of natural resources in the process of decision-making on the conduct of economic activity that can have a significant impact on the environment, taking into account state, public and private interests, DBN A.2.2-1-2003 “Composition and content of Environmental Impact Assessment materials (EIA)” [2] and “Advancement Material Guidelines on Environmental Impact Assessment” (A.2.2-1-2003 to DBN) [3].

The nuclear energy is a reliable source of power supply and it plays a leading role in addressing energy needs of Ukraine. Especially, when the country is under conditions of economic crisis, when there is no sufficient natural fuel, no funds for modernization of the equipment of thermal and hydroelectric power plants and for the development of non-traditional sources of energy generation. The electricity generation allows keeping the wholesale electricity tariff at the acceptable level and reduces the greenhouse gas releases in the atmosphere. The nuclear power plants produce about 50% of the electricity consumed in the country, which is equivalent to combustion of about 40 mln tons of coal per year.

The human health protection, the protection of environment from the negative impact of ionizing radiation and safety nuclear energy application are the main principles of national policy in the area of nuclear energy usage and radiation protection of Ukraine. Specifically, the Law of Ukraine “On Usage of Nuclear Energy and Radiation Protection” [2], Article 8, stipulates “the adherence to norms, rules and standards on nuclear and radiation safety is obligatory in any type of the nuclear energy activity” and the Law of Ukraine “On Human Protection against Ionizing Radiation”[5].

The Assessment of Environmental Impact in the area of the Rivne NPP is provided in seven books.

Book 3 Section 1 evaluates the impact of Rivne NPP on environment, in particular, on climate and microclimate and on air environment in regard to the chemical pollution and reviews the integrated measures implemented at the enterprise to ensure the established environment standards and environmental safety.

1 CLIMATE AND MICROCLIMATE

1.1 Brief summary of climate in the Rivne Oblast – area of Rivne NNP location

The Rivne Oblast is located in the northwest of Ukraine. The area of the Oblast is 20051 km2, which is 3.1% of the total territory of Ukraine.

There are 16 administrative districts and four cities of regional subordination: Rivne, Dubno, Varash, Ostroh. In total there are 1027 urban settlements, including 11 towns, 16 urban-type settlements and 1000 rural settlements. As of 01.01.2017 the population of the region is 1162,7 thousand people.

The climate is moderately continental: a mild winter with frequent thaw periods, a warm summer, an average annual precipitation is 600-700 mm. The winter comes at the end of November and a steady snow cover is formed in the last days of December - the first decade of January. The summer is coming in late May and lasts until September. This is the period of the maximum air and soil temperatures, precipitation, and crop maturation. The rainless, cool early autumn weather is set in early September.

The Rivne Oblast is geomorphologically divided into three parts: Polissya, Volyn Forest Plateau and Male (Small) Polissya, located in the south, between the towns of Radyvyliv and Ostroh, including the spurs of the Podolian Upland with its altitudes of more than 300 meters above the sea.

The location of Rivne Oblast on the border of the Eastern European platform and the Carpathian geosynclinal area caused a rough and multivalued flow of geological history, which was reflected in the heterogeneity of the tectonic structure and the formation of a quite complex association of geological deposits at its greater part.

The territory of the Oblast is located within two major platform structures - the Ukrainian Shield and the Volyn-Podilsky Plate and only a small part on the north-eastern outskirts of Rivne Oblast lies within the Pripyat Trough.

The mineral raw materials base of the Oblast consists of fuel and energy raw materials (peat), precious stones (amber), basalt raw materials for production of mineral wool and fibers, raw materials for the production of building materials (cement, glass, building chalk, building stone, etc.), fresh and mineral groundwater.

Hydrologically, the Rivne Oblast is located in the area of three Artesian basins of the underground waters: the Volyn-Podilsky, Pripyatsky and Ukrainian basins of fracturated waters. The forecast resources of the groundwater are estimated at 1314,9 million m^3/year. The approved reserves of groundwater – 195,8 billion cubic meters/per year.

The Rivne Oblast, like most western and northern region of Ukraine, is rich in surface water. 171 rivers of more than 10 km lengths flow in the Oblast's territory, there are 150 lakes, 12 water storage reservoirs, and 1688 ponds.

The rivers, which belong to the Pripyat basin, are fed mainly by snowmelt waters, less by groundwater and precipitation. The largest of them are Styr with a tributary of Iqua, Stvyha with a tributary of Lev, Goryn and its tributary of Sluch. The main flow direction is from south to north due to the general territory decline from the Volyn Forest Plateau to the Polissy Lowlands.

The largest lakes in the Oblast are Nobel (4,99 km^2) and Bile Ozero (4,53 km^2). There are also a significant number of lakes in the floodplains of the Goryn, Styr, Veseluhka rivers. The lakes are used for recreation and fishing.

The swamps spread throughout the territory of the Oblast, most of them are low, less - intermediate and upland moors. It should be noted that the swampiness is very uneven and varies from 40% on the north to 2-3% on the south.

The soil cover of the Oblast is heterogeneous. The most common sod-podzolic, podzolic, turf and peat soils. The sod-podzolic soils are typical for Polissya. The South Polissya is represented by turf and peat soils. In the forest part of the Volyn Plateau, the light gray soils and podzolized chernozems were formed, most of them were plowed.

The flora of the Rivne Oblast has more than 1,600 species of higher plants. The forests and other forested areas dominate in the vegetation cover. Polissia has the most widespread pine and pine-oak forests, the Volyn Forest Plateau - mostly deciduous forests and Male Polissia - oak-pine forests with more rich herbaceous cover than Polissia.

The wild animals are typical for the forested zone and they are widely represented by mammals, birds, reptiles, amphibians, cyclostomes and fish.

The Polissya zone is characterized by a large variety of fauna, among its representatives there are some rare vertebrates for nowadays (elk, lynx, deer, dandelion, hazel grouse, etc.).

In the forest-steppe zone of the Oblast, the number of hares, foxes, mussel rodents and steenbrases increases, but the species composition of the forest fauna is considerably poorer here than in the forests of Polissya (more often there are only squirrels, pine martens and less often wolves, wild boars, etc.). However, there are many types of vertebrates distributed throughout the territory of the Oblast, without certain location. Among such representatives of ornithofauna there are waterfowls, wading and prairie birds (ducks, tattlers, quails, etc.).

The 30-kilometer area of the Rivne NPP is located within the physical-geographical zone of mixed forests in the Volyn Polissya region. This region has a number of physico-geographical features that distinguish it from other regions of Ukrainian Polissya.

In the geomorphologic structure of the territory, a significant proportion has alluvial plains, widespread monticule-moraine, moraine-frontal forms of relief, presenting denudation forms on the cretaceous basis and karst forms [7].

The climate within the physical and geographical area of Volyn Polissya is less continental, longer duration of freeze-free period and large amount of precipitation. The precipitation ratio of this territory is more than 2,4. Considerable forest cover characterizes the 30-kilometer zone of the Rivne NPP. The forests and shrubs occupy about 40% of the territory here. Among the forests, pine-tree and hornbeam-oak forests occupy large areas. [7, 8].

1.2 Quantitative indicators of climate main characteristics

1.2.1 Meteorological and aeroclimatic conditions

The review of the meteorological and aeroclimatic climate parameters allows us to determine the climatic conditions of the Rivne NPP area including the conditions that favour or slow down the process of self-purification of atmospheric air in the monitoring area.

According to the map of climatic zonation for construction (DSTU-N B V.1.1-27-27-2010) [9], the area of the Rivne NPP and its 30-kilometer zone are located in the second climatic region (subarea II-B), in the zone of moderate-continental climate with a positive water balance, a mild and wet winter, a relatively cool and rainy summer, a long-lasting wet autumn and an unstable weather in the transitional seasons.

The climate of the area is formed under the influence of both maritime and continental air masses. The nature and intensity of the main climatogenic factors significantly differ depending on the seasons of the year.

Winter. The cyclonic activity is the most evident in this season. The passage of western and northwest cyclones often follows by short-term warming, intense snowfall, strong winds and snowstorms. January is the coldest winter's month. The average monthly air temperature in January varies from minus 4,5°C on the north of the monitoring area to minus 4,9-5,0°C on the east and southeast.

Spring. In the presence of significant fluctuations of warm and cold weather, the spring transition is characterized by dynamic rise of air temperature, intense melting of snow cover and rapid drying of soil. In April and May, there is often a return of cold weather caused by invasion of the Arctic air, which ends with cold snap and freezing.

Summer. The weather conditions of the summer season are characterized by a significant increase of air temperature due to the warming of the land surface, an evident repetition of clear days, minor fogs, increased rainfalls and heavy thunderstorm activity. The summer season is set in the middle of May. The warmest summer month is July. The average monthly air temperature in July may fluctuate within 18,1-18,5°C. The highest daily temperatures can also be observed in June and August. The heavy rainstorms are typical for summer.

Autumn. The supply of solar radiation decreases followed by air cooling. The autumn starts in September and lasts till end of November. The first part of the autumn is mostly characterized by dry and warm weather without precipitation. General deterioration of weather, abundance of dull days, long rains and fogs characterize the second half. The passage of Western cyclones in this period often follows by an increase in wind and ice activity. The nature of the atmospheric circulation in the second half of the autumn is approaching the winter season.

The climate main characteristics in the 30-kilometer zone of the Rivne NPP presented in this section are based on the records from the meteorological stations (Hydrometerological Committee of Ukraine) the nearest to the NPP [10,11] and located in the perimeter of the zone at various distances from the site of the Rivne NPP :

- Lyubeshiv meteorological station - 54 km to the northwest;
- Manevichi meteorological station - 26 km to the west;
- Sarny meteorological station - 50 km to the east;
- Rivne meteorological station - 80 km to the south-southeast;
- Lutsk meteorological station - 78 km to the southwest.

The location of the meteorological stations (Hydrometerological Committee of Ukraine) of the Rivne and Volyn Oblasts the nearest to the Rivne NPP, is shown in Fig.1.1.

The Manevichi meteorological station is the nearest station to the Rivne NPP. This meteorological station is located in a 30-kilometer zone of the NPP and it is determined as the reference station for evaluation of the main climatic characteristics for construction and technological design of the NPP. Its representative function was established during the site screening and based on synchronic inspections performed in 1968-1970 at the temporary meteorological station located in the village of Stara Rafalivka, 9 km north of the construction site.

The aerological climate characteristics are based on the data of Shepetivka meteorological station [12], which is a reference station for the north-western territory of Ukraine. All above listed meteorological stations have long-term observation periods that ensure the reliability of the multi-year climatic parameters.

The metrological conditions of the northern part of the NPP zone are recorded by Lyubeshiv meteorological station, the central and western (including the industrial area of the Rivne NPP) - Manevichi meteorological station, the eastern - Sarny meteorological station, the south-eastern and southern - Rivne meteorological station and the southwest – Lutsk meteorological station. This conditional zonation of the territory of the 30-kilometer zone helped to identify the influence of local factors of some individual parts of the territory on the distribution of meteorological characteristics in the NPP zone.

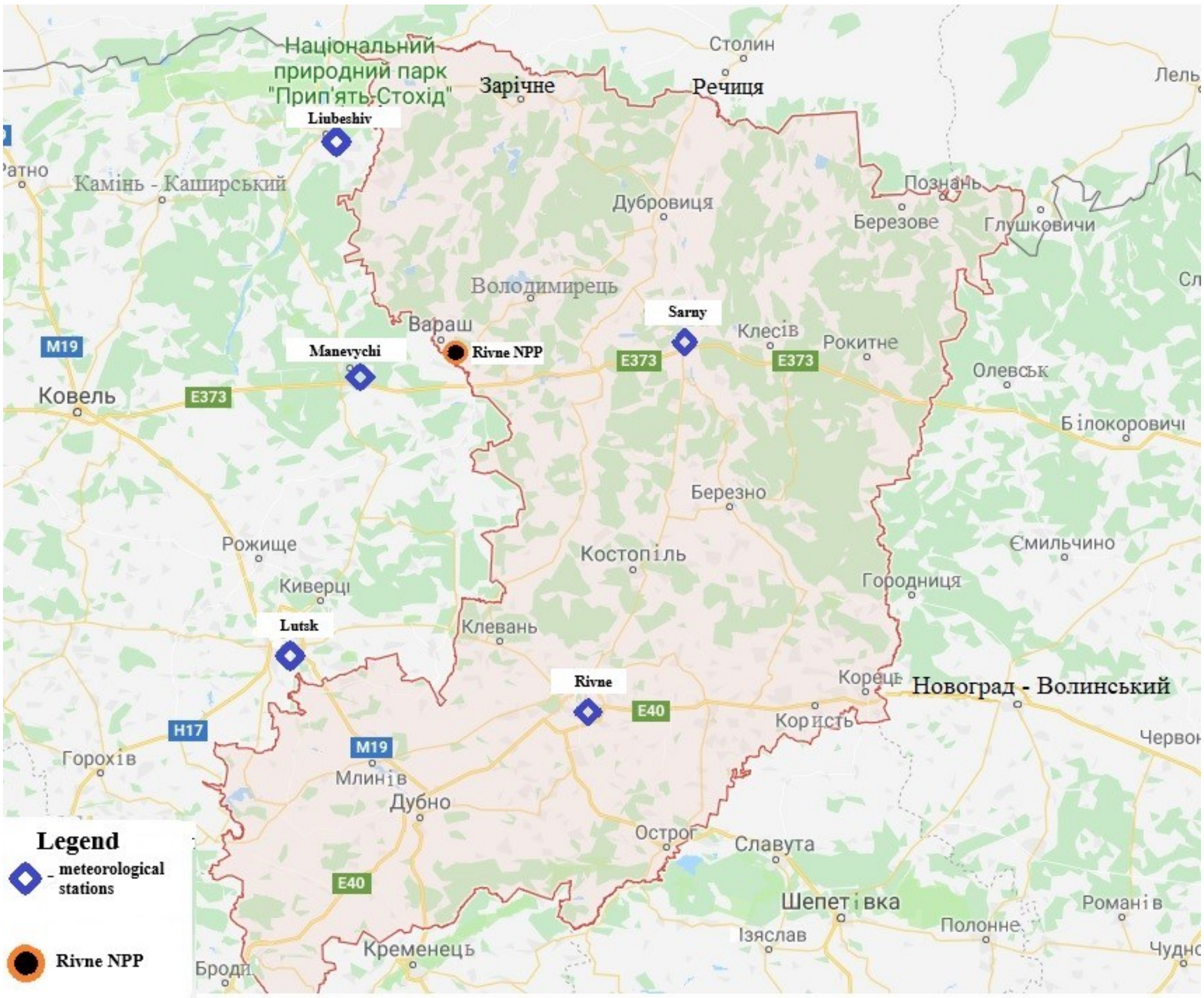


Fig. 1.1. The meteorological stations (Hydrometerological Committee of Ukraine) of the Rivne and Volyn Oblasts, the nearest to the Rivne NNP

1.2.1.1. Air temperature

The average monthly air temperature is of the most important climatic characteristics, reflecting the thermal regime of the area. Its annual rate depends on the radiation conditions and seasonal changes in the atmospheric circulation and is characterized by slight fluctuations from month to month in the winter and summer seasons and sharp fluctuations in the transitional seasons (spring and autumn).

The long-term output of the average monthly and maximum air temperatures in the 30-kilometer zone of the Rivne NPP is provided in Tables 1.1-1.3. according to the data of Lutsk, Rivne, Sarny, Manevich and Lyubeshiv meteorological stations.

Table 1.1. Average monthly and annual air temperature

in ^{0}C

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv meteorological station												
-4,5	-3,8	-0,4	7,6	13,7	16,8	18,1	17,6	12,8	7,7	2,1	-2,0	7,2
Manevichi meteorological station												
-4,7	-3,9	0,3	7,5	13,6	16,8	18,2	17,4	12,8	7,2	1,9	-2,1	7,1
Sarny meteorological station												
-4,9	-4,0	0,3	7,9	14,0	17,2	18,5	17,7	13,1	7,4	2,0	-2,2	7,3
Rivne meteorological station												
-5,0	-4,0	0,2	7,6	13,6	16,8	18,1	17,5	13,1	7,4	1,8	-2,3	7,1
Lutsk meteorological station												
-4,6	-3,6	0,6	7,8	13,7	16,9	18,3	17,6	13,3	7,6	2,3	-2,0	7,3

According to the annual report of average monthly air temperature in the area of the Rivne NPP, the maximum temperature index is observed in July (18,1 – 18,5°C), the minimum in January (minus 4,5-5,0°C).

In some years, the average monthly air temperature in July can reach only 14,9 – 15,7°C or 21,0-22,0°C. In January, in the relatively warm winters, the average monthly temperatures are above zero of 1,3-1,5 0°C, and in the severe winters the average monthly temperatures in January go down to minus 14,0-15,0°C.

The maximum air temperature is observed in the warmest part of the day around 14:00-15:00. The annual fluctuation of maximum air temperatures is similar to the annual average temperature variations: the minimum temperatures are recorded in the winter months and the maximum in the summer.

The absolute maximum and absolute minimum of air temperature determine its highest and lowest values in the certain days.

The data on absolute air temperature in the 30-kilometer zone and in the area of the Rivne NPP site are given in the Tables 1.2 and 1.3.

Table 1.2. Absolute maximum air temperature in ^{0}C

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv meteorological station												
11,6	17,4	23,0	30,0	32,8	34,0	36,0	36,9	32,0	27,4	17,9	14,3	36,9
Manevichi meteorological station												
13,5	16,8	23,4	30,8	33,1	33,9	35,4	35,7	32,0	26,8	18,2	15,4	35,7
Sarny meteorological station												
10,9	16,0	23,7	30,9	32,3	34,3	36,6	37,8	32,9	27,4	18,7	14,8	37,8
Rivne meteorological station												
10,3	16,7	23,0	30,5	35,6	34,2	35,2	37,0	32,6	26,2	18,3	14,5	37,0
Lutsk meteorological station												
11,6	16,9	24,0	29,0	33,2	35,0	35,0	37,0	33,0	28,0	20,7	15,0	37,0

In the winter months, the absolute maximum of air temperature in the monitoring area in some years can reach 14,3-15,4°C in December and 10-12°C in February. After the end of snow cover, the temperature index intensively grows, reaching 23,0-24,0°C in March, 30,0-30,9°C in April and 33,0-35,6°C in May. The maximum air temperatures are observed in July-August, 36,6 -37,8°C.

In October, the temperature index decreases, but the return of warm can cause an increase of air temperature to 26-28°C in the certain days.

The absolute maximum of air temperature 37,8°C in the territory of the 30-kilometer zone of the Rivne NPP was registered at Sarny meteorological station in August 1961.

The movement of cold arctic air masses with low humidity from the east as well as the inflow of cold continental air can cause the significant decrease of air temperature in the monitoring area. The Table 1.3 gives data on the absolute minimum of air temperatures in the area of the Rivne NPP.

Table 1.3 Absolute minimum of air temperature in ^{0}C

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv meteorological station												
-32,6	-30,5	-23,2	-7,4	-3,8	1,3	2,9	-0,1	-3,5	-9,1	-24,8	-27,5	-32,6
Manevichi meteorological station												
-36,9	-30,6	-27,5	-9,0	-5,4	-0,3	4,6	0,5	-4,9	-9,5	-23,9	-27,5	-36,9
Sarny meteorological station												
-35,0	-31,1	-25,2	-10,8	-4,4	-0,1	4,6	0,1	-4,0	-9,3	-24,7	-27,5	-35,0
Rivne meteorological station												
-34,5	-29,0	-25,5	-11,5	-3,8	1,0	5,7	1,8	-3,5	-9,6	-20,1	-26,1	-34,5
Lutsk meteorological station												
-32,5	-34,0	-28,0	-10,0	-3,0	1,0	5,0	0	-5,0	-9,0	-21,0	-28,0	-34,0

The lowest air temperatures are observed in January-February. The absolute minimum of air temperature can be recorded in the same other months. On the territory of the 30-kilometer zone of the Rivne NPP, the absolute minimum of air temperature can reach minus 32,6-36,9°C. The lowest temperature of minus 35,0-36,9°C, was observed at the meteorological stations, which record the temperature regime of the central and eastern part of the monitoring area. In the northern part of the zone, the long-term minimum is slightly higher, minus 34,0-34,5°C. The absolute minimum of minus 36,9°C is acceptable for the site of the NPP as the estimated minimum daily air temperature.

The coldest winters in the monitoring area were observed in 1929, 1950, 1963, 1987.

The freeze-free period in the zone continues averagely 155 days. The longest duration was recorded in 1950 (188 days), the shortest - in 1953 (131 day).

The data on daily fluctuations of air temperature in the monitoring area is given in the Table 1.4.

The daily fluctuations of the air temperature depend on the nature of the weather. In summer, this interrelation is more pronounced than in winter. The daily amplitude is almost twice high under quiet and clear weather conditions than under grey and windy ones. In the winter, the largest daily amplitude depends on the passage of atmospheric fronts and rapid change in the air masses. In the spring and autumn, the largest daily amplitude is observed when the air is well warmed up in the day and cool down at the night by night radiation.

Table 1.4. Average daily amplitude of air temperature fluctuations with blue sky and regardless of sky conditions

Month											
01	02	03	04	05	06	07	08	09	10	11	12
with blue sky											
8,6	9,4	10,0	12,6	13,2	13,1	13,3	13,1	13,4	12,3	8,4	7,2
regardless of sky conditions											
5,8	6,2	7,0	9,4	11,0	11,1	11,2	10,8	10,4	7,9	4,8	4,7

The maximum daily amplitudes of air temperature fluctuations in this area are observed in the summer, reaching 13°C (with blue sky) and 11°C regardless of sky conditions.

The analysis of the temperature regime in the zone of the Rivne NPP shows that the temperature conditions of the eastern and southern parts of the monitoring area are somewhat different from the rest of the territory; there is some continentality here.

1.2.1.2 Air humidity

The air humidity is determined by the water vapour content in the air. The natural processes like intensity of evaporation from water reservoirs surface and soil, transpiration of moisture by plants, freezing and fog formation depend on humidity

The following indicators characterize the air humidity: partial water vapour pressure, relative humidity, saturation deficit and dew point.

The annual rate of relative humidity is characterized by the highest index in the cold period of the year and the lowest - in the warm period, while the annual progress of partial pressure and saturation deficit repeat the annual course of air temperature, it means, the highest index of these indicators are observed in the warmest summer months, and the lowest - in the winter months.

The full summary of air humidity within the 30-kilometer zone of the Rivne NPP is based on the long-term observations data (1945-1997) [11] of Manevichi, Sarny and Rivne meteorological stations and is given in the Table 1.

Table 1.5. Average monthly and annual values of air humidity.

Meteorological station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Manevichi	Degree of air saturation, %												
	86	84	78	71	68	71	72	74	79	82	87	89	79
	Partial water vapour pressure, hPa												
	4,0	4,2	5,0	7,2	10,3	13,2	14,7	14,4	11,6	8,6	6,5	4,9	8,7
	Saturation deficit, hPa												
	0,7	0,8	1,6	3,8	6,2	6,9	7,1	6,4	3,9	2,1	1,0	0,6	3,4
Rivne	Degree of air saturation, %												
	86	85	82	73	70	73	74	75	78	82	87	88	79
	Partial water vapour pressure, hPa												
	4,0	4,2	5,2	7,6	10,8	13,7	15,1	14,7	11,7	8,5	6,4	4,9	8,9
	Saturation deficit, hPa												
	0,6	0,7	1,4	3,5	5,7	6,3	6,6	6,1	4,1	2,2	1,0	0,6	3,2
Sarny	Degree of air saturation, %												
	84	83	78	71	67	69	71	74	78	82	87	88	78
	Partial water vapour pressure, hPa												
	3,7	4,0	4,9	7,3	10,2	13,3	14,8	14,6	11,5	8,4	6,5	5,0	8,7
	Saturation deficit, hPa												
	0,6	0,8	1,6	3,8	6,2	7,5	7,4	6,3	4,2	2,2	1,0	0,6	3,5

According to the Table 1.5, the air humidity parameters within the monitoring area are nearly identical:

- average annual relative humidity is 78-79%;
- average annual partial water vapour pressure - 8,7-8,9 hPa;
- saturation deficit - 3,2-3,5 hPa.

The data on the dewpoint temperature (the temperature to which air must be cooled to become saturated with water vapour under constant pressure) in the monitoring area are given by Manevichi, Rivne, Sarny meteorological stations for the period 1976-1997 (Table 1.6).

Table 1.6. Average monthly and annual dewpoint temperature.

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Manevichi meteorological station												
-6,1	-6,2	-2,6	1,6	7,1	10,7	12,4	12,0	9,0	4,2	-0,2	-3,7	3,2
Sarny meteorological station												
-6,5	-6,5	-2,5	1,9	7,4	11,1	12,5	12,0	8,8	4,1	-0,4	-4,0	3,2
Rivne meteorological station												
-6,5	-6,4	-2,4	2,1	7,6	11,3	12,7	12,2	8,9	4,2	-0,4	-4,1	3,3

The dewpoint temperature is nearly identical within zone: 3,2-3,3°C per year, minus 6,1-6,5°C in the coldest winter months and 12,0-12,7°C in the warmest summer months.

1.2.1.3 Soil temperature

The soil temperature depends on many factors: air temperature, physical and mechanical characteristics of soil, its humidity, presence of vegetation or snow cover, location altitude, etc. The lapse rates of soil temperature differ in the winter and summer periods. In the warm season, the soil temperature decreases in passing to the deeper layers and in the cold season it raises. There are significant fluctuations of soil temperature during the day.

The highest temperatures of soil surface are observed in July. In August, the soil temperature begins to go down. In the next months (September-October), the decrease of temperature is the most intensive. The lowest soil temperatures are observed in January-February.

The Table 1.7 shows the annual course of average monthly temperature of soil surface, as well as the absolute maximum and minimum temperatures of soil layer. Despite the different types of soil layer, its temperature in this territory is characterized by nearly identical index: average annual temperature of soil surface is 8,0°C, the absolute maximum is 58°C, the absolute minimum is minus 39°C.

Table 1.7. Average monthly, maximum and minimum temperature of soil surface.

in ^{0}C

Characteristics	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Sarny meteorological station, sandy soil													
Average	-6	-5	0	9	17	21	23	20	14	8	2	-2	8
Absolute maximum	13	15	32	48	53	58	57	55	46	34	23	13	58
Absolute minimum	-39	-35	-29	-8	-4	1	4	2	-4	-10	-28	-31	-39

As for the soil temperature to a depth of 3,2 m (by removable thermometers), the approximate estimation of annual rate of temperature at standard depths is given in the Table 1.8 and based on the data of Sarny and Lyubeshiv meteorological stations.

Table 1.8. Average monthly and annual soil temperature at standard depths by removable thermometers (under natural cover)

in ^{0}C

Depth, m	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Sarny meteorological station, sandy soil													
0,4	-0,5	-1,6	0,4	6,5	13,9	18,4	20,4	18,8	14,4	8,8	3,8	0,8	8,7
0,6	0,2	-0,3	0,3	6,2	12,8	17,3	19,1	18,3	14,7	9,2	5,0	1,9	8,7
0,8	1,0	0,3	0,7	5,8	12,0	16,4	18,4	17,8	14,7	9,7	5,6	2,6	8,8
1,6	4,1	3,1	2,9	5,3	9,4	12,7	14,8	15,4	14,4	11,1	8,1	5,5	8,9
2,4	6,0	4,9	4,4	6,4	8,0	10,6	12,7	13,7	13,8	11,8	9,6	7,5	9,0
Lyubeshiv meteorological station, sod-podzolic sandy-loam soil													
0,2	-0,9	-1,1	0,4	6,0	13,4	17,6	19,4	17,9	14,4	8,9	3,8	0,7	8,4
0,4	0,0	-0,3	0,6	5,2	12,1	16,1	18,0	17,3	14,1	9,6	4,9	1,6	8,3
0,8	1,7	0,8	1,1	4,5	10,4	14,3	16,3	16,4	14,5	10,8	6,8	3,5	8,4
1,6	3,7	2,8	2,4	4,0	8,2	11,8	14,0	14,9	14,0	11,6	8,6	5,5	8,5
3,2	6,9	5,9	5,2	6,0	7,4	9,1	10,6	12,1	12,3	11,1	9,6	8,0	8,7

The soil temperature at a depth in the northern part of the zone is slightly lower than in the rest of the territory (0,4-0,5˚C at all levels of standard depths). In general, the average annual soil temperature at a depth of 0,4 m is 8,3-8,7˚C, at a depth of 1,6 m – 8,5-8,9˚C, at a depth of 2,4 -3,2 m - about 9˚C which were recorded on the territory of the 30-kilometer zone of the Rivne NPP.

In the cold season, the negative soil temperature remains at a depth of 0,4 m and equals to minus 0,3-1,6˚C. The soil temperature remains positive in deep layers, but continues to decrease until March-April.

The maximum index of soil temperature at a depth of 2,4-3,2 m is observed in August-September (12,3-13,8°C), while the maximum temperature of surface layer is recorded in July-August.

1.2.1.4 Solar radiation

The estimation of solar radiation in the area of the Rivne NPP is based on the long-term data of Kovel meteorological station [13], which is the reference station for actinometric observation in the north-western region of Ukraine. The station is designated for the territory of the 30-kilometer zone of the NP "Rivne NPP".

These data indicate: normal beam, scattered and total solar radiation on the horizontal surface under moderate cloud conditions and radiation balance (Table 1.9).

Table 1.9. Amount of normal beam, scattered and total solar radiation on the horizontal surface under moderate cloud conditions and radiation balance

in MJ/m^2

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Normal beam solar radiation												
27	37	117	154	262	285	264	247	149	71	26	11	1650
Scattered solar radiation												
56	84	160	196	255	258	279	226	163	99	53	41	1870
Total solar radiation												
82	121	277	350	517	542	543	473	312	170	79	52	3528
Radiation balance of surface activity												
34	16	35	178	287	332	308	228	148	51	14	18	1502

The highest index of solar radiation is observed in June-July, the lowest – in November-December. The annual amount of normal beam solar radiation in the area of the Rivne NPP is 1650 MJ/m^2, the scattered - 1870 MJ/m^2.

1.2.1.5 Cloud coverage

The character of cloud regime is determined by the interaction of the main climate-forming factors: atmospheric circulation, radiation factors and geological substrate. The atmospheric circulation plays the essential role, especially in the cold period of the year.

This section reviews the main quantitative characteristics of the cloud regime: number of general and lower clouds and number of clear and grey days [10-13] (Tables 1.10 and 1.11).

Table 1.10. Average monthly and annual general and lower clouds

in balls

Clouds characteristics	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
	Sarny meteorological station												
General	7,4	7,3	6,5	6,1	5,5	5,3	5,2	5,0	5,2	6,3	8,0	8,0	6,3
Lower	5,8	5,7	4,6	4,1	3,4	3,4	3,3	3,2	3,5	4,7	6,8	6,7	4,6
	Rivne meteorological station												
General	8,0	7,8	7,0	6,6	6,2	5,9	5,8	5,6	5,6	6,6	8,2	8,1	6,8
Lower	5,6	5,7	4,6	3,7	3,3	3,3	3,1	2,9	3,1	4,2	6,0	6,2	4,3

The annual amount of clouds within the monitoring area is 6,3- 6,8 points for general cloudiness and 4,3-4,6 points for the lower one. In the context of the year, the maximum cloudiness is observed during the cold period (8,0 – 8,1 points in general cloudiness). The lower cloudiness is mostly observed in November-December (6,0-6,8 points). The minimum cloudiness, both general and lower, is observed in August (5,0-5,2 general and 2,9-3,2 lower points). The diurnal variation of cloudiness is feebly marked in the cold period of the year; in the warm period – the maximum cloudiness is observed in the middle of the day under influence of the convection processes and less at the night.

The annual number of clear and grey days, both under general and lower clouds is shown in the (Table 1.11). The maximum number of clear days under general and lower clouds during the year is in August-September and the minimum in November-December. The maximum number of grey days is observed in the cold period of the year with a peak in December, the minimum - in the warm period of the year, with a lowest number in July.

Table 1.11. The average number of clear and grey days under general and lower clouds

Clouds	Month											Year	
	01	02	03	04	05	06	07	08	09	10	11	12	
	Clear days												
General	3,1	2,1	3,1	1,5	3,3	3,2	3,4	5,7	4,1	2,5	0,9	1,3	34,2
Lower	6,3	5,3	8,5	7,4	9,9	9,3	9,1	11,5	9,5	6,3	2,3	2,9	88,3
	Grey days												
General	16,6	14,4	10,6	9,9	7,1	6,1	5,5	5,2	6,1	11,6	17,5	19,5	130,1
Lower	8,7	8,8	5,0	4,3	3,1	1,5	1,5	2,0	2,5	5,9	11,0	13,1	67,4

1.2.1.6 Atmospheric precipitation

According to the amount of precipitation, the monitoring area, as well as the entire western part of Ukraine, refers to a zone of sufficient moistening. There are all forms of precipitation: liquid, solid and mixed in the monitoring area. The precipitation is distributed quite irregularly during a year.

In the winter, the amount of precipitation in the northern part of the zone is only 15% of the annual amount, on the rest of the territory is 17-18%. In the spring, the amount of precipitation increases to 21% of the annual amount of precipitation. In the summer, the amount of precipitation is 36% of the annual amount on the north, 37% in the western, central and eastern parts of the zone and 39-40% in the territory of the southeastern and south-western parts of the zone.

The Tables 1.12-1.19 show the long-term characteristics of atmospheric precipitation according to the data of Lyubeshiv, Manevichi, Sarny, Rivne and Lutsk [11]. meteorological stations located along the perimeter of the 30-kilometer zone of the Rivne NPP. The data are presented with corrections to the readings of the precipitation gauge. The observation period is 53-63 years.

Table 1.12. Average monthly and annual amount of precipitation.

in mm

Month												Period		Year
01	02	03	04	05	06	07	08	09	10	11	12	cold (11-03)	warm (04-10)	
Lyubeshiv meteorological station														
32	30	29	36	57	76	82	56	58	45	46	42	178	410	588
Manevichi meteorological station														
38	37	34	42	61	79	86	63	62	46	51	49	209	439	648
Sarny meteorological station														
34	33	30	42	63	85	84	65	57	48	45	41	183	444	627
Rivne meteorological station														
29	29	28	44	58	77	86	68	54	43	41	39	166	470	596
Lutsk meteorological station														
29	28	29	39	58	76	82	67	55	41	38	37	161	418	579

According to the annual amount of precipitation, the minimum amount is observed all over the territory in March (28-34 mm). Since April the amount of precipitation increases day by day until July with the maximum monthly amount of precipitation (82-86 mm). Since August the amount of precipitation progressively goes down, reaching 29-38 mm in January-February.

The distribution of precipitation throughout the year and along the territory of the zone is characterized by the largest precipitation in the central part of the zone, in the direction from east to west (627 - 648 mm, Sarny and Manevichi meteorological station); to the north from the central part of the zone the precipitation decreases to 588 mm (Liubeshiv meteorological station) and to the south - to 596-579 mm (Rivne and Lutsk meteorological stations).

Depending on the form of precipitation, it is accepted to divide the year into two periods: cold (November-March) with predominance of solid precipitation and warm (April-October) with predominance of liquid precipitation. On the territory of the Rivne NPP, 27-32% of annual amount of precipitation occurs in the cold period and 68-72%. in the warm one.

In the cold period of the year, the largest amount of precipitation occurs in the central part of the NPP zone (209 mm). To the north and east the amount of precipitation in this period goes down to 178-183 mm.

In the warm period, the amount of precipitation on the territory of the monitoring area varies from 410 mm to the north and 416-418 mm on the south to 434-439 mm in the central part.

Consequently, the monitoring area is considered as one with a continental type of annual amount of precipitation: the amount of precipitation in the warm period exceeds the amount in the cold period.

The Tables 1.13 and 1.14 present the data on the maximum and minimum monthly and annual amount of precipitation in the area.

Table 1.13. Maximum monthly and annual amount of precipitation.

in mm

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv meteorological station												
97	83	75	78	138	187	181	159	136	154	145	96	843
Manevichi meteorological station												
92	84	91	118	142	211	233	146	135	171	136	110	994
Sarny meteorological station												
106	94	95	150	165	242	245	181	212	143	157	98	868
Rivne meteorological station												
84	73	73	118	132	211	203	149	151	159	176	91	793

The maximum annual amount of precipitation on the north of the 39-kilometer zone is 843 mm, in the central and western part of the zone is 994 mm, in the east is 868 mm, in the south-west of 793 mm. The maximum monthly amount of precipitation is recorded in June and July.

In the central part of the zone where the site of the Rivne NPP is located, the maximum monthly amount of precipitation equals to 233-245 mm.

Table 1.14. Minimum monthly and annual amount of precipitation.

in mm

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv meteorological station												
6	3	1	3	18	16	1	6	15	3	11	4	298
Manevichi meteorological station												
7	3	2	10	14	18	15	5	12	3	9	5	326
Sarny meteorological station												
6	3	0	6	15	19	4	5	13	1	10	6	389
Rivne meteorological station												
4	4	1	3	13	21	19	13	7	2	7	6	347

The lowest annual amount of precipitation in the 30-kilometer zone was observed all over the territory in 1961 and equalled to 298 mm on the north and 389 mm in the eastern part of the zone.

Both liquid and solid mixed forms of precipitation may occur in the 30-kilometer zone of the Rivne NPP. The solid and mixed precipitations occur in autumn, winter and even in the spring months (from October to March, less often in April and rarely in May).

According to the data of Manevichi meteorological station (Table 1.15) the distribution of various forms of precipitation during the year in the monitoring area is as follows: 79% liquid, 10% solid and 11% mixed of the annual amount of precipitation.

Table 1.15. Monthly and annual amount of liquid, solid and mixed precipitation.

in mm

Precipi-tation	Month												Year	
	01	02	03	04	05	06	07	08	09	10	11	12	mm	%
Liquid	8	6	7	34	64	86	80	73	57	49	34	14	512	79
Solid	18	19	12	1	0	0	0	0	0	1	3	13	67	10
Mixed	11	12	11	9	1	0	0	0	0	2	10	13	69	11

The summary of daily precipitation is given in the Table 1.16. Unlike the precipitation of long-time periods, the daily precipitation has more evident local character.

Table 1.16. Maximum daily precipitation.

in mm

Meteorolo gical station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv	27	17	20	27	52	68	119	49	65	41	28	26	119
Manevichi	22	23	26	26	36	64	103	50	54	44	33	24	103
Sarny	24	35	21	44	63	97	69	70	106	40	36	22	106
Rivne	17	25	23	42	34	58	66	57	48	42	28	24	66
Lutsk	16	29	29	31	38	52	87	114	52	46	37	25	114

The maximum daily precipitation is usually observed in July, less often in June or August. In total, the maximum amount of precipitation does not vary within the zone of the Rivne NPP, except in the south-eastern part of the zone, where the daily maximum has a tendency to decrease (based on data from meteorological stations). The extremely highest daily precipitation (103-119 mm) may exceed the monthly amount of summer precipitation in approximately 1,2-1,5 times. The lowest daily precipitation is observed in the cold period of the year.

The average number of days with precipitation during the year within the zone (Table 1.17) varies from 145 to 159 days. The greatest number of days with precipitation occurs in the winter months (December - January), 15-17 days in the summer months. The lowest number of days with precipitation is in the summer period, 13-14 days per month.

Table 1.17. Average number of days with precipitation is ≥ 0.1 mm

Meteorolo-gical station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv	15	14	12	11	12	12	12	10	11	11	14	16	150
Manevichi	15	14	13	11	12	14	13	9	12	10	15	17	156
Sarny	15	13	12	11	13	13	13	11	12	12	14	16	154

Meteorolo-gical station	01	02	03	04	05	06	07	08	09	10	11	12	Year
Rivne	16	14	13	11	13	13	13	12	11	11	15	17	159
Lutsk	14	13	12	11	12	13	13	11	11	11	12	14	145

The longest duration of precipitation is observed in the southern part of the 30-kilometer zone, both during the year and in the certain months. In the cold season, the precipitations are the most long lasting (Table 1.18).

Table 1.18. Average monthly and annual precipitation

in hours

Meteorolo-gical station	Month 01	02	03	04	05	06	07	08	09	10	11	12	Year
Manevichi	118	101	75	56	50	62	50	35	60	57	100	129	895
Sarny	124	118	93	71	67	84	70	56	85	74	109	133	1084
Rivne	150	134	97	72	71	82	70	62	78	81	126	171	1196

The data on maximum precipitation intensity at different time intervals were recorded in the periods 1952-1959, 1985-1997 at the Kovel meteorological station, where there is a pluviogram (Table 1.19).

Table 1.19. Maximum intensity and depth of precipitation for different time intervals (observing)

Characteristics	Dimension	Time interval: Minute 5	Minute 10	Minute 20	Minute 30	Hour 1	Hour 12	Hour 24
Intensity	mm/min l/c·h	2,6 434	2,1 350	1,6 266	1,3 217	0,7 117	0,10 17	0,06 10
Depth of precipitation	mm	13	21	32	39	40	68	86
Date		08.08.1958				05-06.09.1992		

Note: The precipitations which fell on September 5-6, 1992 lasted 27 hours and 13 minutes and had the precipitation depth of 90.5 mm; in the interval of 24 hours they were equalled to 86 mm.

The estimated precipitation intensity of 20 minutes with the recurrence rate 1 time per year equals to 0.6 mm/min or 100 l/sec-ha and with the recurrence rate 1 every 5 years equals to 0.96 mm/ min or 160 l/sec-ha. [11].

The wind direction during precipitation in the zone of the Rivne NPP and in the period of the year (Table 1.20) is given according to the data of Manevichi and Sarny meteorological stations. These data were collected within the last 12 years. The most frequent are precipitations with winds of western direction (26-29% cases) and northwest direction (22% cases), most rarely – north-eastern direction (3-5% cases). During calmness the precipitation equals to 5-8% cases.

Table 1.20. Wind direction frequency during precipitation in the period of the year

in % from number of cases

Meteorological station	Wind direction (rhumb)								
	N	NE	E	SE	S	SW	W	NW	Calmness
Manevichi	10,5	3,1	7,6	8,4	8,5	9,3	25,9	21,7	5,0
Sarny	9,0	5,4	8,2	7,0	11,0	10,6	29,5	10,9	8,4

The estimation of atmospheric precipitation data of the monitoring area of the Rivne NPP showed the following:

- maximum annual amount of precipitation falls in the western, central and eastern parts of the area (64-627 mm);
- to the north and south of the central part the precipitation decreases to 588 mm on the north and 579 mm on the south;
- maximum daily precipitation is 103-119 mm;
- Prevailing wind direction during precipitation – the western and the north-western;
- maximum long-term daily amount of precipitation in the territory of the 30-kilometer zone was not exceeded during the years of the NPP operation,
- intensity of precipitation at different time intervals is identical for the entire zone.

1.2.1.7 Snow cover

In the cold period of the year, some precipitation falls in the form of snow. The snow cover is characterised by its depth, density and water reserves in the snow.

The snow cover in the monitoring area is formed averagely within a month, starting from the date of snow cover appearance until the date of stable snow cover formation, it means from November 20 to December 17-19.

In some years, the snow cover may be formed earlier or later than the indicated average dates.

The first snow usually does not stay all winter, under the influence of thaw, the snow is melting.

The melting of stable snow cover occurs in the middle of March. Therefore, the number of days with snow cover in the 30-kilometer zone of the Rivne NPP is 80-85 days (Table 1.21). The intensity of melting of stable snow cover, as well as the loss of snow cover, depends on the local conditions. The latest date of the loss of snow cover is the first decade of April.

Table 1.21. Average number of days with snow cover, date of snow cover formation and snow cover melting (long-term annual average).

Meteorological station	Wind direction (rhumb)								
	N	NE	E	SE	S	SW	W	NW	Calmness
Manevichi	10,5	3,1	7,6	8,4	8,5	9,3	25,9	21,7	5,0
Sarny	9,0	5,4	8,2	7,0	11,0	10,6	29,5	10,9	8,4

From the date of formation of stable snow cover; its depth is gradually increasing during the winter and reaching a maximum in the second decade of February. The average decade depth of snow cover is 9-12 cm in the middle of February in the monitoring area. The average depth of snow cover during the winter is 10-28 cm; the maximum is 39-55 cm (Table 1.22).

Table 1.22. Average decade and maximum snow cover depth measured by a permanent snow stake

in cm

Snow cover depth	Month, ten-days																					Maximum in the winter		
	10			11			12			01			02			03			04					
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	average	maximum	minimum
	Lyubeshiv metrological station (the snow stake is in the exposed place)																							
Average	-	-	•	•	•	1	2	3	3	4	5	6	6	6	6	5	4	2	1	•	•	-	-	
Maximum	14			15			30			41			31			34			18			10	41	
	Rivne metrological station (the snow stake is in the exposed place)																							
Average	-	-	•	•	•	2	3	4	7	8	11	12	10	12	13	10	12	3	•	•	•	-	-	
Maximum	-			15			12			51			49			39			12			21	51	
	Lutsk metrological station (the snow stake is in the exposed place)																							
Average	-	-	•	•	2	2	3	4	4	6	7	8	8	9	10	10	9	4	•	•	-	-	-	
Maximum	1			15			11			55			54			48			22			28	55	
Sarny metrological station (the snow stake is in the exposed place)																								
Average	-	•	•	•	•	1	2	3	3	6	8	9	9	9	9	6	4	2	•	•	•	-	-	
Maximum	•			14			13			39			33			27			•			17	39	

Note. The point (•) means that the snow cover in the beginning and at the end of the winter was observed in less than 50% of the winter and the average depth was not calculated

The density of the snow cover depends on the weather conditions. According to the Sarny, Lutsk and Rivne meteorological stations (snow measuring records), the average density of snow cover in the first decade of January, when the fresh snow is not yet settled, equals to 98 kg/m^3 on the east and 143-150 g/m^3 on the north. By the end of January, the density of snow cover reaches its maximum (133 kg/m^3 on the east and 159-165 kg/m^3 on the south), remaining at this level almost to the loss of snow. At the maximum ten-day depth, the average density is 216 kg/m^3 on the east and 238-240 kg/m^3 on the south of the 30-kilometer zone.

The water reserves of snow cover in the first decade of January equal to 15 mm, increasing by the end of January to 24 mm. The highest water reserves of snow cover are during the winter period and equal to 120 mm on the south of the 30-kilometer zone and 101 mm on the east and the lowest are 8-10 mm. The water reserves depend mostly on the location altitude, its immunity and diversity of the area.

1.2.1.8 Soil freezing

The seasonal soil freezing depends on many factors: degree of soil moisture, depth of snow cover, type of soil and its mechanical composition, landscape, etc. The data on the soil freezing within the monitoring territory of the Rivne NPP is provided in accordance with the observations from Lyubeshiv, Sarny, Rivne, Lutsk meteorological stations [14] and OSSP-2005 [15].

The longest depth of soil freezing based on the observation data of Lyubeshiv meteorological station is 98 cm (sod-podzolic sandstone soil), Sarny meteorological station - 103 cm (sandy soil), Rivne meteorological station - 128 cm (podzolized chernozem soil) and Lutsk meteorological station - 117 cm (grey podzolic loam soil).

The standard depth of seasonal soil freezing in the monitoring area of the Rivne NPP, respectively, [15] is:

- for loam and sandy loam soil - 83 cm;
- for sandy and loamy sand soil - 100 cm.

The maximum depth of soil freezing is determined according to the observations of the above-listed meteorological stations.

1.2.1.9 Evaporation

The evaporation is the flow of water vapour into the atmosphere from the water surface, snow, ice, moistening soil, etc.

The data on evaporation in the monitoring territory are given in the Tables 1.23 and 1.24 according to the observations of Sarny meteorological station [10-13].

The annual amount of evaporation from land surface (total evaporation) within the monitoring area is 365 mm, the highest average monthly amount of 71 mm occurs in July. The observations were not performed during the winter months.

Table 1.23. Total evaporation from land surface

in mm

Characteristics	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Average	-	-	2	33	65	64	71	59	40	25	6	-	365

Characteristics	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Maximum	-	-	26	80	173	141	143	111	100	42	21	-	716
Minimum	-	-	-	4	25	30	23	19	20	7	-	-	236

Table 1.24. Evaporation from water surface

in mm

Characteristics	Month									Year
	03	04	05	06	07	08	09	10	11	
Average	2	49	104	110	120	105	66	38	8	602
Maximum	-	129	173	231	198	152	92	53	-	946
Minimum	-	38	65	42	71	74	46	27	-	419

The average annual amount of evaporation from water surface in the ice-free period is 602 mm, the maximum is 946 mm and the minimum is 419 mm. During the ice-free period, the maximum average monthly amount of evaporation occurs in the summer months (110-120 mm in June-July). In the dry rain-free years, the evaporation in the summer months can increase to 198-213 mm.

1.2.1.10 Wind

The wind is a horizontal movement of air relative to the surface of the earth. The principal wind characteristics are wind speed and wind direction. Both of these characteristics are determined by the pressure (baric) area, which in our case is specific for entire Ukraine and for the irregular surface of the monitoring area.

The wind regime is the main factor determining the distribution of impurities. The wind causes the horizontal dispersion of pollutants, removes them from the source of emissions and transfer outside of the 30-kilometer zone limits.

The unfavourable conditions for distribution of impurities and self-purification of the atmosphere are formed under weak winds at the speed of up to 2 m/s and calmness.

The observation data [14] of five meteorological stations: Lyubeshiv, Manevichi, Sarny, Rivne (1966-1997) and Lutsk (1984-1997) and the aerological station of Shepetivka were used to study the wind characteristics in the 30-kilometer zone of the Rivne NPP. The location of the stations is shown in Fig. 1.1.

The Tables 1.25-1.29 provide data on frequency of wind directions according to the meteorological stations which were determined as the reference stations to estimate the wind conditions in the territory of the 30-kilometer zone of the Rivne NPP and the wind speed in directions. The Fig. 1.2 - 1.6 reflect the wind patterns (wind rose) according to the data of the above-mentioned stations. The characteristics of wind speed with no reference to directions are given in the Table 1.30.

According to the provided data, the wind regime on the territory of the 30-kilometer zone of the Rivne NPP has the following features.

During the year, the winds of western direction predominate on the territory of the Rivne NPP. The same direction is most pronounced during the warm and cold periods, as well as for other seasons of the year.

On the north of the zone, the annual frequency of western winds is 23,0% (Lyubeshiv meteorological station), in the eastern part 19,4% (Sarny meteorological station), in the central and western parts 20.4% (Manevichi meteorological station), in the south-eastern part - 24.6% (Rivne meteorological station) and in the south-western part - 21,1% (Lutsk meteorological station).

The calmness frequency during the year equals to 19,4% in the northern part of the zone, 11,4% in the western and the central parts, 15,7% in the eastern, 8.9% in the south-eastern and 3.1%.in the south-western parts.

Depending on season of the year, the calmness is distributed in the following way: in the northern part of the zone, the calmness equals to 14,7% in winter, 18% in spring and autumn and 26.5% in summer. In the central and western parts of the zone, the minimum calmness is in winter (7,2%) and the maximum in summer (15,8%). In the eastern part of the zone, the maximum calmness is in summer (23%) and the minimum in winter (10,9%). In the south-eastern part of the zone the frequency of calmness is 14,1% in summer, 6%, in winter and 8% in spring and autumn.

In the south-western part of the zone there is a tendency of less calmness frequency. In conclusion, according to the data provided by Lutsk meteorological Station, the calm conditions are observed here occasionally and the number of calmness is practically identical during all seasons of the year (2,5-3,5%). The winds of variable direction at a speed up to 2m/s are more frequent than calmness in this part of the zone. The annual frequency of these winds is 11.3%, the maximum in summer - 19.1%.

Table 1.25. Frequency of wind direction, calmness and average wind speed in the directions. Lubeshiv meteorological station

Month, season, year	Direction (rhumb)								Calmness
	N	NB	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	4,2	6,4	14,1	14,1	10,9	17,2	25,3	7,8	14,3
February	5,6	7,8	17,1	16,1	10,3	13,4	21,4	8,3	15,4
March	5,4	7,5	16,5	16,1	12,6	13,6	19,6	8,7	14,2
April	8,7	9,4	13,1	13,3	10,4	12,2	20,7	12,2	17,5
May	10,5	10,0	15,7	12,9	10,7	9,6	16,7	13,9	21,6
June	10,9	8,9	9,0	8,2	8,5	11,5	25,0	18,0	24,8
July	9,4	7,7	9,0	7,3	8,2	14,2	26,5	17,7	24,4
August	7,8	9,0	11,3	10,3	11,3	13,1	23,0	14,2	30,4
September	5,4	5,9	8,4	11,4	12,0	16,8	27,8	12,3	23,0
October	5,4	4,0	10,4	13,3	13,9	17,2	25,0	10,8	18,9
November	3,7	4,7	11,7	16,4	15,4	19,6	21,4	7,1	14,3
December	4,3	4,7	12,1	12,6	13,9	19,1	24,5	8,8	14,5
Winter	4,7	6,3	14,4	14,3	11,7	16,6	23,7	8,3	14,7
Spring	8,2	9,0	15,1	14,1	11,2	11,8	19,0	11,6	17,8
Summer	9,4	8,5	9,7	8,6	9,4	13,0	24,8	16,6	26,5
Autumn	4,8	4,9	10,1	13,7	13,8	17,9	24,7	10,1	18,5
Warm period	7,9	7,8	11,7	11,6	11,0	13,5	23,0	13,5	21,8
Cold period	4,4	5,9	13,8	14,8	12,6	17,3	23,2	8,0	14,6

Month, season,	Direction (rhumb)								Calmness
Year	6,8	7,2	12,4	12,7	11,5	14,8	23,0	11,6	19,4
b) Wind speed by direction indicator, m/s									
January	2,4	2,6	2,4	2,5	3,0	3,7	4,0	3,7	0,0
February	2,4	2,3	2,4	2,8	3,2	3,7	3,9	3,3	0,0
March	2,4	2,8	2,4	2,7	2,8	3,6	4,6	3,5	0,0
April	3,0	2,6	2,5	2,7	2,8	3,3	4,0	3,5	0,0
May	2,7	2,6	2,2	2,3	2,5	2,8	3,0	2,9	0,0
June	2,5	2,3	1,9	2,1	2,4	2,9	3,3	3,1	0,0
July	2,5	1,9	2,0	2,2	2,4	2,6	3,1	2,8	0,0
August	2,5	2,3	2,0	2,1	2,2	2,5	3,0	2,7	0,0
September	2,8	2,1	1,9	2,3	2,7	3,2	3,4	3,1	0,0
October	2,4	2,3	2,3	2,5	2,5	3,4	3,6	3,1	0,0
November	2,9	2,1	2,3	2,7	2,9	3,8	4,3	3,3	0,0
December	2,8	2,4	2,0	2,6	2,9	3,8	4,0	3,2	0,0
Winter	2,5	2,4	2,3	2,6	3,0	3,7	4,0	3,4	0,0
Spring	2,7	2,7	2,4	2,6	2,7	3,2	3,9	3,3	0,0
Summer	2,5	2,2	2,0	2,1	2,3	2,7	3,1	2,9	0,0
Autumn	2,7	2,2	2,2	2,5	2,7	3,5	3,8	3,2	0,0
Warm period	2,6	2,4	2,2	2,4	2,5	3,0	3,5	3,1	0,0
Cold period	2,6	2,4	2,3	2,7	3,0	3,8	4,1	3,4	0,0
Year	2,6	2,4	2,2	2,5	2,7	3,3	3,7	3,2	0,0

Table 1.26. Frequency of wind direction, calmness and average wind speed in the directions. Manevichi meteorological station

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, (%)									
January	6,2	4,4	12,2	16,0	11,3	15,0	21,8	13,1	7,7
February	7,0	6,1	15,5	17,4	11,3	11,4	18,8	12,5	7,5
March	7,2	6,0	14,3	18,6	13,5	11,5	18,1	10,8	9,5
April	11,3	7,6	12,2	14,6	11,5	10,7	16,7	15,4	12,1
May	14,2	8,6	13,4	15,2	11,6	8,0	14,7	14,3	13,7
June	15,1	7,6	7,5	10,0	9,4	9,8	20,3	20,3	14,3
July	14,6	7,1	7,2	8,6	8,0	10,6	22,8	21,1	14,9
August	13,6	7,8	8,4	12,1	11,2	9,4	20,2	17,3	18,2
September	8,2	4,7	7,1	13,7	12,1	12,5	26,1	15,6	14,3
October	6,5	3,4	8,1	16,4	15,0	15,4	22,7	12,5	10,8
November	5,6	3,7	9,4	18,2	15,5	17,7	19,8	10,1	7,6
December	6,3	4,0	9,4	15,6	13,9	16,1	22,6	12,1	6,3
Winter	6,5	4,8	12,4	16,3	12,1	14,2	21,1	12,6	7,2
Spring	10,9	7,4	13,3	16,1	12,2	10,1	16,5	13,5	11,8
Summer	14,4	7,5	7,7	10,3	9,5	9,9	21,1	19,6	15,8
Autumn	6,8	3,9	8,2	16,1	14,2	15,2	22,9	12,7	10,9
Warm period	11,3	6,6	9,8	13,7	11,5	11,0	20,2	15,9	13,5
Cold period	6,3	4,6	11,6	16,8	13,0	15,0	20,8	11,9	7,3

Year	9,7	5,9	10,4	14,7	12,0	12,3	20,4	14,6	11,4
b) Wind speed by direction indicator, m/s									
January	2,7	2,1	2,6	2,5	2,6	2,9	3,4	3,5	0,0
February	2,6	2,1	2,7	3,1	2,6	3,1	3,4	3,1	0,0
March	2,5	2,3	2,8	2,9	2,7	3,2	3,6	3,6	0,0
April	2,9	2,4	2,5	2,9	2,9	3,1	3,2	3,3	0,0
May	2,7	2,4	2,4	2,6	2,5	2,7	2,7	2,9	0,0
June	2,6	2,2	2,3	2,4	2,4	2,5	2,8	3,1	0,0
July	2,7	2,2	2,1	2,3	2,3	2,4	2,8	2,9	0,0
August	2,4	1,9	2,1	2,2	2,2	2,3	2,7	2,7	0,0
September	2,5	1,9	2,1	2,3	2,4	2,6	2,8	3,2	0,0
October	2,5	2,1	2,2	2,5	2,4	2,8	3,2	3,1	0,0
November	3,0	1,9	2,6	2,9	2,6	3,0	3,6	3,3	0,0
December	2,8	2,1	2,2	2,7	2,6	3,1	3,4	3,4	0,0
Winter	2,7	2,1	2,5	2,8	2,6	3,0	3,4	3,3	0,0
Spring	2,7	2,4	2,6	2,8	2,7	3,0	3,2	3,2	0,0
Summer	2,6	2,1	2,2	2,3	2,3	2,4	2,8	2,9	0,0
Autumn	2,7	2,0	2,3	2,6	2,4	2,8	3,2	3,2	0,0
Warm period	2,6	2,2	2,3	2,5	2,5	2,7	3,0	3,1	0,0
Cold period	2,8	2,1	2,5	2,8	2,6	3,0	3,5	3,3	0,0
Year	2,7	2,1	2,4	2,6	2,5	2,8	3,1	3,2	0,0

Table 1.27. Frequency of wind direction, calmness and average wind speed in the directions. Sarny meteorological station.

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, (%)									
January	7,4	4,9	7,9	13,9	19,3	16,4	20,4	9,8	11,2
February	8,9	5,8	10,7	16,5	16,8	13,0	17,5	10,8	10,0
March	8,5	6,3	12,0	19,1	15,6	11,5	17,4	9,6	12,1
April	12,9	8,3	10,7	14,8	14,2	10,0	16,0	13,1	14,4
May	14,9	9,4	12,2	14,0	13,9	8,2	13,8	13,6	17,5
June	14,8	9,3	7,0	9,2	11,0	10,3	21,2	17,2	20,8
July	14,3	8,8	7,2	7,7	9,7	11,6	21,9	18,8	22,9
August	12,8	9,2	8,6	11,5	11,9	11,6	19,8	14,6	25,4
September	8,8	5,2	6,6	11,5	16,5	14,8	22,5	14,1	18,9
October	7,2	4,4	7,4	16,1	17,2	15,3	21,4	11,0	15,2
November	6,2	3,5	7,6	17,4	19,7	16,2	20,7	8,7	9,8
December	6,5	5,6	7,9	14,4	17,9	16,8	19,9	11,0	10,1
Winter	7,6	5,4	8,8	15,0	18,0	15,4	19,3	10,5	10,4
Spring	12,1	8,0	11,6	16,0	14,6	9,9	15,7	12,1	14,6
Summer	14,0	9,1	7,6	9,5	10,8	11,2	21,0	16,8	23,0
Autumn	7,4	4,4	7,2	15,0	17,8	15,4	21,5	11,3	14,6
Warn period	11,8	7,6	9,0	13,0	13,7	11,7	19,2	14,0	18,4
Cold period	7,2	5,0	8,5	15,6	18,4	15,6	19,6	10,1	10,2
Year	10,3	6,7	8,8	13,8	15,3	13,0	19,4	12,7	15,7

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
b) Wind speed by direction indicator, m/s									
January	3,0	2,5	2,9	3,4	3,3	3,3	3,5	3,8	0,0
February	2,9	3,1	3,2	3,6	3,5	3,3	3,3	3,4	0,0
March	3,1	2,7	3,4	3,3	3,3	3,2	3,7	3,5	0,0
April	3,3	3,1	3,2	3,4	3,3	3,4	3,3	3,4	0,0
May	3,1	3,0	2,9	3,2	3,0	2,8	2,7	2,9	0,0
June	2,8	2,8	2,7	2,5	2,8	2,6	2,7	3,1	0,0
July	3,0	2,4	2,6	2,5	2,6	2,6	2,6	2,9	0,0
August	2,4	2,5	2,4	2,4	2,4	2,5	2,6	2,6	0,0
September	2,8	2,6	2,6	2,9	2,7	2,8	2,8	2,9	0,0
October	2,8	2,4	2,5	2,8	2,8	2,9	3,0	3,0	0,0
November	3,7	2,5	2,7	3,5	3,2	3,1	3,4	3,3	0,0
December	3,2	2,7	2,7	3,2	3,0	3,2	3,4	3,4	0,0
Winter	3,0	2,8	2,9	3,4	3,3	3,2	3,4	3,5	0,0
Spring	3,2	2,9	3,1	3,3	3,2	3,1	3,2	3,3	0,0
Summer	2,8	2,6	2,5	2,5	2,6	2,6	2,6	2,9	0,0
Autumn	3,1	2,5	2,6	3,0	2,9	2,9	3,1	3,1	0,0
Warm period	2,9	2,7	2,8	2,9	2,9	2,8	2,9	3,0	0,0
Cold period	3,2	2,7	2,9	3,4	3,2	3,2	3,4	3,5	0,0
Year	3,0	2,7	2,8	3,1	3,0	3,0	3,1	3,2	0,0

Table 1.28. Frequency of wind direction, calmness and average wind speed in the directions. Rivne meteorological station

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, (%)									
January	5,3	4,0	11,8	14,8	11,8	14,2	28,5	9,6	6,3
February	6,0	4,7	16,8	17,3	11,9	10,6	23,2	9,5	6,6
March	6,4	4,8	16,9	17,9	13,3	11,8	20,8	8,1	6,8
April	10,2	7,7	15,0	14,6	10,5	10,4	19,3	12,3	7,5
May	11,9	8,5	16,9	14,8	11,2	8,5	16,8	11,4	9,8
June	12,4	7,7	10,6	9,2	7,9	10,3	25,4	16,5	12,2
July	12,5	6,6	8,7	7,7	7,4	11,0	28,3	17,8	13,7
August	11,5	8,4	11,4	11,2	9,2	10,8	23,7	13,8	16,6
September	7,6	4,4	9,4	12,4	10,5	13,5	29,0	13,2	10,5
October	5,6	3,3	10,1	15,8	13,8	14,3	26,4	10,7	7,8
November	4,8	3,3	9,8	17,7	15,6	14,8	26,0	8,0	4,5
December	5,0	4,0	10,0	14,5	13,2	15,3	28,0	10,0	5,0
Winter	5,4	4,2	12,9	15,5	12,3	13,4	26,6	9,7	6,0
Spring	9,5	7,0	16,2	15,8	11,7	10,2	19,0	10,6	8,1
Summer	12,1	7,6	10,2	9,4	8,2	10,7	25,8	16,0	14,1
Autumn	6,0	3,7	9,8	15,3	13,3	14,2	27,1	10,6	7,6
Warm period	9,8	6,4	12,4	12,9	10,5	11,3	23,7	13,0	10,6
Cold period	5,3	4,0	12,1	16,1	13,1	13,7	26,4	9,3	5,6

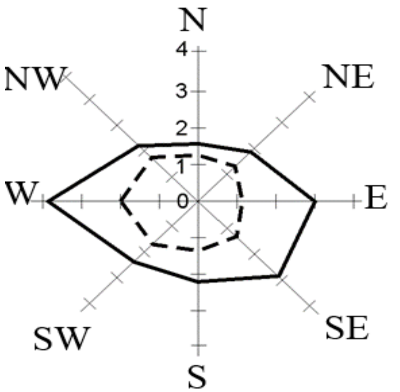
Year	8,3	5,6	12,3	14,0	11,4	12,1	24,6	11,7	8,9
b) Wind speed by direction indicator, m/s									
January	3,7	3,1	3,9	3,9	4,2	5,0	5,8	5,6	0,0
February	4,4	3,7	4,1	4,4	4,3	4,7	5,3	4,9	0,0
March	3,9	3,8	4,2	4,2	4,2	4,6	5,5	5,3	0,0
April	4,5	4,2	4,0	4,2	4,3	4,7	5,1	5,1	0,0
May	4,3	3,8	3,7	3,8	3,8	3,8	4,2	4,5	0,0
June	3,9	3,4	3,2	3,2	3,4	3,5	4,2	4,5	0,0
July	4,0	3,4	2,9	3,1	3,4	3,5	4,0	4,4	0,0
August	3,6	3,6	2,9	3,0	3,2	3,2	3,9	4,2	,0,0
September	3,9	3,4	3,3	3,4	3,7	4,0	4,7	4,9	0,0
October	3,8	3,7	3,7	4,0	3,8	4,3	5,0	5,4	0,0
November	4,3	3,4	4,0	4,4	4,2	4,9	5,8	5,3	0,0
December	4,2	3,7	3,8	4,1	4,4	5,0	5,7	5,6	0,0
Winter	4,1	3,5	3,9	4,1	4,3	4,9	5,6	5,4	0,0
Spring	4,2	3,9	3,9	4,1	4,1	4,3	4,9	5,0	0,0
Summer	3,8	3,5	3,0	3,1	3,3	3,4	4,0	4,4	0,0
Autumn	4,0	3,5	3,6	3,9	3,9	4,4	5,2	5,2	0,0
Warm period	4,0	3,6	3,5	3,6	3,7	3,9	4,6	4,8	0,0
Cold period	4,1	3,5	3,9	4,2	4,3	4,9	5,7	5,3	0,0
Year	4,0	3,6	3,6	3,8	3,9	4,3	4,9	5,0	0,0

Table 1.29. Frequency of wind direction, calmness and average wind speed in the directions. Lutsk meteorological station.

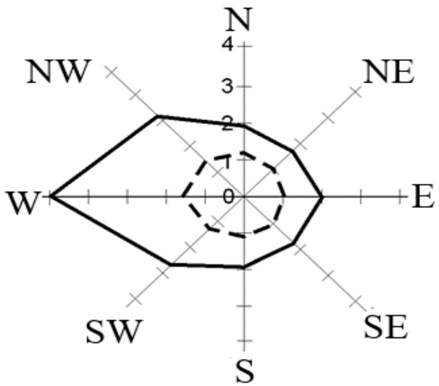
Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, (%)									
January	3,1	3,9	11,9	11,7	13,7	17,7	27,4	10,6	3,3
February	4,7	3,9	14,6	14,1	14,9	13,6	22,9	11,3	3,1
March	5,5	6,0	18,5	18,8	14,8	11,0	16,7	8,7	3,2
April	7,3	5,9	19,5	16,8	13,3	8,1	16,0	13,1	2,4
May	12,6	9,2	15,4	15,8	13,3	8,3	13,2	12,2	3,3
June	12,5	4,4	8,4	9,0	10,0	9,4	24,7	21,6	2,4
July	12,8	6,7	7,0	8,8	9,8	10,2	24,7	20,0	3,9
August	8,8	8,3	10,9	13,1	13,0	10,1	19,2	16,6	4,1
September	6,7	3,6	8,7	10,0	13,5	16,8	26,5	14,2	2,8
October	4,5	2,3	12,4	18,1	16,2	13,8	21,7	11,0	2,6
November	4,9	3,3	11,9	20,5	19,0	12,9	18,9	8,6	2,1
December	5,4	3,4	13,1	13,8	17,7	16,3	20,9	9,4	2,3
Winter	4,4	3,8	13,2	13,2	15,4	15,9	23,7	10,4	2,9
Spring	8,5	7,0	17,8	17,1	13,8	9,2	15,3	11,3	3,0
Summer	11,4	6,5	8,7	10,3	10,9	9,9	22,9	19,4	3,5
Autumn	5,4	3,1	11,0	16,2	16,2	14,5	22,4	11,2	2,5
Warm period	8,8	5,8	12,6	13,8	13,0	11,0	20,3	14,7	3,1
Cold period	4,5	3,6	12,9	15,1	16,3	15,1	22,5	10,0	2,7

Year	7,4	5,1	12,7	14,2	14,1	12,3	21,1	13,1	3,0
b) Wind speed by direction indicator, m/s									
January	4,1	3,4	4,2	4,7	5,4	5,6	5,8	5,4	0,0
February	4,7	3,3	4,9	5,5	4,9	5,3	5,3	5,1	0,0
March	4,1	4,0	5,4	5,1	4,9	5,3	5,4	4,7	0,0
April	4,7	3,9	5,1	5,3	4,6	4,9	5,3	5,3	0,0
May	4,7	4,3	4,4	4,6	4,6	4,5	4,4	4,6	0,0
June	4,3	4,3	4,2	4,2	4,1	4,2	4,2	4,5	0,0
July	4,1	4,0	4,0	3,9	3,8	4,0	4,2	4,3	0,0
August	3,9	3,8	4,1	3,9	3,9	3,7	4,2	4,1	0,0
September	4,2	3,5	4,4	4,7	4,4	4,5	5,1	4,8	0,0
October	4,3	3,4	4,2	5,2	4,8	4,3	4,9	4,5	0,0
November	4,5	4,0	5,0	5,6	4,8	5,0	4,9	4,6	0,0
December	4,4	3,9	5,1	5,5	5,1	5,4	5,9	5,1	0,0
Winter	4,4	3,5	4,7	5,2	5,1	5,4	5,7	5,2	0,0
Spring	4,5	4,1	5,0	5,1	4,7	4,9	5,0	4,9	0,0
Summer	4,1	4,0	4,1	4,0	3,9	4,0	4,2	4,3	0,0
Autumn	4,3	3,6	4,5	5,2	4,7	4,6	5,0	4,6	0,0
Warm period	4,3	3,9	4,5	4,7	4,4	4,4	4,7	4,6	0,0
Cold period	4,4	3,7	4,8	5,3	5,1	5,3	5,5	5,1	0,0
Year	4,3	3,8	4,6	4,9	4,6	4,7	5,0	4,8	0,0

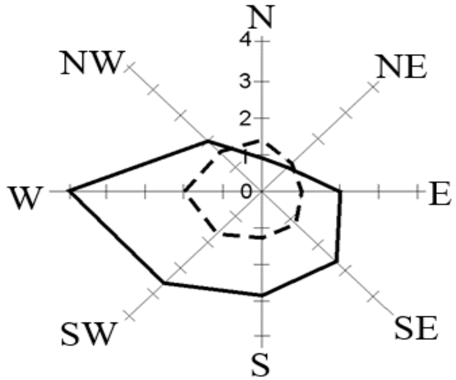
Spring (calmness 17,8 %)



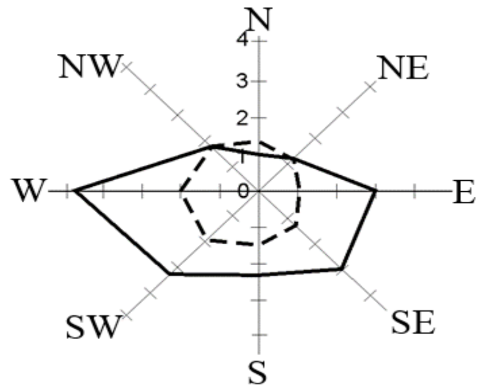
Summer (calmness 26,5 %)



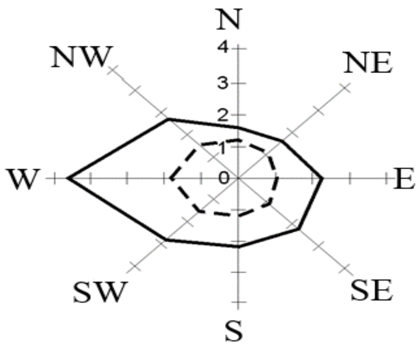
Autumn (calmness 18,5 %)



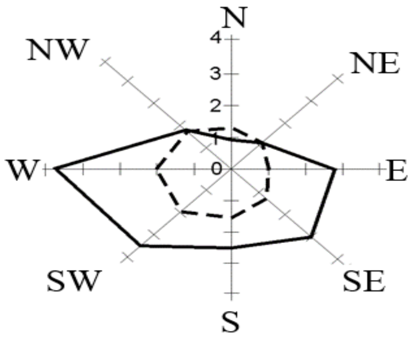
Winter (calmness 14,7 %)



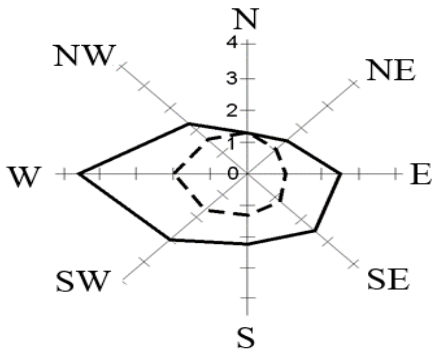
Warm period (calmness 21,8 %)



Cold period (calmness 14,6 %)



Year (calmness 19,4 %)

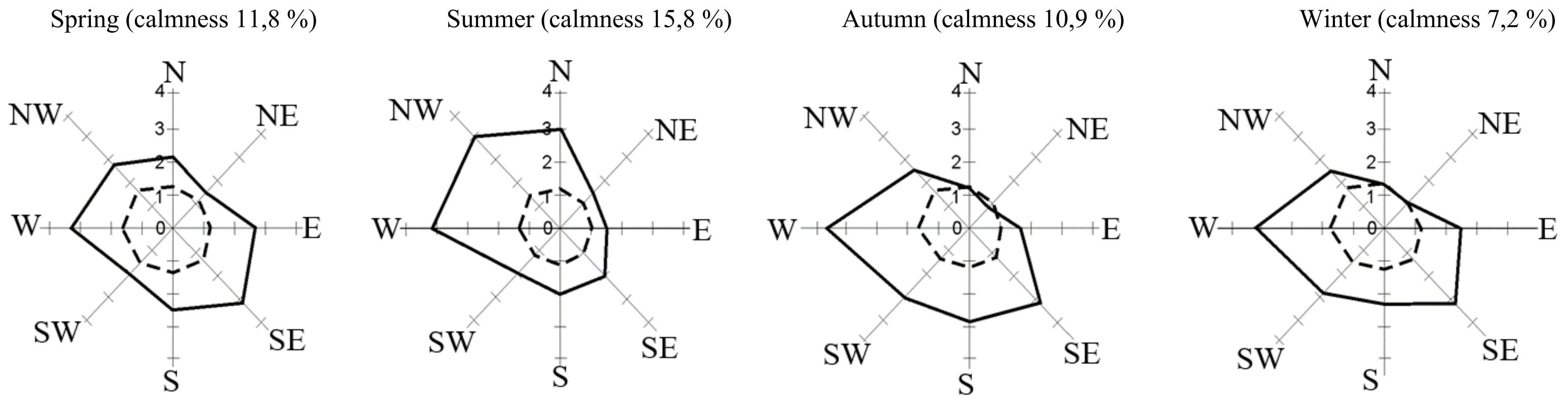


Conventional symbols

——— frequency, %
(1 graduation line = 5 %)

- - - wind speed, m/s
(1 gradation line = 2 m/s)

Fig. 1.2. Wind pattern (wind rose) of Lyubeshiv meteorological station (per season, per period and per year)



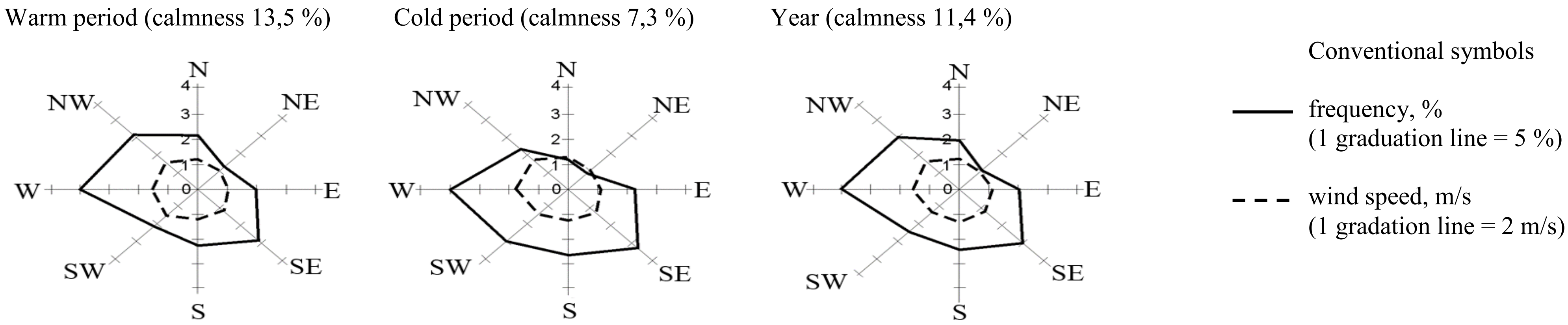


Fig.1.3. Wind pattern (wind rose) of Manevichi meteorological station (per season, per period and per year)

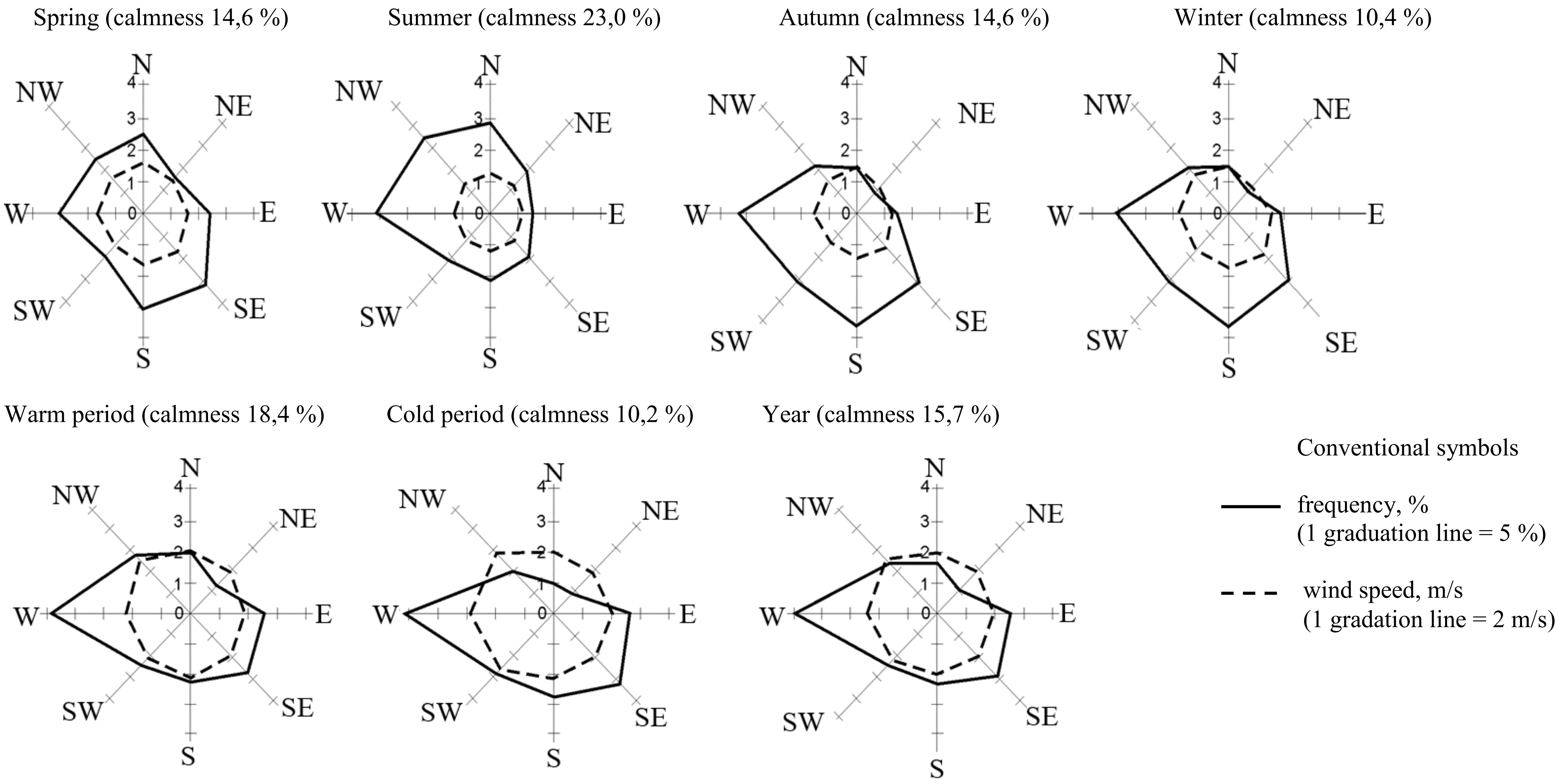


Fig.1.4. Wind pattern (wind rose) of Sarny meteorological station (per season, per period and per year)

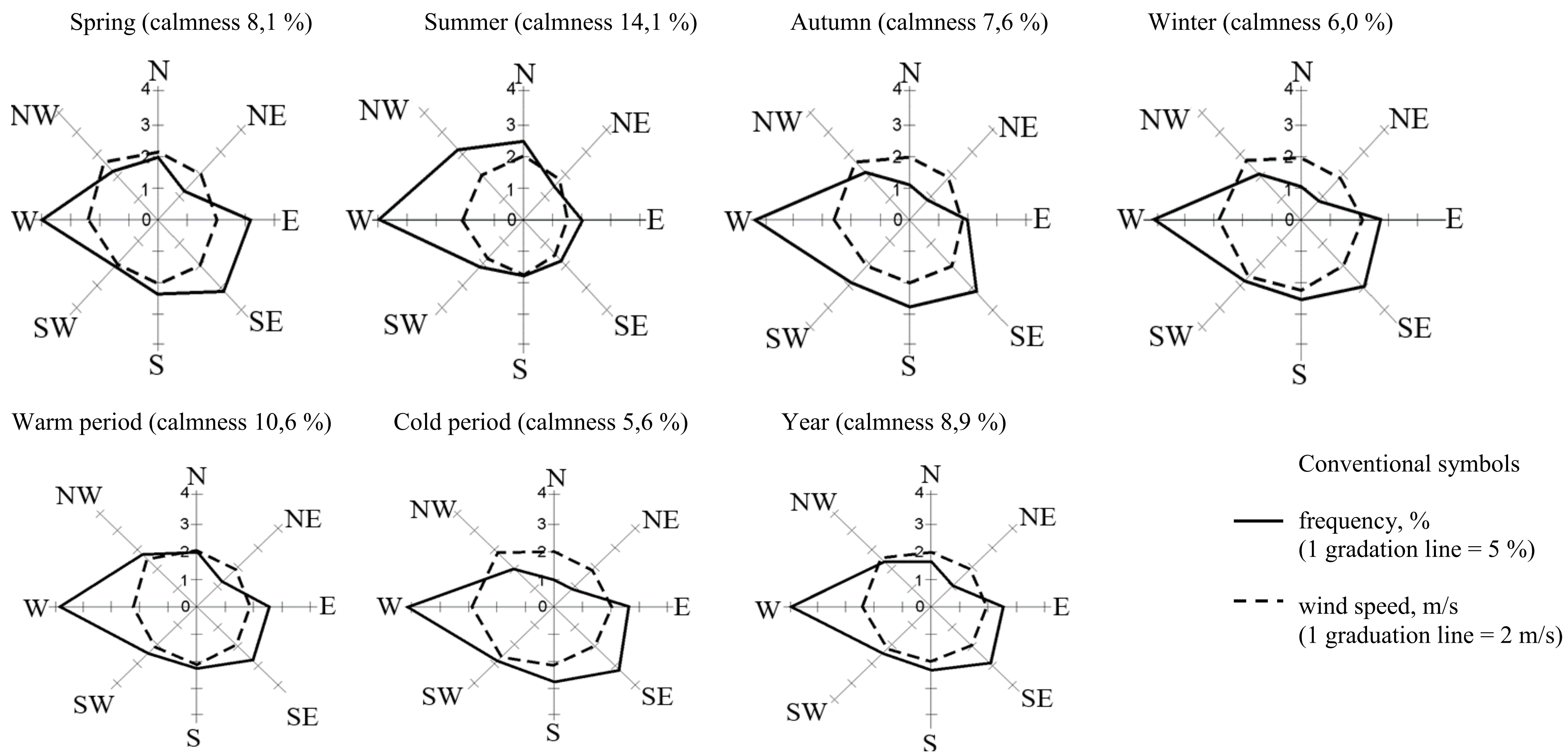


Fig.1.5 Wind pattern (wind rose) of Rivne meteorological station (per season, per period and per year)

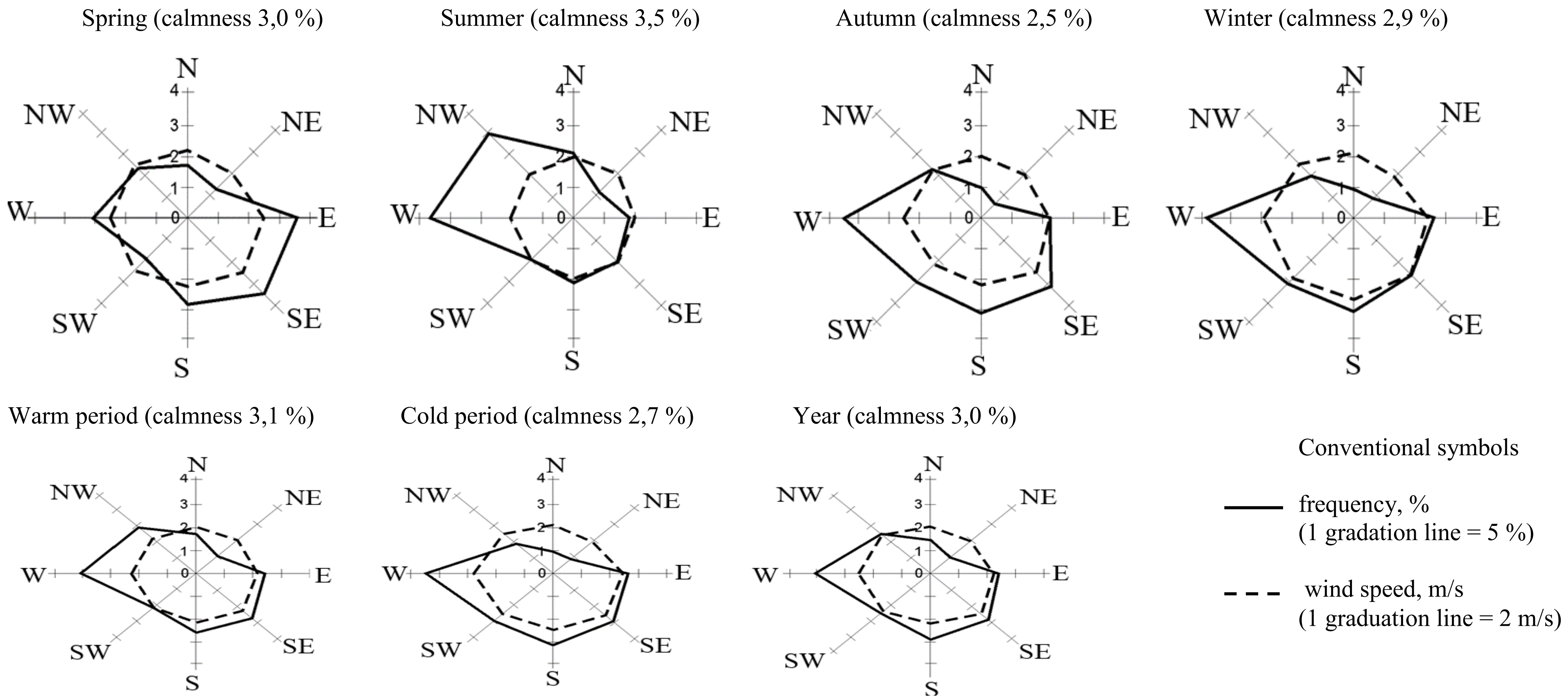


Fig.1.6. Wind pattern (wind rose) of Lutsk meteorological station (per season, per period and per year)

The distribution of wind speed on the territory of the 30-kilometer zone of the Rivne NPP has the following features. During the year, the maximum average annual wind speeds are observed in the southern part of the zone, equal to 4,7-5,0 m/s and have the west and the northwest wind direction. In the central and western part of the zone, including the area of the NPP, the wind speeds are decreased to 3,1-3,2 m/s and remain the same wind direction, W and NW. To the north, the wind speed is increased to 3,7 m/s (with the western winds). The minimum average wind speeds (2,1-3,2 m/s) are observed all over the territory and have the northern, the north-eastern and eastern directions of wind.

The specific character of distribution of wind speeds within the 30-kilometer zone of the Rivne NPP is an increase of average wind speed from north to south from 2,5 to 4,1 m/s (Table 1.30). The same regularities observe in the certain months of the year. In the central, western and eastern parts of the zone, the average annual wind speeds are within the range of 2,8-3,0 m/s.

Table 1.30. Average monthly and annual wind speeds without reference to the directions

Meteorological station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv	3,0	2,8	2,8	2,6	2,0	2,0	2,0	1,7	2,2	2,5	3,0	2,9	2,5
Manevichi	3,5	3,5	3,4	3,1	2,7	2,7	2,7	2,5	2,7	2,9	3,5	3,3	3,0
Sarny	3,4	3,4	3,3	3,1	2,6	2,4	2,3	2,1	2,4	2,7	3,3	3,2	2,8
Rivne	4,9	4,6	4,4	4,2	3,7	3,5	3,3	3,0	3,7	4,2	4,8	4,8	4,1
Lutsk	4,7	4,4	4,4	4,1	3,5	3,3	3,1	2,9	3,5	3,9	4,4	4,5	3,9

During the year, the winds with a speed of up to 5 m/s (with 44-52% cases) are more frequent in the territory of the zone, the winds with a speed of 10-15 m/s – with 0.7% cases in the eastern part of the zone, with 1.7-1.8% in the northern and in the central parts of the zone and about 6% cases in the southern zone.

The minimum wind speeds, 0-3 m/s, are mostly frequent in summer in the area of the zone. In the northern and eastern part of the zone, they are observed in 68-78% cases; in the central, western and southern parts, their frequency is slightly less (55-67%). The minimum wind speeds, 0-3 m/s, are observed in all wind directions. They have the longest duration.

The maximum wind speeds are usually observed with the prevailing wind directions and in the cold period of the year.

The frequency of maximum wind speeds is given in the gradation scale (estimated) (14-15, 16-20, 21-25 m/s) for the monitoring territory and it is determined according to the number of cases of this and another gradation of maximum wind speed over a long period. These observations were performed at the Lubeshiv, Manevichi, Sarny and Rivne meteorological stations. The results of estimation are presented in the Table 1.31.

According to the performed observations, we can estimate that the maximum wind speeds, in the mentioned gradients, in the territory of the 30-kilometer zone of the Rivne NPP, are mostly frequent in the western and north-western directions and rarely in the southwest direction (with wind speed ≥ 25 m/s). The extreme wind speeds were recorded in the southern part of the zone and reached 38 m/s (Rivne meteorological station) and 40 m/s (Lutsk meteorological station) in the north-western direction. The maximum wind speeds are usually observed during cyclone activity.

The average number of days per year with the wind speed that equals or exceeds the predetermined value in this area is given in the data of Sarnia meteorological station and it is as follows:

≥ 8 m/s - 53 days, ≥ 15 m/s - 3 days, ≥ 20 m/s – 0,2 days.

The days with a wind speed of ≥ 20 m/s are often observed in the cold season of the year and at a speed of 8 to 15 m/s – all over the year.

Table 1.31. Frequency of maximum wind speeds in the directions

in % from number of cases

Speed graduation, m/s	Wind direction (rhumb)							
	N	NE	E	SE	S	SW	W	NW
The northern part of the 30-kilometer zone, Lyubeshiv meteorological station								
14 – 15	4,3	5,4	8,7	2,3	5,4	18,5	46,7	8,7
16 – 20	-	1,0	2,0	-	2,0	29,3	52,5	13,2
21 – 25	-	-	-	3,2	-	32,3	51,6	12,9
≥ 25	The recorded wind gusts: 28-29 m/s - 7 cases with W, SW, WSW direction 30 m/s - 2 cases with SSW, WSW direction 34 m/ s - 1 case with W direction							
The western and the central part of the 30-kilometer zone, Manevichi meteorological station								
14 – 15	7,1	1,0	4,0	8,0	6,0	11,4	37,3	25,4
16 – 20	6,0	-	8,4	1,7	4,5	9,5	46,4	23,5
21 – 25	-	-	-	14,3	-	-	71,4	14,3
≥ 25	The recorded wind gusts: 28 m/s – 2 cases with WNW and SSW direction 29 m/s – 1 case with NW direction							
The eastern part of the 30-kilometer zone, Sarny meteorological station								
14 – 15	16,5	4,4	6,9	14,9	10,3	7,0	25,8	14,2
16 – 20	9,3	-	4,6	11,6	14,0	14,0	18,6	27,9
21 – 25	5,6	-	-	16,7	5,6	33,3	27,7	11,1
≥ 25	The recorded wind gusts: 28 m/s – 1 case with WNW direction 30 m/s – 1 case with NE, W, SW direction							
The southern part of the 30-kilometer zone, Rivne meteorological station								
14 – 15	9,0	1,5	5,0	11,7	6,2	12,4	41,0	13,2
16 – 20	4,0	-	4,0	10,0	4,0	7,0	52,0	19,0
21 – 25	-	-	-	-	-	3,3	66,7	30,0
≥ 25	The recorded wind gusts: 26 m/s, 27 m/s, 31 m/s, 33 m/s – 1 case 30 m/s – 2 cases (all with NW direction)							

1.2.1.11 Atmospheric phenomena: fogs, snowstorms, and thunderstorms

The origin of atmospheric phenomena is usually associated with the nature of the synoptic processes occurring over the monitoring area. The duration and intensity of most of them have a significant impact on the physicogeographical features of the territory.

The fogs are the formation of tiny water droplets in the atmosphere as a result of the moist air cooling. The fogs affect the sanitary and hygienic quality of atmospheric air, as they absorb various impurities and favour an increase of air pollution. The fog characteristics in the monitoring area are provided according to the data of Manevichi, Sarny, Rivne, Lutsk and Lyubeshiv meteorological stations. (Tables 1.32-1.33).

Table 1.32. Number of days with fog

Number of days	Month											Period		Year	
	01	02	03	04	05	06	07	08	09	10	11	12	10-03	04-09	
Lyubeshiv meteorological station															
Average	2	3	2	1	1	1	1	1	2	4	4	4	19	7	26
Maximum	9	10	7	7	3	3	6	7	9	14	8	10	-	-	57
Manevichi meteorological station															
Average	3	2	3	1	1	1	1	1	2	4	4	4	20	7	27
Maximum	6	9	8	3	3	3	3	4	6	9	11	8	-	-	41
Sarny meteorological station															
Average	3	4	3	2	1	1	1	2	3	4	4	5	23	10	33
Maximum	10	11	8	5	4	4	7	4	10	10	12	12	-	-	55
Rivne meteorological station															
Average	4	5	4	2	2	2	1	3	3	4	5	6	28	13	41
Maximum	8	12	11	5	6	5	7	6	13	10	16	12	-	-	69
Lutsk meteorological station															
Average	4	4	4	1	2	2	1	1	3	4	4	5	25	10	35
Maximum	9	11	10	3	5	6	4	7	10	10	11	13	-	-	53

According to the distribution of fogs along the territory of the zone "Rivne NPP" there is an increase in the number of fog days from north to south (from 26 days on the north to 35-41 days on the south). In the warm period of the year, the number of fog days is approximately the same in the zone (8-10 days) and in the cold period this number varies from 19 days in the northern zone to 24-28 days in the southern zone. The maximum number of fog days on the north, east, and southwest of the zone is nearly the same (57-53 days), in the south-eastern zone is 69 days.

Table 1.33. Fog duration

Meteorological station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv	Average duration												
	9	7	10	3	2	2	2	2	5	14	21	15	92

Meteorological station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
	Maximum duration												
	31	56	54	9	7	11	8	13	17	44	66	57	193
Manevichi	Average duration												
	14	11	17	3	3	3	3	3	8	16	26	23	130
	Maximum duration												
	55	70	60	16	9	12	12	13	28	52	63	64	185
Rivne	Average duration												
	22	24	25	7	6	4	3	5	12	15	27	33	183
	Maximum duration												
	62	89	107	19	24	13	12	16	70	52	104	76	406

The minimum average fog duration during the year on the territory of the monitoring area of the Rivne NPP is on the north (92 hours) and the maximum on the south (182 hours). In the area of the NPP (the central part of the zone), the average fog duration is 131 hours per year. The maximum fog duration within a year is observed in the southern part of the zone (406 hours). During certain months, the maximum fog duration is in November-December (21 hours on the north and 33 hours on the south); the minimum - in June-July - 2-3 hours.

The maximum fog frequency (Table 1.34) is observed in November. In the northern part of the zone and in its central part, the fog frequency is 17-18%, on the south of the zone - 12-13%. The minimum fog frequency 3-4%, occurs in May-August all over the territory. During other months, the fog frequency varies from 9 to 12% in the entire territory of the monitoring zone.

Table 1.34. Fog frequency

in % from fog cases

Month											
01	02	03	04	05	06	07	08	09	10	11	12
Lyubeshiv meteorological station											
8,3	7,9	10,2	3,6	3,3	3,1	4,0	4,0	8,8	15,0	17,1	14,5
Manevichi meteorological station											
9,6	7,1	11,5	4,9	5,6	3,9	3,7	3,5	10,5	8,9	18,2	12,6
Rivne meteorological station											
10,1	11,4	10,8	5,0	5,0	4,2	4,3	6,2	8,9	9,4	11,8	13,0

The data on fog frequency of different duration in the zone are given in the Table 1.35. The fogs with 0-4 hours duration are the most frequent (52.1% per year and 86.1% in the summer in June), while the fogs with 32-36 hours duration - only 0.4% per year and 0.5-1.0% in the cold season of the year.

Table 1.35. Fog frequency of different duration

in %

Fog duration	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
0-4	46,7	46,6	45,3	61,2	80,0	86,1	85,4	72,7	75,8	48,4	39,9	34,2	52,1
4-8	26,7	28,1	27,3	29,4	20,0	13,9	14,6	26,0	18,1	31,6	30,8	32,4	27,3

Fog duration	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
8-12	10,0	14,6	13,3	7,1	-	-	-	-	2,0	14,0	15,7	14,6	10,5
12-16	7,2	5,1	8,0	2,4	-	-	-	-	4,0	4,2	6,1	8,7	5,2
16-20	3,3	3,4	3,3	-	-	-	-	1,3	-	-	4,0	4,1	2,2
20-24	3,3	0,6	0,7	-	-	-	-	-	-	0,5	1,5	2,3	1,1
24-28	0,6	1,1	-	-	-	-	-	-	-	-	1,0	1,0	0,4
28-32	0,6	0,6	0,7	-	-	-	-	-	-	0,5	-	1,0	0,4
32-36	0,6	-	0,7	-	-	-	-	-	-	1,0	0,5	1,0	0,4
>36	1,1	-	0,7	-	-	-	-	-	-	-	0,5	1,0	0,4

The thunderstorms are the electric discharges in the atmosphere accompanied by a flash of light (lightning) and a sharp acoustic effect (thunder).

The thunderstorm discharges cause the significant damages to the national economy including the infrastructure, provoke the fires and affect the operation of communication and power lines facilities. Their danger is increased due to the fact that strong windsquals, storm rainfalls and hailstones often accompany them. The general circulation processes and the physicogeographical features of the area and the land surface have the significant influence on the origin and the development of the thunderstorms.

The average number of days with thunderstorms on the monitoring territory is 29-32, the maximum is 48 (Table 1.36). The peak of thunderstorm activity is observed in the summer (May-August) and the winter storms are rarely observed.

The longest thunderstorms are in June and July with duration from 12 to 24 hours, the shortest – during all months of the year from 6 to 12 hours.

The average daily duration of thunderstorm is 2.4 hours, maximum continuous - 9.4 hours.

Table 1.36. Number of days with thunderstorms

Number of days	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Lyubeshiv meteorological station													
Average	-	0,05	0,1	2	6	7	8	6	2	0,2	-	-	31
Maximum	-	1	1	8	13	14	14	11	4	2	-	-	42
Manevichi meteorological station													
Average	-	0,05	0,05	2	6	7	8	6	3	0,2	-	-	32
Maximum	-	1	1	7	14	13	14	11	7	2	-	-	48
Rivne meteorological station													
Average	-	0,03	0,2	1	6	7	7	6	2	0,2	-	-	29
Maximum	-	1	2	6	14	15	14	10	6	2	-	-	44
Note. The number of days with thunderstorms of less than 1 day means that the thunderstorms are not observed in this month.													

Table 1.37. Thunderstorm duration

in hour

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
Average duration												
-	0,02	0,01	2,3	15,6	18,1	18,4	14,3	3,3	0,1	-	-	72,2

The snowstorm is a transit of snow from the snow cover under the influence of a strong abrupt wind that causes the redistribution of the snow cover depth, as well as the change of the snow structure. The snowstorms complicate the operation of transport, communication and power lines facilities and they are accompanied by strong winds and heavy snowfall. The data on the snowstorms on the monitoring territory are given in the Tables 1.38 - 1.39.

The average number of days with snowstorms per year in the 30-kilometer zone of the Rivne NPP varies from 9 days in the northern zone to 6 days in the central part and up to 22 days in the southern zone. The maximum monthly number of days with snowstorm is observed in February (3-6 days average and up to 10 days maximum). In the last 10 days, the snowstorms were observed very rarely, 1-3 days per year.

The average duration of snowstorm per year in the 30-kilometer zone increases from north to south: on the north of the zone, as well as in the central part, the duration of snowstorm equals to 30 hours per year, on the south - about 100 hours. The average daily duration of snowstorm is 5,0-6,3 hours. (Table 1.39).

Table 1.38. Average number of days with snowstorm

Month							Year
10	11	12	01	02	03	04	
Lyubeshiv meteorological station							
0,1	0,2	1	3	3	2	0,1	9
Sarny meteorological station							
0,08	0,1	0,8	2	2	0,5	0,06	6
Rivne meteorological station							
0,2	2	4	6	6	3	0,4	22

Table 1.39. Average snowstorm duration

in hour

Month							Year	Average daily duration of snowstorm
10	11	12	01	02	03	04		
Sarny meteorological station								
0,3	1	5	10	9	4	0,5	30	5,0
Lutsk meteorological station								
0,5	4	20	21	32	20	3	101	6,3

The dust storms are the transfer of a large amount of dust or sand with a strong wind in the surface air that can be accompanied by the rise of sand and soil particles in the air and simultaneously the accumulation of dust on a large territory.

The dust storms are usually observed in the period from April to October (Table 1.40). However, with a slight snow cover or its absence, the dust storms may occur in winter as it was in February 1969. The average duration of dust storm is about 1 hour; in 80% cases the dust storms lasted less than one hour. The maximum duration of dust storm was recorded in February 1969 - up to 10-14 hours according to some stations in the northern part of Ukraine.

The maximum number of days with dust storm is 3-6 days per year.

Table 1.40. Average number of days with dust storm

Meteorological station	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Shepetivka	-	-	-	-	0,02	0,2	0,02	-	0,02	0,02	-	-	0,3
Rivne	-	-	-	0,08	0,2	0,1	0,2	0,05	-	0,03	-	-	0,7
Yampil	-	-	-	-	0,3	0,3	0,04	0,05	0,04	-	-	-	0,7

1.2.1.12 Meteorological disasters

The, according to [7], the meteorological disaster are phenomena that, in their intensity, area of distribution and duration, are not ordinary. These disasters include the heavy rains (rainfall ≥ 50 mm during 12 hours or less); large-sized hail (diameter ≥ 20 mm); wind at speeds ≥ 25 m/s, hurricanes, squalls and tornadoes; heavy blizzards (at wind speeds ≥ 15 m/s), snowstorms (snowfall ≥ 20 mm for 12 hours or less); strong fogs (visibility less than 100 m); heavy glaze (ice diameter ≥20 mm).

The meteorological disasters are characterized by considerable variability in the duration and orientation and differ by their extraordinary complexity and mixed character. There is very limited information about many of meteorological disasters, since some of them do not fall into the field of observation due to the high discretion and short duration.

Therefore, the generalization of data on meteorological disasters is carried out not in the separate area, but on the certain territories. The particularly dangerous weather phenomena, revealing in the area of the SS "Rivne NPP", can be detected on the territory outside the 30-kilometer zone of the Rivne NPP.

Accordingly, the territory with a radius of up to 200 km from the nuclear power plant, including the monitoring area of the Rivne NPP, is considered. This observation covers the administrative Oblasts of Ukraine: Volyn, Rivne, the northern part of the Khmelnytsky and Ternopil Oblasts, the north-eastern part of the Lviv and the western part of the Zhytomyr Oblasts. In addition, 200-kilometer zone includes the southern part of the territory of the Republic of Belarus (up to 100-120 km along from the state border with Ukraine).

The records on meteorological disasters occurring in the territories adjacent to the site of the Rivne NPP (Table 1.41) are based on the data from the Hydrometeorological Committee of Ukraine about the dangerous weather disasters [6-13].

Table 1.41. Number of reports on dangerous weather disasters within a radius of 200 km from the Rivne NPP

Administrative Oblast	Wind, m/s		Precipitation, mm/24 hours		Heavy glaze, ice diameter ≥ 20 mm	Blizzards and snowstorms with 12 hours and more duration	Hail, diameter ≥ 20 mm	Dust storms
	strong ≥ 25	hurricane ≥ 33	≥ 70	≥ 100				
Rivne	14	5	8	3	3	12	5	-
Volyn	20	10	12	4	2	6	5	2
Khmelnytsky	14	9	10	2	1	2	8	1
Ternopil	13	12	18	4	9	14	9	-
Lviv	15	8	8	3	1	9	3	1

Strong wind (wind speed ≥ 25 m/s).

The increase of wind to 25 m/s or more occurs throughout the entire territory of Ukraine and within the monitoring Oblasts and it is observed once in 2-3 years. In total for the analyzed period, the strong wind (≥ 25 m/s) in the Rivne and Khmelnytsky Oblasts was observed in 14 cases, in the Volyn oblast in 20 cases (Table 1.41), it means that the frequency of this wind in the monitoring territory of the Rivne and Khmelnytsky Oblasts equals to 30-40% and in the territory of the Volyn Oblast - about 41-50% [6].

The squalls (a kind of strong wind with a short-term velocity of 21-35 m/s).

The squalls refer to the atmospheric phenomenon associated with the wind energy. They represent a whirlwind of a horizontal vector, characterized by a sharp, short-term increase in the wind speed and a sudden change of its direction.

The squalls have a destructive power and, apart from the damages to agriculture, they can damage the infrastructure (destroy buildings, communication lines and power lines facilities, etc.).

The squall zones, as a rule, dominate in the small areas and have a local nature. Most often, the squalls are recorded on the territory of one Oblast and less – in two or four Oblasts.

The squall winds have a short duration. In general, the squalls last not more than 0,5 hours, less often - up to 1 hour.

The frequency of squalls in the Rivne and Khmelnytsky Oblasts is approximately once every 10 years [11].

The hurricanes (wind speed ≥ 33 m/s of long duration).

Over the past 30 years, the long winds at a speed of ≥ 33 m/s on the territory of the Rivne Oblast have been reported in 5 cases, in the Volyn and Khmelnytsky Oblasts in 9-10 cases (Table 1.41). The hurricane winds were observed in 1983 (March 7th and 8th) in the Izyaslav and Slavuta districts of the Khmelnytsky Oblast; in 1984 (2-4 November) the same winds were registered by the Yampil and Khmelnytsky meteorological stations; in 1986 (January 20-21) – by Khmelnitsky, Rivne, Sarny and Manevich meteorological stations; in 1992 (September 6) – by Shepetivka and Yampil meteorological stations; in 1993 (January 23 and 24), the storm winds went through the territory of the Volyn Oblast. At the same time, the highest speeds in some years reached 34-40 m/s and the maximum duration of some hurricanes was 14-31 hours.

The tornados The tornado is a strong, small-scale whirlwind formed under maturing thunderclouds and spreads out in the form of a tall dark cloud column of air that spins very fast over the land surface (or sea). Approaching the land surface, the whirlwind draws and sometimes raises water, dust, sand, and often very heavy objects (logs, roofs of houses, etc.) to the high altitude. The tornados have a strong destructive power. Usually, the tornadoes are observed simultaneously with a thunderstorm, a heavy rainfall, sometimes hail.

According to the zonation of the rotationally dangerous tornado risk phenomena, the site of the Rive NPP is located in the tornado risk area [12]. Following the Catalo of the registered tornadoes on the territory of the USSR from 1945 to 1986 [12] and the data of the Hydro meteorological Committee of Ukraine for the period 1986-1997 [11], on 08.06.1974 the tornado of a zero-intensity was registered directly on the territory of the 30-kilometer zone of the Rivne NPP by Manevich meteorological station.

Within the radius of 200 km from the Rivne NPP, for the specified period, 9 tornadoes (Table 1.42) were registered, including 5 tornadoes of zero intensity, 3 tornados of the first rate and 1 tornado of the second rate intensity.

The nearest to the "Rivne NPP" SP were tornadoes of the zero intensity in the village Lobachivka, the Volyn Oblast (20.05.1960, 55 km south of the Rivne NPP), in Rivne (20.08.1973, 80 km south of the Rivne NPP), the first rate tornado in Kovel (July 14, 1984, 82 km to the west of the Rivne NPP) and Kamen-Kashirsky (23.06.1997, ~ 72 km northwest of the Rivne NPP) in the Volyn Oblast, as well as in Novograd-Volynsky the Zhytomyr Oblast (02.06.1980, in 142 km to the south of the Rivne NPP). The tornado of the second rate intensity was registered on May 28, 1951, 120 km northwest of the Rivne NPP in the territory of the Republic of Belarus.

The probability of potentially dangerous tornado risk phenomenon in the limited area, which is the 30-kilometer zone of the Rivne NPP, according to [8], is estimated on the basis of the annual probability of tornado and its intensity rate. These characteristics are as follows:

- An annual probability of tornado passing through any point of the 30-kilometer zone of the Rivne NPP NP is 9,25 x 10-7 reactor/per year;

- an estimated intensity rate of the potential tornado is 1,92. The probability of tornado intensity rate exceed is equal to 0,90 (in 90 of 100 cases the estimated intensity rate will not be exceeded).

Table 1.42. Tornados registered within a radius of 200 km from the Rivne NPP in the period from 1951 to 1997

Tornado location	Date	Intensity rate	Distance from the Rivne NPP and the direction (rhumb)
1. Davyd – Gorodok district, Brest Oblast	28.05.1951	2	~120 km on NW (the territory of the Republic of Belarus)
2. Village Lobachivka, Volyn Oblast	20.05.1960	0	~ 55 km on SW
3. Village Obroshyne, Lviv Oblast	23.08.1966	0	~ 165 km on SW
4. Rivne	20.08.1973	0	~ 80 km on SSE
5. Manevichi, Volyn Oblast	08.06.1974	0	~ 26 km on W
6. Novograd-Volynsky, Zhytomyr Oblast	02.06.1980	1	~ 142 km on SE
7. Kovel, Volyn Oblast	14.07.1984	1	~ 82 km on W

Tornado location	Date	Intensity rate	Distance from the Rivne NPP and the direction (rhumb)
8. Village Shelviv, Lokachyn district, Volyn Oblast	20.07.1987	0	~ 102 km on SSW
9. Kamen-Kashirsky, Volyn Oblast	23.06.1997	1	~ 72 km on SW

Heavy rain. The heavy rains are the most frequent natural phenomenon observed in Ukraine. They are characterized by nonregular distribution. The areas of heavy rainfall are usually small and only in some cases can be extended to large areas and cover the whole area. The heavy rains were observed in 13-14 cases for the analyzed period in the Rivne and Khmelnytsky Oblasts. The rainfall exceeded 100 mm/per day in 5 cases in the Rivne Oblast and in 2 cases in the Khmelnytsky Oblast.

The heavy rainfalls accompanied by strong winds caused floods and catastrophic destruction of urban settlements, power lines, roads and other facilities in 1969 (October 28), 1990 (May 25), 1993 (22-23 July) and 1997 (June 23rd).

The frequency of heavy rains in the year with precipitation ≥100 mm/per day equals to 9% in the Volyn and Khmelnytsky Oblats and 4.5% in the Rivne Oblast.

Heavy hail. The hail with a diameter of 20 mm or more was observed 7 times in the territory of the Rivne and Khmelnytsky Oblasts and 12 times in the territory of the Volyn Oblast. The maximum number of hail days per year in this territory is 6-10 days, the average is 2 days. The maximum hail duration is 1-2 hours.

The frequency of hail with a diameter of more than 30 mm - about 20% of all cases for the analyzed period.

The maximum hail diameter in most Oblasts of Ukraine reaches 50-80 mm. The hail of large diameter is observed from end of April - beginning of May to the end of August - middle of September. [11].

Heavy dust storms. The origin of dust storm is related to the influence of strong wind on the dried soil surface that results in the transit of large amounts of dust or sand. The formation of dust storms depends on the nature of the land surface.

It is almost impossible to limit the area with a dust storm, as it is an extremely migratory phenomenon. In most cases, the dust storms occur on small areas and have a local nature. However, the long, intense storms extend over large areas, covering several administrative units - Oblasts.

During the last 30 years, the strong dust storms in Ukraine were observed in 1966-1972, 1974, 1984. In particular, the intensive and prolonged dust storms were observed in January-March 1969 (the dust storms covered 15 Oblasts of Ukraine). In the recent years, the dust storms have not been observed, which is obviously due to the sufficient rainfalls and a decrease of strong winds.

The probability of intensive spontaneous dust storms in the northern and western regions of Ukraine (where the Rivne NPP is located) is about 5%, it means that they can occur one time in 20 years.

Severe blizzards. The severe blizzards occur at an overwhelming wind speed of 15 m/s or more during the day or night. The blizzards create huge snowdrifts on roads and cause the deterioration of visibility.

The particularly dangerous blizzards with duration of 12 hours or more are observed in this area quite rarely. In the monitoring period, the long-term blizzards were observed 12 times in the Rivne Oblast, 6 times in the Volyn Oblast and 2 times in the Khmelnytsky Oblast.

The frequency of severe blizzards in the Rivne Oblast is 11-20% and 21-30%.in the territory of the Khmelnytsky Oblast.

Heavy snowfalls. On the territory of Ukraine, the heavy snowfalls are observed from October to April, but they are mostly frequent in January-February.

The frequency of heavy snowfalls in the monitoring area is 21-30%, it means that the heavy snowfalls occur once in 3-5 years.

The maximum amount of precipitation during a severe snowfall is 37-63 mm in the Rivne and 30 mm in the Khmelnytsky Oblasts.

Heavy fog (visibility 100 m or less). The heavy fogs are observed in the cold period of the year. The classification of fogs by their origin has no fundamental importance for the nuclear power plant. Whatever origin of the fog, its presence does not contribute to the distribution of impurities in the surface layer of atmospheric air.

The fogs with visibility ≤ 100 m are observed in 7% cases in the western part of Ukraine. At the same time, the heavy fogs were not observed on the territory of the Rivne and Khmelnytsky Oblasts.

Heavy glaze. (ice diameters ≥ 20 mm). The heavy glaze was observed 3 times during the monitoring period in the territory of the Rivne Oblast, 2 times in the Volyn Oblast and 1 time in the territory of the Khmelnytsky Oblast. The glaze duration varies, from 15 minutes to 15 days or more. In the majority of cases, the ice lasts less than 12 hours, less often - about a day.

The ice deposits of especially dangerous glaze are characterized by high intensity of growth, from 1,1 to 2 mm/per year (in 50% of cases) [11].

It should be noted that the meteorological disasters have a multiple effect on the nuclear power plant - from surcharge load on the plant's facilities (strong wind, tornadoes, ice, snowfall) to creating favourable conditions for both distribution of impurities and pollutants transfer at large distances (heavy rainfall and flood, strong wind, dust storms).

During the operation of the Rivne NPP, the meteorological disasters did not cause any emergency situations.

1.3 Trends in climate change

The Rivne Oblast is characterized by a favourable climate for people living. However, the local characteristics and the growth of atmospheric processes create the conditions for the meteorological disasters, which can have a catastrophic and destructive character. Obviously, weather conditions, climate, water resources have a significant impact on all aspects of human life.

The Rivne Regional Hydrometeorology Centre including the meteorological stations of the Oblast (Rivne, Dubno, Sarny) monitors on a daily base, analyses and collects the data on weather and climate, more specifically – observations of temperature regime, precipitation, dangerous and natural meteorological disasters - thunderstorms, hail, squall wind, snowstorms, dazzles, fogs, etc.

The global warming is an irreversible process that we will face in the coming decades. In the Rivne Oblast during the last 10 years, the average daily temperature has increased by 0,8-1,0°C. In general, the maximum temperature increase occurs in the cold period of the year. It means that the probability of very long and cold periods is significantly shortened, but the probability of short-term periods with strong cold temperature remains. The same approach applies to the summer period, when the probability of temperature rises to 30°C (and above) is significantly increased. According to the nearly 70-year period of continuous observation, the absolute minimum air temperature of minus 35 degrees was recorded at Rivne and Dubno meteorological stations in 1987, the absolute maximum - 39 degrees at Sarny meteorological station in 2001. The tendency in the recent years is that the spring warming comes later and September is considered as a summer month.

The cold period is characterized by the following atmospheric phenomenon: fogs of different intensity, freezing, snowstorms, dazzles, strong storm winds which are observed annually, and have a high probability (80-95%).

In the warm period, there is a strong heat, an emergency fire risk, as well as the atmospheric phenomena associated with towering clouds (intense rains, thunderstorms, hailstones, squalls, tornadoes). These phenomena are observed with a certain frequency and intensity and have mostly a local nature.

In general, 2016 turned out to be very warm year with average index of 1°C higher than the reference period (reference period 1981-2010) - average air temperature in 2016 was 9°C. The coldest month was January with an average temperature of minus 4-5°C and the absolute minimum of minus 19,8°C was recorded on January 4 at Sarny meteorological station. The warmest month was July with an average temperature of 20-21°C and the absolute maximum of the year - 34,9°C was recorded on July 13 at Sarny meteorological station. This year, like the preceding one, is characterized by a positive temperature anomaly with the average monthly temperatures of 1-3°C higher than the average index of the reference period (in February, 5-6°C higher than the average index of the reference period). Except for January and October, when the average temperature was 1-2°C lower than the average index of the reference period and May, November and December, when the average temperature was close to the average index of the reference period.

The annual precipitation equalled to 520-685 mm (82-106% of the average index of the reference period). The maximum amount of precipitation was recorded in October - according to the Rivne aviation meteorological station, 116 mm (270% of the average index of the reference period). The higher amount of precipitation was observed in November, which equalled to 80 mm on the south (200% of the average index of the reference period) and to 50 mm (119-131% of the average index of the reference period) on the rest of the territory. In January, the amount of precipitation equalled to 36-48 mm (123-150% of the average index of the reference period), in April, when 55-61 mm fell on most of the territory (139-160% of the average index of the reference period) and in December, when the amount of precipitation was from 55 to 60 mm (137 -154% of the average index of the reference period).

The minimum amount of precipitation was recorded in September at Rivne aviation meteorological station - 6 mm (11% of the average index of the reference period), on the rest of the territory - 6-8 mm (11-12% of the average index of the reference period). This is the lowest monthly amount of precipitation in the post-war period. The higher precipitation deficit of 36-42 mm (37% of the average index of the reference period) was observed in July in the most of the territory and in June on the north - 27 mm (34% of the average index of the reference period). The precipitation deficit was also observed in August in most of the territory - 27-34 mm (46-62% of the average index of the reference period) and in May in the central part of the Oblast - 33 mm (54% of the average index of the reference period).

In general, the year of 2016 was satisfactory for the economic activity of the Oblast. There were 6 cases of natural hydrometeorological disasters (NHD) in the territory of the Oblast and 3 cases of abrupt change of weather (ACW) - no significant losses were incurred, and the most active synoptic processes were observed as follows:

– on April 21-23, 2016, the weather was determined by the rear cyclone displaced from the north-eastern regions of Ukraine to the central regions of the ETR. From the northwest of Europe there was an invasion of the arctic air. On the night of April 21 there were the light rains. In the zone of the significant barometric pressure gradients during the day of 21 and 22 April the wind increased to 15-19 m/s. The air temperature at night was +1°C + 4°C on April 21-22, on April 21, the ground frosts 0-1°C (NHD) were observed on April, 23 there were the air frosts 0-2°C and 0-4°C (NHD) of ground frosts. During the day the temperature was around +12-15 °C;

– on April 27-29, 2016 there was no precipitation in the flat field of high pressure. On April 27, at night, there were the air frosts of 0/-2 °C, the ground frosts of 0/-3°C (NHD), April, 28-29 the air frosts of 0/-3°C were observed on the north of the region. The daily temperature was around +13-18°C;

– on July 3, 2016, the active cold atmospheric front from the west caused light and moderate rains and very strong rainfalls (NHD) occurred at Dubno meteorological station, the precipitation was 50.3 mm within 1 hour and 12 minutes, there were observed the thunderstorms at Rivne aviation meteorological station, the squalls of 15-21 m/s and light hail (5 mm) at Dubno meteorological station. The air temperature at night was +18-20°C, during the day - +30-32°C;

– on August 10-11, 2016, the slow-moving cold atmospheric front caused the light rains, the thunderstorm was observed on the evening of August 10 at Dubno meteorological station. The air temperature at night was +12-13°C, on August 10 the daily temperature was +29-31°C and on August 11 the daily temperature was 17°C - the temperature decreased by 12-14°C (ACW);

– on October 4-5, 2016, the most active atmospheric processes were observed when the weather was determined by a centred cyclone over the central regions of Ukraine. During the day of October 4 and on the night of October 5, the heavy rains (precipitation of 15-30 mm) were observed. The precipitation of 2 days equalled to 45-85 mm. On the evening of October 4, in the zone of the significant barical pressure gradients and due to the passage of the atmospheric front the wind increased to 15-18 m/s according to the data of Rivne aviation meteorological station. The abrupt change of weather (ACW) was observed (the night temperature fell down by 10-11°C, the daily temperature was at 7°C). The air temperature at the night of October 4 was +13-14°C, on October 5 - +3-5°C. The air temperature during the day of October 4 was +13 -15°C, on October 5 - +7-9°C;

– on October 6-9, 2016, the flat field of high pressure formed in the cold air mass determined the weather. There were no precipitations, only during the day of October 7, the light rains occurred. On the night of October 6 and October 8, the ground frosts were observed and the air frosts equalled to 0 -2°C (NHD);

– on November 12-14, 2016, the weather was determined by the active cyclone displaced from the Balkans to the southern and eastern regions of Ukraine. The light and moderate snow fell down. On November 13, the most active atmospheric processes were observed: the moderate snow, the strong snowfall was observed at Dubno meteorological station (snow precipitation of 11 mm at night and 17 mm in the day), in the zone of significant barical pressure gradients the wind was amplified to 15-18 m/ s, the snow cover was formed, the snowstorms, the blizzards and the ice-glazing on the roads and the snow drifts. Therefore, on November 13, the abrupt change of weather

(ACW) was observed (snowfall, blizzards, strong wind after a stable weather). The air temperature at night was 0 /-3 °C, the daily temperature on November 12 was 0 /+ 1°C, on November 13-14 - 0 /- 2°C.

The natural disasters didn't cause any significant losses to the economic activity of the Oblast.

The climate change on the planet is one of the most challenging environmental problems nowadays and has the increasing negative impacts on the environment, economy and society. The climate change is not only a change in the environment, but it concerns the human rights for millions of people and communities around the world. The recognition of the global significance of anthropogenic climate change is based on the fact that 194 countries have ratified the United Nations Framework Convention on Climate Change and 187 countries have signed the Kyoto Protocol.

The greenhouse gas emissions become a part of the atmospheric air and in accordance with the Law of Ukraine "On Atmospheric Air Protection": the atmospheric air is a vital component of the natural environment, which is a natural mixture of gases located outside residential, industrial and other premises. The air is essential for the respiration of living beings and is one of the primary resources for human life, the right to which is guaranteed by the Article 27 of the Constitution of Ukraine. The life without air is impossible, that is why the Article 13 of the Constitution of Ukraine stipulates that the atmospheric air is the subject of the property rights of the Ukrainian people; on behalf of and in the interests of people, the efficient management of the atmospheric air is carried out by state authorities and local self-government bodies. Taking into consideration that a number of Ukrainian authorities are endowed with a legislative function in the field of climate change, in their work on the development and adoption of the normative legal acts, they are obliged to act in the interests of their people to ensure the constitutional rights of each person to life and the right to live in a safe and ecologically balanced environment.

Notwithstanding the lack of specific laws on climate change, the Ukrainian current legislation laid dawn the foundations for protection, conservation and restoration of the atmospheric air as one of the vital elements of the environment, in some of the laws even before the ratification of the Framework Convention and the Kyoto Protocol by Ukraine.

In particular, the general requirements in the field of atmospheric air protection are provided in the Laws of Ukraine "On Atmospheric Air Protection" and "On Environmental Protection". The Law of Ukraine "On Atmospheric Air Protection" defines the legal and organizational framework and the environmental requirements in the field of the atmospheric air protection, among them are the following norms of environmental safety of the atmospheric air: maximum permissible emissions of pollutants by stationary sources, maximum permissible impact of physical and biological factors of stationary sources, content of pollutants in the exhaust gases, impact of the physical factors of mobile sources and permissible emission of pollutants.

The regulation of the negative impact on climate is almost not covered in the above mentions law. Only Part 2 of Article 16 of the Law of Ukraine "On Atmospheric Air Protection" entitles "Control of Economic Activity Which May Effect Weather and Climate" stipulates that "the enterprises, institutions and organizations, in accordance with the international agreements, are obliged to reduce and further completely stop the production and use of chemicals that harm the ozone layer as well as to reduce the carbon dioxide emissions and other substances that accumulate in the atmospheric air and can lead to adverse climate change."

At the same time, the mechanism for the implementation of this Article is still not enshrined in this law or other normative legal acts. Therefore, the enterprises, institutions and organizations do not take any measures to reduce emissions of substances that accumulate in the atmosphere and can lead to adverse climate change; there is no information on the allowable amount of these substances discharged as a result of the enterprise activity and what negative impact they can cause to the climate. Taking into account that most of greenhouse gases are the polluting substances and according to the explanatory statement of the Ministry of Natural Resources of Ukraine, the inventory of anthropogenic emissions of greenhouse gases is carried out in line with the issued permits on the pollutant emission in the atmospheric air.

The Ecology and Natural Resources Department of the Rivne Oblast State Administration prepared and submitted to the State Environmental Investment Agency of Ukraine the proposals for development of the National Plan for Adaptation to the Impacts of Climate Change and Reductions of GHG Emission.

The proposals included the implementation of integrated measures, namely, the Regional Program for the Environment Protection for 2012-2016; The Regional Program for the Development of the Nature Reserved Fund and Formation of the Regional Ecological Network of the Rivne Oblast for 2010-2020; Programs of Water Management Development of the Rivne Oblast for the period up to 2021.

In addition, the proposals include the following measures: removal of unauthorized waste deposits, protection against flooding and overflowing, implementation of forest regeneration works, modernization of regional, local and target alerting systems for population in case of emergency situation, etc.

2. AIR ENVINRONMENT

In order to protect the atmospheric air from harmful effects of the NPP emissions [16, 17], it is important to monitor the meteorological and aerological characteristics of the atmosphere, which affect directly the dispersion of radionuclides, deteriorate the intensity of the natural mechanism of atmospheric self-purification and contribute to the accumulation of impurities in the air environment.

The main aerological characteristics of the surface layer of the atmosphere are considered in this section, which are as follows:

- direction and wind speed at the altitudes;
- temperature inversions (surface and raised);
- frequency of air "stagnation", height of the mixing layer, cloudiness mode, atmospheric stability.

To evaluate the aerological regime of the monitoring territory there were used the materials of high radiozone observation of the atmosphere for the 10 years period (1971-1980) performed by the nearest to the Rivne NPP, Shepetivka aerological station of Hydrometeorological Committee of Ukraine. By the nature of climate change in this region, the analyzed period can be compared with the current one.

In the process of evaluation the observation series, all cases of thermal probing were relatively divided into 2 groups - with normal atmospheric stratification, when air temperature decrease with the height and with inversion change of air temperature, characterized by temperature increase with the height.

Depending on the height of the lower edge of atmospheric air there are:

- surface inversions, the stratification cases characterized by air temperature increase with the height;
- raised inversions characterized by destratification at the certain heights above the underlying surface.

Since the scavenging of atmosphere in the inversion layers is significantly decreased, the statistical analysis was performed mainly for series of sounding data containing the layers with reduced turbulence.

2.1 Wind regime at altitudes

According to the specific nature of the atmospheric circulation in the area of the Rivne NPP, the north-western and western winds dominate at the altitudes throughout the year. In the summer, the probability of the northern and in the winter – the south-eastern and southern winds increases. During the mid-seasons, the number of the south-eastern, southern winds and the northern winds at an altitude of 100 m increases (Tables 2.1 - 2.3).

The frequency and the wind speed at altitudes are determined in the layers with a height up to 100 m, a height up to 200 m (a height of distribution, in most cases, the active part of radionuclide emission plume) and a height up to 500 m (average height of the mixing layer in the area of the Rivne NPP) [14] .

The average wind speed increase with an altitude from 10 m (the underlying surface level) to 100 m and equals from 3.5 m/s to 7.6 m/s; at the altitude of 200 m and 500 m, the wind speed equals respectively to 7.8 and 8.8 m/s.

During the year there is an increase in the average speed in the cold period to 8-11 m/s and a decrease in the warm period - to 7.0-7.3 m/s.

Compared to the surface layer, the number of calmness at altitudes is much lower. At an altitude of 100 m, the calmness frequency in the monitoring period was less than 0.01%, while at the land surface it was 12-13%.

The wind pattern (wind rose) at altitudes of 100, 200 and 500 m is given in the Figures 2.1 - 2.3 [12].

Table 2.1. Frequency of wind direction and its speed at an altitude of 100 m

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	6,0	6,9	11,2	10,3	11,2	9,5	19,0	25,9	0,0
February	10,9	7,0	15,6	14,1	7,8	6,4	14,8	23,4	0,0
March	9,3	5,3	24,0	12,7	12,0	10,7	11,3	14,7	0,0
April	19,2	14,9	7,0	11,4	5,7	5,7	9,9	26,2	0,0
May	15,5	12,8	14,9	12,8	8,1	3,4	8,8	23,7	0,0
June	17,6	14,6	7,9	6,0	3,6	5,5	15,8	29,0	0,0
July	14,2	8,0	7,4	3,1	4,9	5,6	21,0	35,8	0,0
August	28,3	9,0	9,7	6,9	4,0	2,1	10,3	29,7	0,0
September	19,7	7,8	4,2	9,2	4,2	3,5	19,0	32,4	0,0
October	11,8	5,0	9,2	11,8	11,0	5,0	23,5	22,7	0,0
November	6,9	3,1	3,0	8,5	12,3	5,4	42,3	18,5	0,0
December	8,4	3,5	2,8	8,5	11,3	10,6	23,9	31,0	0,0
Winter	8,4	5,8	9,9	11,0	10,1	8,8	19,2	26,8	0,0
Spring	14,7	11,0	15,3	12,3	8,6	6,6	10,0	21,5	0,0
Summer	20,0	10,5	8,3	5,4	4,2	4,4	15,7	31,5	0,0
Autumn	12,8	5,3	5,5	9,8	9,2	4,6	28,3	24,5	0,0
Warm period (03-10)	16,9	9,7	10,5	9,2	6,7	5,2	15,0	26,8	0,0
Cold period (11-02)	8,0	5,1	8,2	10,3	10,7	8,0	25,0	24,7	0,0
Year	14,0	8,2	9,7	9,6	8,0	6,1	18,3	26,1	0,0
b) Wind speed by direction indicator, m/s									
January	7,3	7,1	9,2	6,6	8,2	8,7	8,9	8,0	-
February	7,8	5,2	7,9	7,2	6,2	6,5	8,5	9,8	-
March	7,7	7,8	8,3	7,3	6,4	6,7	7,4	8,9	-
April	7,7	7,3	7,8	8,1	7,6	7,0	9,8	8,3	-
May	7,4	7,1	7,1	7,2	6,2	5,0	7,0	7,5	-
June	7,7	6,6	6,9	7,3	6,0	6,6	7,6	7,6	-
July	8,3	7,5	6,9	6,4	4,6	6,9	6,9	8,1	-
August	7,3	6,9	6,9	5,4	7,0	5,3	7,1	7,5	-
September	6,8	6,6	6,7	7,5	6,7	7,4	7,5	8,3	-
October	8,0	5,0	8,3	7,4	7,0	5,2	8,7	7,4	-
November	7,8	6,3	8,0	7,1	7,1	6,6	8,5	9,1	-
December	7,0	7,0	8,5	7,3	6,6	8,5	8,0	8,2	-
Winter	7,4	6,5	8,5	7,0	7,0	8,0	8,4	8,6	-
Spring	7,6	7,4	7,8	7,5	6,7	6,2	8,1	8,2	-

Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
Summer	7,8	7,0	6,9	6,4	5,9	6,3	7,2	7,7	-
Autumn	7,5	6,0	7,6	7,4	6,9	6,4	8,2	8,3	-
Warm period	7,6	6,8	7,4	7,1	6,4	6,3	7,7	7,9	-
Cold period	7,5	6,4	8,4	7,0	7,0	7,6	8,5	8,8	-
Year	7,6	6,7	7,7	7,1	6,6	6,7	8,0	8,2	-

Table 2.2. Frequency of wind direction and its speed at an altitude of 200 m

Month, season, year	Wind direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	6,0	5,2	10,3	13,8	9,5	12,1	20,7	22,4	0,0
February	10,9	6,3	12,5	16,4	11,7	7,0	17,2	18,0	0,0
March	7,3	3,3	17,3	18,0	14,7	10,7	16,7	12,0	0,0
April	15,6	11,4	9,9	13,5	5,7	7,8	11,4	24,7	0,0
May	12,2	10,1	15,5	13,5	10,8	2,7	12,8	22,4	0,0
June	12,7	12,1	9,7	8,5	3,6	7,3	24,2	21,9	0,0
July	9,3	6,8	8,6	4,3	5,6	6,8	27,8	30,8	0,0
August	20,6	8,3	9,0	8,3	5,5	4,1	15,9	28,3	0,0
September	16,2	7,8	2,1	11,3	5,6	7,0	23,9	26,1	0,0
October	6,7	4,2	7,6	15,1	11,8	6,7	29,4	18,5	0,0
November	3,9	3,8	1,5	10,0	13,1	8,5	41,5	17,7	0,0
December	7,0	2,8	2,1	7,0	14,1	10,6	31,7	24,7	0,0
Winter	8,0	4,7	8,3	12,4	11,8	9,9	23,2	21,7	0,0
Spring	11,7	8,3	14,2	15,0	10,4	7,1	13,6	19,7	0,0
Summer	14,2	9,1	9,1	7,0	4,9	6,1	22,6	27,0	0,0
Autumn	8,9	5,3	3,7	12,1	10,2	7,4	31,6	20,8	0,0
Warm period	12,6	8,0	10,0	11,5	7,9	6,6	20,3	23,1	0,0
Cold period	7,0	4,5	6,6	11,8	12,1	9,5	27,8	20,7	0,0
Year	10,7	6,8	8,9	11,6	9,3	7,6	22,8	22,3	0,0
b) Wind speed by director indicator, m/s									
January	7,0	8,0	8,8	8,0	9,9	10,1	10,2	7,9	-
February	6,6	4,8	7,8	9,2	7,0	8,9	9,9	9,4	-
March	8,5	7,2	8,4	8,2	7,4	7,3	8,3	7,5	-
April	7,1	6,9	6,9	9,1	9,3	8,2	8,7	7,1	-
May	6,4	6,9	7,5	7,2	6,6	6,8	6,0	7,3	-
June	7,5	6,3	6,0	7,7	6,5	6,7	7,1	7,2	-
July	7,7	5,9	7,3	6,0	5,4	7,6	7,0	7,7	-
August	6,1	7,2	6,0	7,2	7,9	6,0	7,7	6,6	-
September	6,0	6,2	7,0	8,9	8,0	7,5	7,9	7,8	-
October	7,3	4,8	7,6	9,3	8,1	7,9	8,7	6,5	-
November	8,6	5,6	7,0	8,9	9,0	9,5	9,7	7,9	-
December	6,1	7,8	4,7	10,4	7,6	10,3	9,4	8,3	-
Winter	6,6	6,8	7,1	9,2	8,2	9,8	9,8	8,5	-

Spring	7,3	7,0	7,6	8,1	7,8	7,4	7,7	7,3	-
Summer	7,1	6,5	6,4	7,0	6,6	6,7	7,3	7,2	-
Autumn	7,3	5,5	7,2	9,1	8,4	8,3	8,8	7,4	-
Warm period	7,1	6,4	7,1	7,9	7,4	7,2	7,7	7,2	-
Cold period	7,1	6,5	7,1	9,1	8,4	9,7	9,8	8,4	-
Year	7,1	6,5	7,1	8,3	7,7	8,0	8,4	7,6	-

Table 2.3. Frequency of wind direction and its speed at an altitude of 500 m

Month, season, year	Wind direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, %									
January	6,9	1,7	6,9	13,0	12,1	11,2	24,1	24,1	0,0
February	7,8	7,0	7,0	15,6	14,8	8,6	18,0	21,2	0,0
March	4,0	4,0	10,0	18,7	17,3	15,3	17,3	13,4	0,0
April	13,5	13,5	11,4	12,0	6,4	8,5	14,2	20,5	0,0
May	11,5	8,8	13,5	14,9	12,7	4,1	16,9	17,6	0,0
June	10,3	13,9	6,7	9,1	6,7	6,1	23,0	24,2	0,0
July	8,6	3,0	9,3	6,8	5,6	8,6	27,2	30,9	0,0
August	17,9	6,9	9,0	9,7	6,9	4,8	19,3	25,5	0,0
September	12,6	7,8	3,5	5,7	10,5	8,5	26,7	24,7	0,0
October	10,1	1,7	6,7	15,1	10,1	10,1	25,2	21,0	0,0
November	3,1	4,6	2,3	3,1	15,4	11,5	42,3	17,7	0,0
December	5,6	5,6	2,8	2,8	12,7	12,7	25,4	32,4	0,0
Winter	6,8	4,8	5,5	10,5	13,2	10,8	22,5	25,9	0,0
Spring	9,7	8,8	11,6	15,2	12,1	9,3	16,1	17,2	0,0
Summer	12,3	7,9	8,3	8,5	6,4	6,5	23,2	26,9	0,0
Autumn	8,6	4,7	4,2	8,0	12,0	10,0	31,4	21,1	0,0
Warn period (03-10)	11,1	7,5	8,8	11,5	9,5	8,2	21,2	22,2	0,0
Cold period (11-02)	5,9	4,7	4,8	8,6	13,8	11,0	27,4	23,8	0,0
Year	9,3	6,6	7,4	10,5	10,9	9,2	23,3	22,8	0,0
b) Wind speed by direction indicator, m/s									
January	6,9	8,0	9,6	10,2	13,7	12,5	12,6	9,9	-
February	7,4	5,1	10,2	11,1	9,9	10,4	10,7	10,3	-
March	7,0	8,2	8,5	9,6	8,9	8,8	10,0	7,8	-
April	6,5	7,2	7,1	11,5	9,3	8,1	8,8	8,3	-
May	6,6	6,5	8,3	8,6	6,8	5,8	6,2	7,1	-
June	6,1	6,5	7,4	8,2	7,8	5,6	7,3	7,5	-
July	6,4	9,6	7,3	6,5	5,9	8,1	7,6	8,3	-
August	7,2	7,5	7,2	8,7	8,0	6,1	8,1	6,5	-
September	7,6	6,2	6,2	7,5	10,5	7,6	9,1	8,2	-
October	6,3	2,0	7,3	10,8	11,4	8,9	10,6	8,4	-
November	7,3	9,5	5,0	10,5	11,3	11,7	12,0	10,0	-
December	7,8	9,0	7,8	6,8	10,6	10,8	12,9	11,0	-

Winter	7,3	7,4	9,2	9,3	11,4	11,2	12,1	10,4	-
Spring	6,7	7,3	8,0	9,9	8,3	7,6	8,3	7,7	-
Summer	6,6	7,9	7,3	7,8	7,2	6,6	7,7	7,4	-
Autumn	7,0	5,9	6,2	9,6	11,0	9,4	10,6	8,9	-
Warm period	6,7	6,7	7,4	8,9	8,6	7,4	8,5	7,8	-
Cold period	7,3	7,9	8,2	9,6	11,4	11,3	12,1	10,3	-
Year	6,9	7,1	7,7	9,2	9,5	8,7	9,7	8,6	-

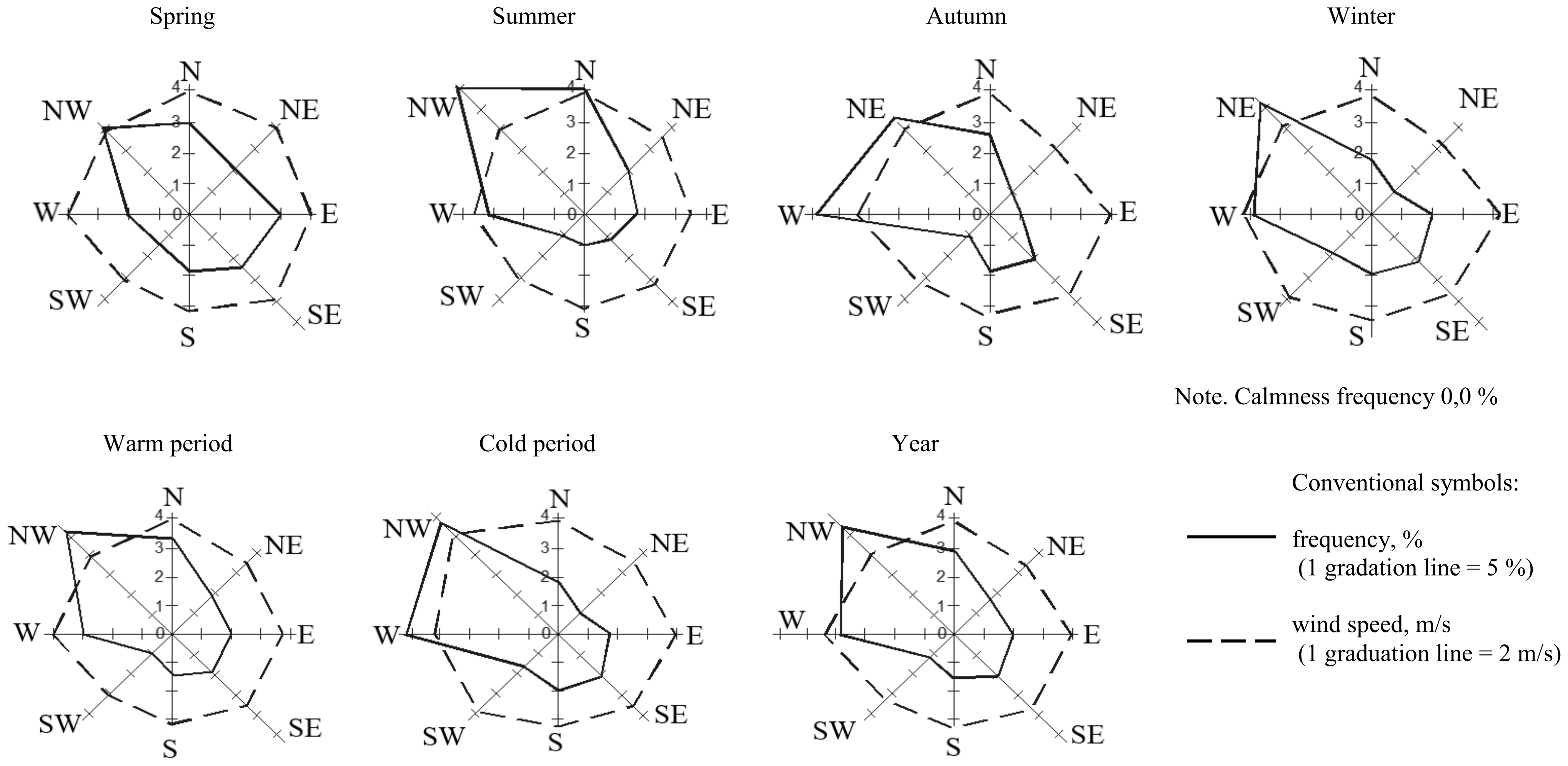


Fig. 2.1. Wind pattern (wind rose) at an altitude of 100 m. The Shepetivka aerological station.

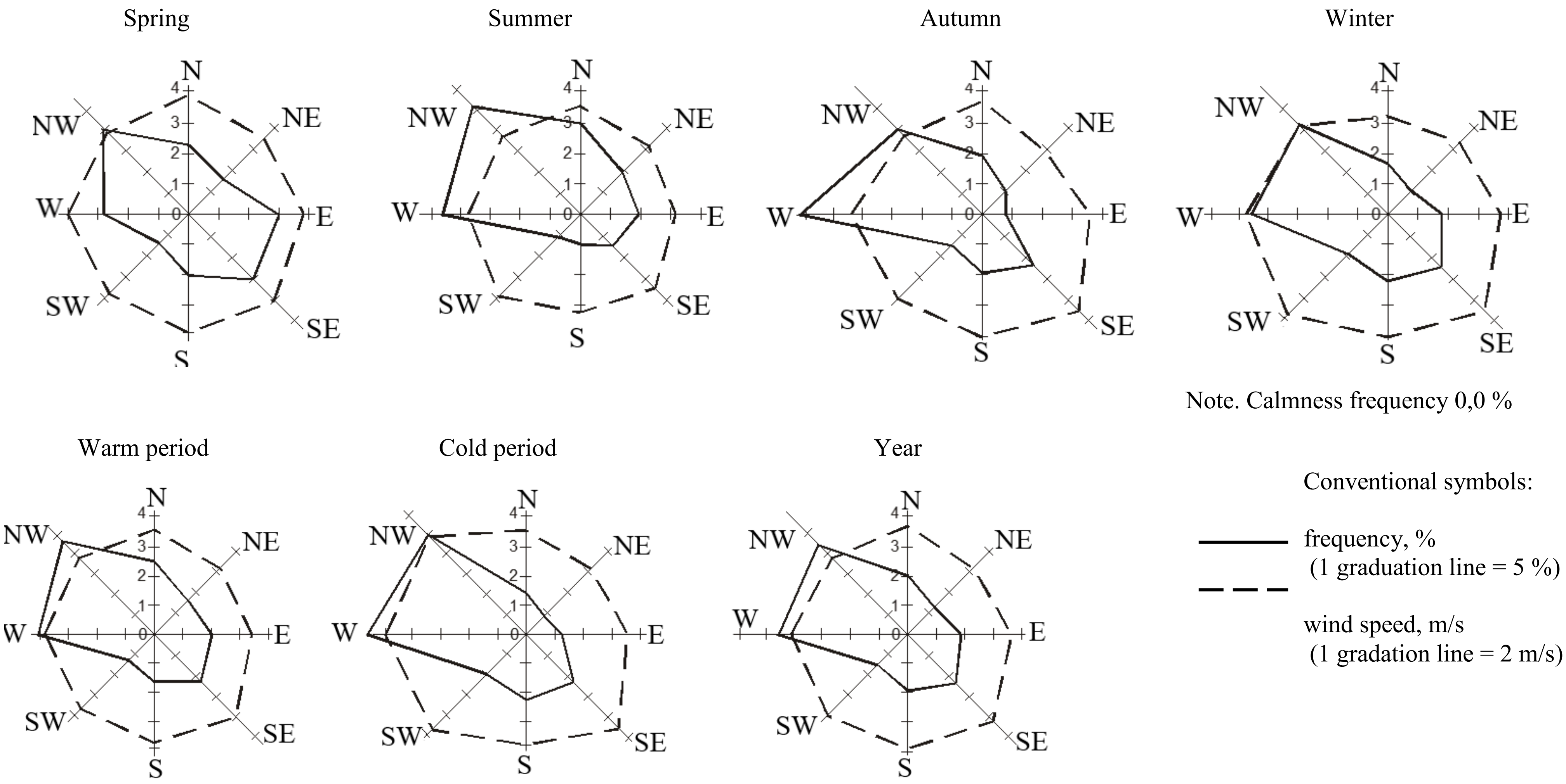


Fig.2.2. Wind pattern (wind rose) at an altitude of 200 m. The Shepetivka aerological station

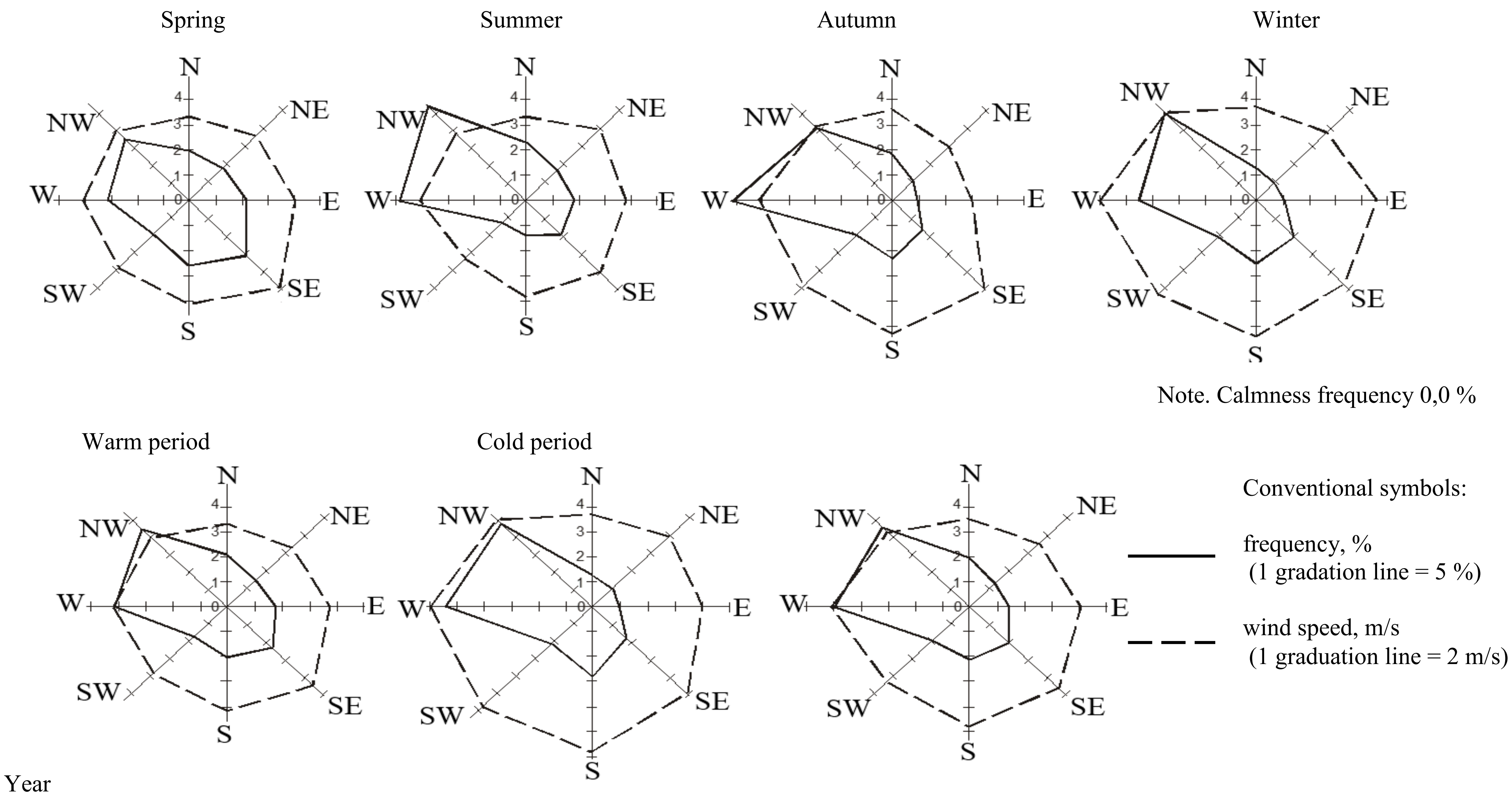


Fig. 2.3. Wind pattern (wind rose) at an altitude of 500 m. The Shepetivka aerological station.

2.1.1 Frequency, average strength and intensity of the surface inversion

The intensity of impurities dispersion is definitely determined by the atmospheric stability and the regime of turbulent diffusion. The layers in which the air temperature increases with a height (inversion) or does not change (isothermy) are particularly stable [10-12].

The annual frequency of surface inversions has the maximum index in the summer (75-78%) due to the variety of factors occur in this period. In the winter, the frequency of surface inversions is gradually reduced to 35.5-42.4% (Table 2.4) due to the predominance of the cooling processes.

The daily frequency of surface inversions is strongly pronounced from the end of the spring and during the summer months (from 69,3-77,6% at night time to complete absence at day time). In the winter, the frequency of surface inversions at night is approximately 3 times more than during a day (Table 2.4).

Table 2.4. Frequency of the surface inversion at day and nighttime

in %

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
03 hours												
42,4	35,5	45,1	53,0	69,3	75,7	75,7	77,6	60,8	47,7	36,2	38,0	54,8
15 hours												
16,5	8,7	3,3	1,0	0,0	1,7	0,7	1,5	1,2	2,4	3,2	13,6	4,5

The average annual strength of the surface inversions in this area is 260 m during the day and 310 m in the night, decreasing to 150-250 m in the summer during the day and increasing to 380-540 m in the winter at night (Table 2.5).

The most intense surface inversions are formed in the winter at night time (3,4-6.2˚C/100 m). In the summer due to the intensive warming, the intensity of inversions decreases: to 2,8-3,4˚C/100 m at night time and 0,30-0,35˚C/100 m during the day (Table 2.5).

Table 2.5. Average strength (ΔH) and intensity (ΔT) of surface inversions at day and night time.

Characteristics	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
03 hours													
ΔH, м	540	461	328	253	234	215	229	227	252	267	326	380	310
ΔT, ^{0}C	6,18	4,79	3,14	3,02	3,04	3,11	2,82	3,420	3,287	3,176	3,143	3,429	3,54
15 hours													
ΔH, м	471	413	345	123	0,0	153	210	250	107	240	425	395	261
ΔT, ^{0}C	3,89	1,56	1,45	1,06	0,0	0,30	1,00	0,350	0,033	1,317	2,087	2,272	1,20

It is important to consider in the evaluation of the atmospheric self-purification ability the data on mutual frequency of surface inversions and light winds or the weather conditions under which the transit of radionuclides is difficult and they accumulate near the emission source. In the area of SE "Rivne NPP" the frequency of air "stagnation" is the maximum in the summer at night time - 38,2-42,9% (prevalence of radiation cooling), decreases to 8,4-20,4% in the winter (prevalence of advective currents). Specifically, such situations are rare during the day, even in the winter (2,26-6,90%) and they never occur in the summer. (Table 2.5).

Table 2.5. Frequency of surface inversions and light winds (0-1 m/s) near the land surface at day and night time

in %

Month											
01	02	03	04	05	06	07	08	09	10	11	12
03 hours											
16,94	20,43	20,39	26,17	41,58	38,19	42,62	42,86	24,13	16,88	11,79	8,44
15 hours											
6,90	2,26	1,33	0,34	0,0	0,0	0,0	0,0	0,0	0,4	0,0	5,66

The prevalence of the radiation cooling (the major factor of the surface inversions formation) and the typical low wind weather in this period explain the increased probability of the mutual frequency of calmness and surface inversions: in winter 12-24%, in the summer – 28-37%, Table 2.6.

Table 2.6. Frequency of wind direction and calmness under the surface inversions

in %

Month, season, year	Wind direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
January	0,6	0,7	9,7	15,2	22,4	18,2	4,8	4,2	24,2
February	1,7	1,7	12,4	18,3	11,7	12,5	13,3	4,2	24,2
March	0,0	0,7	13,2	23,6	17,4	15,3	7,6	1,4	20,8
April	5,0	3,1	9,4	16,3	16,3	12,0	11,3	3,5	23,1
May	5,8	2,0	11,6	11,6	9,7	6,3	10,1	6,7	36,2
June	5,2	5,1	5,1	10,1	14,3	11,3	15,2	5,6	28,1
July	1,8	2,6	5,2	6,1	10,0	11,4	17,5	8,3	37,1
August	3,3	2,9	5,8	11,3	15,8	8,3	11,3	6,3	35,0
September	3,0	3,5	4,0	18,7	18,8	12,9	12,8	7,0	19,3
October	2,0	1,0	5,8	15,4	23,3	21,4	7,8	3,9	19,4
November	1,3	0,0	0,0	8,0	21,3	32,0	20,0	2,7	14,7
December	2,0	0,0	2,4	12,0	27,2	27,1	16,2	1,0	12,1

2.1.2 Frequency, average strength and intensity of the raised inversions

The frequency of raised inversions in layers at a height of 10-250 m and 260-500 m equals to 0,33-5,28% in the summer and increases to 5,24-29,5% in the cold period (Table 2.7). In the highest layer (500-2000 m), the raised inversions are most likely in the autumn-winter period (5,5-28,5%). In total, in the layer of 10-2000 m, the raised inversions occur in the summer and equals to

9,7-10,5% cases at night time and 22-26% during the day, whereas in winter their frequency is 42-61%, at night and 70-78% in the daytime.

In the average annual estimation, the raised inversions have the same probability from a height of 260 m (10,5-11,8%), Table 2.8.

Table 2.7. Frequency of raised inversion in the daytime by height gradation

in %

Height gradation, km	Month											
	01	02	03	04	05	06	07	08	09	10	11	12
03 hours												
0,01 - 0,25	7,49	11,1	7,24	3,69	5,28	3,47	2,95	2,27	2,45	4,64	5,24	11,4
0,26 - 0,50	14,1	14,0	6,91	7,72	3,30	2,08	3,93	1,62	3,85	11,0	16,2	18,6
0,51 - 1,00	13,0	10,0	10,5	4,70	4,95	1,74	0,98	1,30	2,80	10,1	13,5	16,5
1,01 - 2,00	7,49	6,45	8,55	5,03	2,31	2,43	2,62	2,27	2,10	5,49	11,8	14,8
0,01 - 2,00	42,0	41,6	33,3	21,1	15,8	9,72	10,5	7,47	11,2	31,2	46,7	61,2
15 hours												
0,01 - 0,25	19,5	12,8	4,67	1,02	0,33	0,35	0,71	1,48	1,15	2,44	5,95	15,5
0,26 - 0,50	29,5	22,2	13,3	6,93	2,33	2,08	1,77	3,32	3,08	13,8	25,8	24,5
0,51 - 1,00	18,8	22,2	23,3	12,0	8,97	5,88	5,65	4,43	10,4	28,5	23,8	16,6
1,01 - 2,00	9,96	9,77	15,7	20,5	18,6	17,7	14,5	24,7	29,2	23,2	15,1	14,0
0,01 - 2,00	77,8	66,9	57,0	40,3	30,2	26,0	22,6	34,0	43,8	67,9	70,6	70,6

Table 2.8. Annual average gradation of raised inversion

in %

The raised inversions from low edge layer				
Layer edge, km	0,01–0,25	0,26–0,50	0,51–1,00	1,01–2,00
Inversion frequency, %	5,5	10,5	11,2	11,8

Under the low frequency of raised inversions, its seasonal variation is well expressed with maximum in the cold period (up to 19.5%). As the raised inversions are formed both in the process of destruction of surface inversions by radiation heating, further convection and advection, the maximum frequency of raised inversions occurs in the summer in the morning of 3-5% (during the day ~ 1%). The average height of the low edge of raised inversions at night is 140-620 m, in the daytime - 550-1550 m (Table 2.9).

Table 2.9. Average height of raised inversion low edge

in km

Month											
01	02	03	04	05	06	07	08	09	10	11	12
03 hours											
0,45	0,48	0,49	0,34	0,23	0,14	0,18	0,10	0,27	0,62	0,61	0,56
15 hours											
0,55	0,62	0,79	1,24	1,11	1,42	1,55	1,43	1,35	0,94	0,77	0,61

The maximum raised inversions are observed in the daytime, both in the warm and cold periods of the year. The inversion lower edge in this case is at a height of 10-250 m, and the inversion strength reaches 730 m during the warm period and 640 m in the cold period (Table 2.10).

The average annual strength of raised inversions within the standard altitude range in total equals to 380-400 m (Table 2.11).

Table 2.10. Average strength of raised inversions

in km

Low edge gradation,km	Month											
	01	02	03	04	05	06	07	08	09	10	11	12
03 hours												
0,01-0,25	0,42	0,47	0,40	0,41	0,30	0,36	0,19	0,30	0,26	0,23	0,57	0,41
0,26-0,50	0,44	0,48	0,59	0,34	0,30	0,39	0,35	0,40	0,25	0,44	0,34	0,49
0,51-1,00	0,53	0,41	0,36	0,40	,039	0,29	0,62	0,35	0,31	0,52	0,45	0,35
1,01-2,00	0,29	0,42	0,39	0,35	0,46	0,34	0,27	0,38	0,48	0,28	0,34	0,38
0,01-2,00	0,42	0,45	0,43	0,37	0,36	0,35	0,36	0,36	0,32	0,37	0,43	0,41
15 hours												
0,01-0,25	0,45	0,64	0,31	0,19	0,73	0,25	0,50	0,23	0,32	0,34	0,64	0,45
0,26-0,50	0,47	0,49	0,46	0,30	0,18	0,52	0,22	0,35	0,34	0,45	0,49	0,47
0,51-1,00	0,53	0,41	0,40	0,38	0,30	0,25	0,35	0,25	0,47	0,47	0,41	0,43
1,01-2,00	0,40	0,39	0,41	0,43	0,38	0,39	0,46	0,37	0,42	0,39	0,46	0,35
0,01-2,00	0,46	0,47	0,39	0,32	0,40	0,35	0,38	0,30	0,39	0,41	0,50	0,42

Table 2.11. Average annual intensity and strength of raised inversions

The raised inversion from layer base edge				
Layer edge, km	0,01–0,25	0,26–0,50	0,51–1,00	1,01–2,00
Intensity, ^{0}C	2,0	2,5	2,4	1,4
Strength, km	0,38	0,40	0,40	0,38

The intensity of raised inversions is more frequent in the winter, in the mixing layer (3,5-6,0˚C). In warm period, the average intensity does not exceed 0,6-1,6˚C (Table 2.12).

Table 2.12. Average intensity of raised inversion

in ^{0}C

Low edge gradation, km	Month											
	01	02	03	04	05	06	07	08	09	10	11	12
03 hours												
0,01 - 0,25	5,77	3,42	3,14	1,11	1,69	1,13	1,19	1,21	1,87	1,71	2,81	3,66
0,26 - 0,50	5,96	4,58	3,93	2,21	1,01	1,85	0,94	0,0	1,35	3,28	3,35	4,97
0,51 - 1,00	4,76	5,52	3,12	1,87	1,19	1,52	0,67	0,13	2,25	3,21	3,92	2,44
1,01 - 2,00	3,28	1,73	1,77	1,52	0,70	1,07	0,19	0,74	1,03	1,60	2,07	2,13
0,01 - 2,50	4,94	3,81	2,99	1,68	1,15	1,39	0,75	0,52	1,63	2,45	3,04	3,30
15 hours												
0,01 - 0,25	4,41	3,18	2,53	1,57	0,0	0,0	0,0	0,85	0,67	1,23	2,23	3,33
0,26 - 0,50	4,83	4,57	2,84	1,23	1,39	0,75	0,84	0,0	1,47	2,31	2,93	3,50
0,51 - 1,00	4,56	3,77	2,07	1,50	0,57	0,98	0,54	1,00	1,01	2,45	2,67	3,87
1,01 - 2,00	2,23	1,92	2,09	1,08	0,72	0,84	0,72	0,84	1,19	1,56	1,53	1,88
0,01 - 2,50	4,03	3,23	2,37	1,35	0,67	0,64	0,52	0,67	1,09	1,89	2,34	3,14

The frequency of raised inversions with a low layer edge of 10-500 m at the wind speed 0-1 m/s near the land surface is significantly lower than that of stagnation cases (Table 2.13). Such situations are observed in 10% cases only at night time in the summer, in the rest of the time, their probability is reduced to 4-7% cases. They are not observed in the daytime during the warm period.

Table 2.13. Frequency of raised inversion with low layer edge 0,01-0,50 km at the wind speed 0-1 m/s near the land surface

in %

Month											
01	02	03	04	05	06	07	08	09	10	11	12
03 hours											
5,40	9,39	7,32	10,5	1,45	10,0	10,2	10,5	4,07	8,46	5,6	4,75
15 hours											
5,26	3,03	1,46	0,0	0,0	0,0	0,23	0,42	0,0	0,19	0,5	4,24

2.2 Height of mixed layer

The mixed layer or the boundary layer is identified as the lower layer, which starts at the land surface. The dynamic and thermal effects of the underlying surface determine its specific characteristics. The maximum height of mixed layer (HML) was determined by aerodynamic diagram and the data on maximum air temperature.

To restore the vertical profile of air temperature, the observations were made at an altitudes of 20, 500, 1000, 1500, 2000 and 3000 m. The average of maximum HML was calculated on the basis of maximum index (Table 2.14).

Table 2.14. Average height of mixed layer

in km

Month												Year
01	02	03	04	05	06	07	08	09	10	11	12	
0,29	0,31	0,46	0,70	0,87	0,75	0,74	0,71	0,65	0,49	0,30	0,25	0,54

The character of air temperature variation at different height, mentioned above, affects the formation of mixed layer. In winter, this layer extends to a height of 250-460 m and limits the volume of the atmospheric air, where the impurities are "diluted" and distributed.

In the warm period, the volume of the HML increases to 700-870 m due to the warming up of the underlying surface and under influence of convective processes.

In total, the annual capacity of mixed layer in this area is only 540 m (the average of 800-900 m on the territory of Ukraine) which reduces the mechanism of natural self-purification of the atmospheric air in the area of the Rivne NPP.

The height frequency of mixed layer ≤ 500 m (Table 2.15) is maximum in the winter (85-92%). In this period, the mechanism of air mixing is the most complicated. In the warm period, the frequency of thin mixed layers is reduced to 32-42%, which characterizes a more intense mixing in the lower layers of the atmosphere.

Table 2.15. Annual frequency of mixed layer height ≤ 0,5 km

in %

Month											
01	02	03	04	05	06	07	08	09	10	11	12
85,9	85,2	68,5	44,3	32,2	41,7	34,2	37,2	47,3	57,6	81,2	91,6

Under inverse air temperature, the HML is determined by inversion characteristics and mostly by height of the lower edge of raised inversions.

2.3 Cloud cover regime

This section covers the annual variation of cloud cover up to 1 km above the land surface, affecting the impurities dispersion in the lower atmospheric layers (Table 2.16).

The frequency of cloud base was determined for the cases with high overcast (8-10 points). In the Table 2.16, the frequency of height of cloud base is given in the increasing order.

In the cold period of the year, the cloud cover is observed more often (due to the cyclonic nature of the weather). In November-February, in 51-60% cases, the cloud base is observed in the layer of up to 1.0 km and in the upper layers above1 km and equals to 40-49%. In the cold period of the year, the cloud base has the maximum frequency in the layer of 0,2-0,4 km (from 17-18% in January-February to 20-26% in November-December).

In the summer, the clouds formation occurs due to convective air exchange and the high overcast in this period is quite rare.

In summer, the maximum frequency of cloud base is observed in the layers of above 1 km. In the layer up to 1 km, the cloud base is extremely rare. From May to September, the cloud base at a height of 0.4-1.0 km was not observed.

Table 2.16. Frequency of cloud base height (in the layer from the land surface to the specified height)

in %

Height above the land surface, km	Month											
	01	02	03	04	05	06	07	08	09	10	11	12
0,1	2	3	1	0	0	1	0	0	1	1	3	5
0,2	14	12	6	4	3	9	0	2	4	5	10	25
0,4	32	29	16	9	-	-	-	-	-	15	36	45
0,6	39	40	22	15	-	-	-	-	-	24	47	52
0,8	45	47	26	20	-	-	-	-	-	29	60	58
1,0	51	51	30	24	-	-	-	-	-	36	70	59
Number of cases*)	247	270	362	405	417	397	379	397	387	355	297	277
*) – including the cases observed in the layers at a height > 1,0 km												

2.4 Atmospheric stability

The thermodynamic conditions of lower atmospheric layer determine by the atmospheric stability classes. In accordance with the classification proposed by Pasquill, later improved by Turner and Ulug, and specified by the Institute of Experimental Meteorology (Russia, Obninsk) for the European territory of the former USSR, there are seven categories (classes) of atmospheric stability [12].

The average annual characteristics of atmospheric stability in the area of the Rivne NPP are shown in the Tables 2.17 and 2.18. The observations of Manevichi meteorological station were used as the source of meteorological data.

Table 2.17. Frequency of atmospheric stability classes under all weather conditions per season and per year

in %

Atmospheric stability class	Season				Year
	Winter	Spring	Summer	Autumn	
I Extremely unstable	-	3,1	9,0	1,0	3,3
II Moderately unstable	-	9,9	16,0	6,0	8,0
III Slightly unstable	1,6	24,9	28,4	26,3	20,4
IV Neutral	31,1	36,4	18,4	44,2	32,5
V Slightly stable	27,6	4,5	3,3	2,4	9,4
VI Moderately stable	27,0	10,5	11,7	8,0	14,3
VII Extremely stable	12,8	10,7	13,2	11,9	12,1

According to the data in the Table 2.17, in the area of the Rivne NPP, the neutral atmospheric stability class prevails (32.5%) during the year. The slightly unstable class is less frequent (20.4%) in the year. The extremely and moderately unstable classes are within 3.3-8.0%.

In the seasonal context, the winter season is remarkable. Due to the lack of convective mixing process in the winter, the extremely unstable class of the atmosphere is completely absent (the stable classes prevails in 67.4% cases). During the warm period of the year, the vertical air mixing processes increase, reaching a maximum in the summer and in this period in 25% cases there is an extremely and moderately unstable atmospheric stability. In the daytime, the dynamic and thermal factors determine the stable atmospheric stability at night, and during the day, especially during the warm period; it is unstable (due to the prevalence of the convectional processes in the daytime).

The distribution of atmospheric stability classes under different wind directions and wind speeds is presented in the Table 2.18. According to the data taken in the area of the Rivne NPP during the year, the extremely unstable class of atmospheric stability (class I) is repeated in 0,3-0,5% cases at the low speeds (1-3 m/s) and under any wind direction. The moderately unstable class of atmospheric stability (class II) is more often repeated at the wind speeds of 1-3 m/s under the south-eastern wind direction (1.2% cases) and at the wind speeds of 4-5 m/s this class of stability occurs with the same frequency of 0,1-0,3% under any wind direction. The slightly unstable class of the atmospheric stability (class III) has the maximum frequency (2,0-2,8%) with the western and eastern winds at the speed of 1-3 m/s. The neutral class of the atmospheric stability (class IV) has the maximum frequency at the wind speeds of 4-5 m/s in the western direction (3,1%), and at the speed of 20 m/s this class is observed only with the wind of western direction (frequency less than 0,2%). The slightly stable class of atmospheric stability (V class) is often repeated (1.9%) at the wind of south-eastern direction and under the wind speed of 1-3 m/s. The moderately stable class of atmospheric stability (VI class) is often observed in the winds of eastern, south-eastern and western directions at the speed of 1-3 m/s (0,8-1,0% cases). The extremely stable class of atmospheric stability (class VII) is observed at the winds of eastern, south-eastern, southern and western directions at the speed of 1-3 m/s.

The VII class of atmospheric stability is most frequent 5.6% under the calmness conditions during the year.

The stratification of the atmosphere basically determines the height of mixed layer. Under neutral atmospheric stability, the height of mixed layer with an edge of less than 500 m is most frequent. The interdependency between the height of mixed layer and atmospheric stability can be proximately estimated by the data on the seasonal frequency of the categories (classes) of atmospheric stability and the data on the frequency of the height of mixed layer ≤ 500 m.

The prevalence of the stable classes of atmospheric stability and the low-strength mixed layers in the area of the Rivne NPP determines the less intense mechanisms of natural self-purification of the atmosphere in the monitoring area.

Table 2.18. Classification of atmospheric stability classes under different wind directions and speeds during a year

in %

Atmospheric stability class	Speed scale, m/s	Wind direction (rhumb)								Total
		N	NE	E	SE	S	SW	W	NW	
I (A) Extremely unstable	Calmness									0,3
	1-3	0,4	0,5	0,4	0,4	0,2	0,3	0,4	0,4	3,0
	total	0,4	0,5	0,4	0,4	0,2	0,3	0,4	0,4	3,3

Atmospheric stability class	Speed scale, m/s	Wind direction (rhumb)								Total
		N	NE	E	SE	S	SW	W	NW	
II (B) Moderately unstable	Calmness									0,6
	1-3	0,9	0,6	0,8	1,2	0,5	0,5	0,8	0,7	6,0
	4-5	0,3	0,2	0,1	0,2	0,1	0,1	0,3	0,2	1,5
	total	1,2	0,8	0,9	1,4	0,6	0,6	1,1	0,9	8,1
III (C) Slightly unstable	Calmness									1,5
	1-3	1,9	1,5	2,1	2,3	1,4	2,0	2,8	1,9	15,9
	4-5	0,2	0,1	0,3	0,4	0,2	0,2	0,3	0,1	1,8
	6-7	0,1	-	0,1	0,2	0,1	0,1	0,3	0,2	1,1
	total	2,2	1,6	2,5	2,9	1,7	2,3	3,4	2,2	20,3
IV (D) Neutral	Calmness									2,6
	1-3	1,2	0,8	1,0	1,0	0,7	1,2	1,6	1,3	8,8
	4-5	0,8	0,5	1,4	1,7	0,7	1,8	3,1	1,5	11,5
	6-7	0,3	0,1	0,7	1,0	0,2	1,0	2,0	0,7	6,0
	8-9	0,2	0,0	0,3	0,2	0,1	0,4	0,7	0,4	2,3
	10-14	0,1	0,0	0,1	0,1	0,0	0,2	0,6	0,1	1,2
	15-19	-	-	-	-	0,0	-	0,0	-	0
	20	0,0	-	-	-	-	0,0	0,2	-	0,3
	total	2,6	1,4	3,5	4,0	1,7	4,6	8,2	4,0	32,7
V (E) Slightly stable	Calmness									0,0
	1-3	0,4	0,5	1,1	1,9	0,8	1,3	1,4	0,7	8,1
	4-5	-	0,1	0,2	0,2	0,1	0,1	0,1	0,1	0,9
	6-7	-	-	0,0	0,1	-	0,0	0,1	0,0	0,2
	total	0,4	0,6	1,3	2,2	0,9	1,4	1,6	0,8	9,2
VI (F) Moderately stable	Calmness									3,0
	1-3	1,1	0,8	1,7	1,9	1,2	1,1	1,8	1,3	10,9
	4-5	-	-	0,1	0,0	0,0	0,0	0,1	0,0	0,3
	total	1,1	0,8	1,8	1,9	1,2	1,1	1,9	1,3	14,2
VII Extremely stable	Calmness									5,6
	1-3	0,5	0,6	1,0	1,0	1,0	0,8	1,0	0,7	6,6
	total	0,5	0,6	1,0	1,0	1,0	0,8	1,0	0,7	12,2
Note. The classes of atmospheric stability by Pasquill are indicated in brackets (A)										

2.5 Aeroclimatic conditions in the area of the SS "Rivne NPP" in the period of 2006-2017

The ARMS (Automatic radiation monitoring system) observations at the meteorological station of the Rivne NNP [18] were performed by the automatic station MAWS-301 under Kyiv time zone.

Change time of the day:
- Kyiv time - 00 hours 00 minutes;
- Greenwich - 22 hours 00 minutes.
- under daylight saving time, the change of the day at Greenwich is 21 hours 00 minutes.

The ARMS meteorological station of the Rivne NPP is registered in the State Hydrometeorological Service of Ukraine since November 2005, the current registration certificate No. 02/10 HM dated October 28, 2015.

The meteorological station monitors the following meteorological parameters:
- wind direction;
- wind speed;
- air temperature;
- degree of air saturation;
- atmospheric pressure;
- solar irradiance;
- radiation balance;
- amount of precipitation;
- precipitation intensity;
- visibility;
- weather pattern.

The category (class) of atmospheric stability is a parameter that characterizes the conditions of impurities dispersion in the atmosphere. It depends on two main factors: turbulent diffusion and wind speed, which, in their turn, depend on many meteorological characteristics.

There are a number of classification systems of atmospheric stability. The Pasquill classification, which is used in this report, is recommended by the IAEA [19] and it is based on seven classes sorted by increasing degree of atmospheric stability from A to G.

2.5.1 Meteorological parameters in the period of 2006-2017

Wind speed:
- average index 2,73 m/s;
- maximum index 25,6 m/s recorded on 15.03.2014

The average wind pattern (wind rose) in the period of 2006-2017 is given in the Table 2.19.

Table 2.19. Wind pattern (wind rose) in the monitoring period of 2006-2017, %

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S
2006-2017	4,73	5,42	5,3	4,24	2,53	4,89	7,84	8,89	6,95
Direction	SSW	SW	WSW	W	WNW	NW	NNW	Calmness	Total
2006-2017	7,34	9,02	7,81	7,91	5,99	6,11	5,03	7,36	100,0

The average wind speed depending on wind directions is given in the Table 2.20.

Table 2.20. Average wind speed depending on wind directions in the period of 2006-2017, m/s

Year	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NW	Period
2006	3,21	2,98	2,48	3,07	2,45	3,21	3,11	2,99	2,48	2,33	2,62	3,09	3,13	3,01	2,74	2,97	2,74
2007	3,18	2,95	2,68	3,41	2,96	3,24	3,32	3,10	2,71	2,54	3,11	3,59	3,49	3,40	2,89	3,15	2,90

Year	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NW	Period
2008	3,11	3,13	2,55	3,28	2,66	3,12	3,33	3,24	2,90	2,72	3,16	3,79	3,39	3,16	2,95	3,19	2,96
2009	2,83	2,81	2,45	3,10	2,53	3,27	3,14	3,07	2,61	2,55	2,84	3,14	2,95	3,18	2,84	3,02	2,60
2010	2,95	2,57	2,94	3,56	2,88	3,18	3,16	3,25	2,72	2,80	3,24	3,52	3,17	3,18	2,82	3,08	2,76
2011	3,13	2,86	2,65	2,70	2,53	3,21	3,11	3,12	2,65	2,73	2,97	3,34	3,23	3,35	3,15	3,46	2,66
2012	3,00	2,72	2,72	2,94	2,45	2,81	3,26	2,98	2,64	2,68	3,05	3,39	3,16	3,23	3,15	3,48	2,71
2013	3,16	3,00	2,96	3,09	2,63	3,06	2,92	2,94	2,70	2,77	3,03	3,50	3,00	3,11	3,08	3,36	2,71
2014	2,90	2,71	2,76	3,30	2,90	2,97	3,14	3,06	2,66	2,53	2,91	3,33	3,31	3,12	2,75	3,03	2,65
2015	2,92	2,71	2,43	2,93	2,24	2,73	2,71	2,67	2,21	2,22	2,65	3,21	3,09	2,87	2,72	2,88	2,67
2016	2,99	2,79	2,31	2,67	2,21	2,84	3,03	3,19	2,39	2,41	2,62	2,86	2,84	2,69	2,55	2,86	2,67
2017	2,93	2,59	2,44	2,94	2,28	2,41	2,64	2,82	2,39	2,60	3,05	3,00	2,89	2,74	2,65	2,93	2,73
2006 - 2017	3,03	2,83	2,61	3,11	2,59	3,02	3,08	3,04	2,59	2,56	2,94	3,31	3,13	3,08	2,86	3,13	2,73

The frequency of wind speed during time intervals is given in the Table 2.21.

Table 2.21. Frequency of wind speed during time intervals in the period of 2006-2017, %.

Wind speed	0.0<=v< 0.4 (calmness)	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4
2006	4,315	5,024	22,15	27,52	21,08	17,54	2,207	0,168	-	-
2007	7,297	3,385	18,09	26,38	21,54	18,45	3,997	0,852	0,009	-
2008	5,866	3,233	17,66	26,33	22,31	20,23	3,789	0,571	0,003	-
2009	10,59	2,600	19,36	28,71	21,61	15,10	1,882	0,141	0,001	-
2010	10,58	1,482	15,74	29,34	22,42	17,75	2,437	0,238	0,001	-
2011	13,18	1,480	15,48	29,51	22,06	15,20	2,565	0,520	0,007	-
2012	10,31	1,907	17,52	29,36	22,07	15,69	2,814	0,329	0,001	-
2013	10,74	1,882	17,55	28,86	21,63	16,27	2,702	0,368	< 0,001	-
2014	10,92	2,547	17,25	29,09	22,04	15,60	2,337	0,220	0,002	< 0,001
2015	1,704	8,766	24,31	26,88	20,28	15,49	2,305	0,275	0,001	-
2016	1,839	8,607	23,57	27,41	20,78	15,50	2,161	0,148	-	-
2017	1,045	6,967	23,95	28,32	21,75	15,66	2,085	0,227	0,002	-
Period	7,366	3,990	19,39	28,14	21,63	16,54	2,607	0,338	0,003	< 0,001

Air temperature:

- average index of +8,94ºC for 12 years;
- absolute maximum of +35,5ºC, recorded on 04.08.2014 and 11.08.2015;
- the hottest day - 29.07.2012, the average daily temperature +28,49ºC;
- absolute minimum of -29,8ºC, recorded on 03.02.2012;

- the coldest day 20.01.2006, the average daily temperature -23,99ºC.

Degree of air saturation:

- average index of 74,5% for 12 years;
- absolute minimum of 13,0% recorded on 05.05.2006, 27.04.2009, 28.10.2014 and 10.08.2015.

Atmospheric pressure at the meteorological station level (the barometer was installed at a height of 172.8 meters above sea level):

- average index of 995,4 hPa;
- absolute maximum of 1026,8 hPa (23.01.2006);
- absolute minimum of 955,3 hPa (29.10.2017);
- maximum pressure drop of 30,1 hPa in the day interval (18.01.2007).

Total solar radiation:

- average annual amount of solar energy - 4136,3 MJ/m^2;
- average annual sunshine duration - 1961 hour 1 minute;
- average long-term index of total solar radiation – 221,1 W/m^2;
- absolute maximum of minute index of surface flow density;
- solar radiation - 1406 W/m^2 (07.07.2016).

Amount of precipitation:

- RG-13H - average annual amount of precipitation is 577,75 mm;
- PWD-11 - average annual amount of precipitation is 549,83 mm;
- average annual snow depth – 901,67 mm;
- average intensity - 0,59 mm/h;
- maximum precipitation intensity of 2,45 mm/min recorded on 14.07.2008;
- PWD -maximum amount of precipitation in the day interval is 43,3 mm (15.07. 2006);
- RG-13H - maximum daily amount of precipitation is 51,4 mm (13.08.2012);
- maximum monthly amount of precipitation is 161.53 mm (July 2008);
- minimum monthly amount of precipitation is 1,6 mm (August 2015);
- maximum daily snow depth - 183 mm (24.01.2007);
- maximum duration of continuous precipitation - 46 hours and 45 minutes (15.12.2012-17.12.2012);
- precipitation was observed in the form of light and moderate snow;
- precipitation was observed 2683 days from 4377 days (61%); average annual amount of days with precipitation is 224 days.

The average annual of 32.2 fog days was observed in the period of 2006-2017. The number of fog days per month is given in the Table 2.22.

Table 2.22. Number of fog days

Month, year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2006	0	2	7	2	2	3	0	1	4	5	11	0	37
2007	0	4	3	1	1	0	1	1	2	1	4	3	21
2008	5	1	3	3	2	1	3	2	2	5	8	4	39
2009	6	3	6	1	0	4	2	2	5	2	8	4	43
2010	2	6	1	2	3	3	3	2	1	1	7	4	35
2011	6	0	1	1	1	2	1	2	4	1	5	2	26
2012	3	0	2	2	4	0	0	1	3	8	7	3	33
2013	2	1	2	3	3	2	0	2	6	8	3	4	36
2014	1	5	2	5	1	2	2	2	1	4	4	3	32
2015	4	3	1	0	0	0	1	0	6	4	5	9	33
2016	4	2	1	1	2	1	0	1	4	3	1	6	26
2017	4	6	0	4	0	0	2	0	0	2	3	4	25
Period	37	33	29	25	19	18	15	16	38	44	66	46	386
Average annual	3.1	2.8	2.4	2.1	1.6	1.5	1.3	1.3	3.2	3.7	5.5	3.8	32.2

The average annual meteorological parameters are given in the Table 2.23.

Table 2.23. Average annual meteorological parameters of the monitoring period, per year.

№	Parameters	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Period
1.	Prevailing wind direction	SSE	SW	SSE	SSE	SE	SW	SW	SSE	SE	SW	SW	SW	SW
2.	Maximum wind speed, m/s	18,3	24,0	24,3	18,8	18,8	22,1	19,0	18,8	25,6	21,2	16,9	21,0	25,6
3.	Average wind speed, m/s	2,74	2,90	2,96	2,60	2,76	2,66	2,71	2,71	2,65	2,67	2,67	2,73	2,73
4.	Calmness frequency, %	4,32	7,30	5,87	10,60	10,58	13,18	10,31	10,74	10,92	1,70	1,84	1,04	7,36
5.	Maximum air temperature, °C	32,2	34,7	34,7	32,3	34,5	33,7	35,4	34,0	35,5	35,5	33,7	34,0	35,5
6.	Average air temperature, °C	8,18	9,23	9,24	8,48	8,17	8,85	8,41	8,94	9,35	10,01	9,29	9,12	8,94
7.	Minimum air temperature, °C	-27,0	-16,6	-15,7	-22,5	-25,8	-16,8	-29,8	-19,3	-22,8	-18,7	-18,9	-21,5	-29,8
8.	Maximum air humidity, %	104	104	100	110	110	99	97	97	97	96	99	98,9	110
9.	Average air humidity, %	77,2	75,9	76,4	76,8	76,8	73,4	74,1	74,5	71,1	68,9	72,6	76,1	74,5
10.	Minimum air humidity, %	13	14	17	13	17	16	15	15	13	13	19	17,6	13
11.	Maximum atmospheric pressure, hPa	1026,8	1017,9	1021,6	1013,3	1019,2	1018,9	1022,3	1018,0	1018,3	1023,4	1017,9	1020,5	1026,8
12.	Average atmospheric pressure, hPa	996,4	994,7	995,1	994,5	993,3	997,0	995,2	994,8	996,4	997,1	995,6	995,1	995,4
13.	Minimum atmospheric pressure, hPa	968,7	957,2	957,6	963,4	968,3	966,1	964,5	962,8	968,7	956,2	964,0	955,3	955,3
14.	Maximum atmospheric pressure above mean sea level (AMSL0, hPa	1051,4	1040,4	1045,1	1035,5	1043,6	1041,7	1046,1	1040,9	1042,0	1046,3	1040,2	1043,5	1051,4
15.	Average atmospheric pressure above mean sea level (AMSL0, hPa	1017,5	1015,7	1016,1	1015,6	1014,4	1018,1	1016,3	1015,9	1017,5	1018,2	1016,7	1016,2	1016,5
16.	Minimum atmospheric pressure above mean sea level (AMSL0) hPa	989,8	977,4	978,0	984,1	988,7	987,0	985,5	984,2	989,5	976,6	984,8	975,6	975,6
17.	Maximum atmospheric pressure above mean sea level, W/m^	1352	1259	1292	1343	1263	1282	1286	1286	1324	1403	1406	1324	1406
18.	Average atmospheric pressure above mean sea level, W/m^	218,7	215,4	207,8	220,8	218,9	233,6	226,2	220,1	231,5	230,0	220,1	212,3	221,3
19.	Amount of solar energy, MJ/m^2	3992,1	4032,1	3898,3	4138,9	4052,5	4316,7	4234,5	4120,8	4311,0	4329,8	4186,9	4022,7	49636,4
20.	Sunshine duration (number of days)	80d 20:34	78d 17:05	77d 10:06	81d 00:03	80d 10:22	86d 22:46	83d 07:10	81d 10:15	85d 05:24	86d 10:24	80d 12:38	78d 05:27	2y 250d 12:14

21.	Maximum radiation balance, W/m^2	858	874	925	887	863	836	863	906	904	1053	1017	952	1053
22.	Average radiation balance, W/m^2	35,9	39,1	36,6	38,5	38,4	38,1	39,9	40,2	45,2	49,8	48,3	48,2	41,5
23.	Minimum radiation balance, W/m^2	-500	-458	-418	-398	-199	-198	-198	-198	-199	-199	-199	-199	-500
24.	Total radiation balance, MJ/m^2	1116,1	1231,9	1158,7	1209,8	1200,2	1196,2	1260,4	1265,3	1424,4	1570,6	1525,6	1517,8	15677,1
25.	Amount of precipitation (RG-13H), mm	568,8	527,6	695,0	600,6	583,8	485,8	681,4	554,8	525,0	511,6	494,6	654,0	6933
26.	Amount of precipitation (PWD-11), mm	578,59	521,42	701,01	580,64	527,49	481,42	627,86	535,39	437,20	460,30	478,13	668,50	6597,96
27.	Average precipitation intensity (PWD-11), m/l'hour	0,62	0,62	0,68	0,55	0,50	0,58	0,63	0,56	0,55	0,61	0,52	0,65	0,59
28.	Maximum precipitation intensity (PWD-11), mm/s	1,015	1,559	2,453	1,011	0,943	1,677	1,166	1,918	0,721	1,630	1,484	1,476	2,453
29.	Snow length, mm	1093	814	594	1013	1291	620	1277	1463	437	283	852	1083	10820
30.	Precipitation duration	38d, 17:30	34d, 19:22	43d, 00:59	43d, 21:10	44d, 06:41	34d, 15:17	41d, 10:27	39d, 13:20	33d, 10:06	31d, 07:14	38d, 03:04	43d, 00:17	1y 101d, 05:27
31.	Maximum duration of continuous precipitation	18:35	20:46	16:52	24:00	17:52	14:30	24:00	24:00	14:22	10:45	15:14	16:35	24:00:00
32.	Minimum visibility, m	35	30	87	83	25	60	66	40	88	95	54	66	25
33.	Duration of reduced visibility	14d, 04:13	6d, 17:51	8d, 07:08	10d, 22:57	11d, 18:37	8d, 08:10	9d; 17:37	11d, 17:44	7d, 07:06	8d, 10:04	5d, 23:54	8d, 15:37	112d, 02:58
34.	Weather conditions 'without precipitation', m	293d, 19:02	315d, 14:03	307d, 21:43	303d, 06:25	300d, 08:47	314d, 14:15	307d, 20:43	308d, 11:27	318d, 02:27	321d, 01:21	315d, 11:02	307d, 05:35	10y 63d, 16:50
35.	Weather conditions 'Dust haze' (V > 1km)', minute	00:19	-	-	-	-	-			00:03	-	-	-	0:22
36.	Weather conditions 'Dry fog', minute	4d, 02:34	20:56	1d, 01:10	1d, 11:14	1d, 20:19	1d, 21:07	1d, 06:03	2d, 04:18	1d, 11:09	2d, 00:32	1d, 05:01	1d, 13:22	20d, 21:45
37.	Weather conditions 'Fog', minute	5d, 17:11	2d, 08:10	3d, 13:13	3d, 16:27	3d, 23:19	2d, 04:40	3d; 01:53	3d, 02:59	2d, 13:07	2d, 21:39	2d, 02:59	2d, 23:12	38d, 04:49
38.	Weather conditions 'Freezing mist', minute	3d, 04:37	2d, 10:53	5d, 17:06	3d, 10:23	1d, 17:20	4d, 02:56	1d, 07:15	2d, 08:09	2d, 05:32	4d, 08:40	2d, 16:24	2d, 10:57	36d, 00:12

39.	Weather conditions 'Rain', minute	21d, 13:24	26d, 00:33	33d, 21:12	28d, 03:01	23d, 18:47	21d, 23:19	24d, 17:06	22d, 04:59	25d, 16:28	28d, 01:44	28d, 14:23	34d, 12:09	319d, 03:05
40.	Weather conditions 'Snow', minute	28d, 20:09	16d, 23:46	13d, 03:00	23d, 05:14	30d, 08:37	18d, 15:57	27d, 16:53	25d, 14:12	14d, 07:10	6d, 10:07	15d, 20:27	16d, 02:18	237d, 03:50
41.	Operating hours of the meteorological station	359d, 07:35	364d, 08:51	365d, 07:58	363d, 07:42	362d, 01:11	363d, 11:00	365d, 22:03	364d, 05:03	364d, 18:35	364d, 20:16	365d, 22:27	364d, 21:19	11y 353d, 16:36

The classification of atmospheric stability classes is given in the Table 2.24.

Table 2.24. Frequency of atmospheric stability classes depending on wind direction and wind speed in the period of 2006–2017, %

Class	Speed	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
A	0.0<=v<0.4	0.006	0.006	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.006	0.008	0.007	0.007	0.006	0.006	0.006	0.087
	0.4<=v<1.0	0.014	0.012	0.012	0.010	0.008	0.009	0.009	0.010	0.011	0.012	0.013	0.014	0.013	0.014	0.015	0.013	0.190
	1.0<=v<2.0	0.069	0.059	0.054	0.042	0.038	0.043	0.055	0.057	0.065	0.069	0.084	0.072	0.073	0.073	0.081	0.072	1.007
	2.0<=v<3.0	0.083	0.075	0.066	0.045	0.040	0.056	0.094	0.097	0.087	0.086	0.100	0.075	0.085	0.098	0.117	0.102	1.306
	3.0<=v<4.0	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
	4.0<=v<6.0	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	-	-	-	<0.001
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	0.171	0.152	0.136	0.100	0.090	0.111	0.163	0.168	0.169	0.173	0.206	0.168	0.179	0.191	0.220	0.193	2.592
B	0.0<=v<0.4	0.018	0.017	0.014	0.008	0.006	0.006	0.009	0.010	0.016	0.028	0.043	0.029	0.020	0.017	0.020	0.016	0.278
	0.4<=v<1.0	0.016	0.014	0.012	0.008	0.007	0.007	0.009	0.010	0.014	0.021	0.032	0.023	0.016	0.015	0.018	0.016	0.238
	1.0<=v<2.0	0.073	0.080	0.083	0.043	0.036	0.044	0.064	0.078	0.097	0.109	0.116	0.083	0.082	0.083	0.090	0.079	1.239
	2.0<=v<3.0	0.143	0.157	0.144	0.080	0.063	0.093	0.206	0.247	0.204	0.189	0.213	0.141	0.161	0.171	0.185	0.168	2.566
	3.0<=v<4.0	0.202	0.172	0.150	0.109	0.077	0.127	0.298	0.317	0.229	0.220	0.263	0.165	0.211	0.228	0.259	0.251	3.278
	4.0<=v<6.0	0.133	0.106	0.091	0.066	0.029	0.052	0.143	0.166	0.119	0.123	0.149	0.101	0.134	0.118	0.133	0.138	1.803
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Class	Speed	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	0.583	0.546	0.493	0.315	0.220	0.329	0.729	0.828	0.678	0.691	0.815	0.542	0.624	0.631	0.707	0.669	9.402
C	0.0<=v<0.4	0.024	0.026	0.027	0.012	0.007	0.008	0.010	0.012	0.021	0.042	0.061	0.039	0.032	0.023	0.025	0.019	0.388
	0.4<=v<1.0	0.011	0.013	0.014	0.008	0.007	0.007	0.008	0.009	0.015	0.021	0.034	0.025	0.019	0.015	0.015	0.011	0.232
	1.0<=v<2.0	0.061	0.081	0.091	0.047	0.042	0.045	0.059	0.071	0.098	0.112	0.121	0.096	0.102	0.093	0.098	0.067	1.285
	2.0<=v<3.0	0.182	0.205	0.178	0.101	0.084	0.122	0.221	0.250	0.241	0.221	0.270	0.185	0.208	0.214	0.231	0.193	3.106
	3.0<=v<4.0	0.205	0.187	0.154	0.123	0.075	0.126	0.290	0.315	0.197	0.209	0.309	0.217	0.262	0.239	0.249	0.230	3.388
	4.0<=v<6.0	0.212	0.185	0.145	0.150	0.054	0.107	0.278	0.312	0.170	0.207	0.332	0.274	0.349	0.249	0.231	0.235	3.490
	6.0<=v<8.0	0.026	0.026	0.018	0.020	0.004	0.005	0.019	0.032	0.020	0.027	0.041	0.038	0.043	0.025	0.019	0.025	0.390
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	0.721	0.723	0.626	0.462	0.274	0.419	0.886	1.001	0.762	0.839	1.168	0.875	1.015	0.857	0.869	0.781	12.279
D	0.0<=v<0.4	0.077	0.095	0.137	0.084	0.071	0.059	0.061	0.070	0.126	0.203	0.242	0.163	0.142	0.083	0.076	0.052	1.740
	0.4<=v<1.0	0.037	0.051	0.065	0.042	0.043	0.041	0.041	0.045	0.068	0.103	0.139	0.117	0.100	0.063	0.051	0.035	1.042
	1.0<=v<2.0	0.236	0.399	0.403	0.232	0.221	0.282	0.325	0.388	0.488	0.572	0.556	0.397	0.474	0.358	0.412	0.242	5.986
	2.0<=v<3.0	0.471	0.604	0.502	0.325	0.237	0.469	0.660	0.817	0.741	0.647	0.765	0.582	0.631	0.535	0.619	0.447	9.054
	3.0<=v<4.0	0.374	0.400	0.338	0.327	0.154	0.392	0.641	0.787	0.438	0.361	0.589	0.564	0.572	0.444	0.433	0.390	7.205
	4.0<=v<6.0	0.343	0.343	0.296	0.481	0.124	0.410	0.556	0.604	0.235	0.291	0.651	0.856	0.749	0.519	0.372	0.386	7.216
	6.0<=v<8.0	0.082	0.083	0.050	0.118	0.026	0.070	0.102	0.091	0.021	0.091	0.275	0.467	0.332	0.198	0.105	0.110	2.220
	8.0<=v<12.0	0.008	0.014	0.002	0.007	0.001	0.003	0.006	0.004	0.002	0.012	0.048	0.106	0.060	0.037	0.014	0.015	0.339
	12.0<=v<25.0	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.002
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	1.629	1.989	1.793	1.616	0.878	1.726	2.391	2.807	2.120	2.281	3.265	3.252	3.061	2.238	2.083	1.676	34.805
E	0.0<=v<0.4	0.012	0.014	0.012	0.007	0.010	0.009	0.009	0.013	0.015	0.031	0.031	0.024	0.022	0.014	0.010	0.006	0.238
	0.4<=v<1.0	0.006	0.008	0.007	0.007	0.012	0.014	0.013	0.011	0.013	0.015	0.016	0.013	0.016	0.011	0.009	0.005	0.177
	1.0<=v<2.0	0.053	0.079	0.055	0.040	0.050	0.069	0.079	0.091	0.093	0.107	0.113	0.090	0.116	0.087	0.091	0.046	1.259
	2.0<=v<3.0	0.141	0.182	0.126	0.108	0.083	0.158	0.209	0.251	0.216	0.158	0.199	0.157	0.178	0.147	0.157	0.125	2.597
	3.0<=v<4.0	0.091	0.115	0.108	0.110	0.047	0.156	0.192	0.229	0.144	0.084	0.147	0.133	0.145	0.122	0.110	0.113	2.048
	4.0<=v<6.0	0.091	0.096	0.088	0.146	0.044	0.144	0.176	0.185	0.066	0.111	0.233	0.301	0.241	0.160	0.113	0.146	2.343
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Class	Speed	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	0.395	0.493	0.396	0.420	0.246	0.551	0.679	0.781	0.547	0.507	0.739	0.719	0.718	0.540	0.491	0.441	8.662
F	0.0<=v<0.4	0.005	0.007	0.005	0.004	0.003	0.004	0.005	0.006	0.008	0.016	0.016	0.010	0.009	0.006	0.004	0.002	0.109
	0.4<=v<1.0	0.003	0.003	0.003	0.002	0.004	0.003	0.003	0.003	0.005	0.008	0.010	0.008	0.009	0.006	0.004	0.002	0.076
	1.0<=v<2.0	0.017	0.028	0.023	0.016	0.022	0.023	0.021	0.029	0.041	0.043	0.045	0.033	0.039	0.032	0.035	0.014	0.462
	2.0<=v<3.0	0.055	0.076	0.054	0.042	0.031	0.053	0.072	0.083	0.078	0.079	0.089	0.074	0.075	0.063	0.073	0.055	1.052
	3.0<=v<4.0	0.077	0.087	0.070	0.071	0.035	0.076	0.103	0.117	0.084	0.076	0.124	0.119	0.118	0.087	0.091	0.088	1.420
	4.0<=v<6.0	0.021	0.021	0.019	0.040	0.014	0.038	0.053	0.055	0.025	0.040	0.078	0.089	0.064	0.042	0.032	0.034	0.668
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	-	-	-	<0.001
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	0.177	0.223	0.173	0.175	0.109	0.197	0.257	0.293	0.242	0.262	0.362	0.333	0.314	0.236	0.239	0.197	3.788
G	.0<=v<0.4	0.142	0.210	0.332	0.219	0.166	0.097	0.131	0.157	0.331	0.600	0.800	0.494	0.401	0.191	0.156	0.096	4.522
	0.4<=v<1.0	0.052	0.088	0.125	0.085	0.065	0.041	0.047	0.077	0.140	0.242	0.345	0.265	0.218	0.123	0.081	0.042	2.037
	1.0<=v<2.0	0.222	0.439	0.760	0.360	0.258	0.245	0.373	0.441	0.735	1.101	0.786	0.559	0.689	0.433	0.489	0.241	8.131
	2.0<=v<3.0	0.380	0.392	0.493	0.298	0.193	0.500	1.002	1.063	0.899	0.741	0.625	0.420	0.434	0.258	0.428	0.324	8.450
	3.0<=v<4.0	0.166	0.124	0.106	0.176	0.094	0.394	0.676	0.738	0.311	0.228	0.337	0.269	0.222	0.138	0.162	0.164	4.301
	4.0<=v<6.0	0.032	0.021	0.012	0.045	0.022	0.110	0.153	0.147	0.033	0.061	0.092	0.097	0.081	0.053	0.035	0.038	1.030
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	0.994	1.274	1.828	1.183	0.797	1.387	2.383	2.622	2.449	2.972	2.984	2.105	2.046	1.194	1.350	0.904	28.471
All classes	0.0<=v<0.4	0.284	0.375	0.530	0.337	0.266	0.187	0.229	0.272	0.523	0.925	1.200	0.765	0.633	0.339	0.299	0.198	7.360
	0.4<=v<1.0	0.140	0.189	0.237	0.163	0.146	0.123	0.130	0.165	0.267	0.423	0.589	0.465	0.393	0.246	0.193	0.125	3.990
	1.0<=v<2.0	0.730	1.170	1.470	0.781	0.667	0.750	0.978	1.160	1.620	2.110	1.820	1.330	1.570	1.160	1.300	0.761	19.400
	2.0<=v<3.0	1.450	1.690	1.560	1.000	0.732	1.450	2.460	2.810	2.470	2.120	2.260	1.640	1.770	1.490	1.810	1.410	28.100
	3.0<=v<4.0	1.110	1.080	0.926	0.916	0.483	1.270	2.200	2.500	1.400	1.180	1.770	1.470	1.530	1.260	1.300	1.240	21.600

Class	Speed	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
	4.0<=v<6.0	0.832	0.772	0.651	0.929	0.288	0.862	1.360	1.470	0.649	0.833	1.540	1.720	1.620	1.140	0.917	0.976	16.600
	6.0<=v<8.0	0.108	0.109	0.068	0.138	0.030	0.075	0.121	0.122	0.041	0.118	0.316	0.505	0.375	0.223	0.124	0.135	2.610
	8.0<=v<12.0	0.008	0.014	0.002	0.007	0.001	0.003	0.006	0.004	0.002	0.012	0.048	0.106	0.060	0.037	0.014	0.016	0.339
	12.0<=v<25.0	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	0.002
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total:	4.670	5.400	5.450	4.270	2.610	4.720	7.490	8.500	6.970	7.720	9.540	7.990	7.960	5.890	5.960	4.860	100.000

The data on distribution of the atmospheric stability classes in the period of 2006-2017 are given in the Table 2.25.

Table 2.25. Distribution of atmospheric stability classes in the period of 2006-2017

Category (class)	A	B	C	D	E	F	G	Total
	2,6	9,4	12,3	34,8	8,7	3,8	28,4	100

3. CHEMICAL POLLUTION OF AIR ENVINRONMENT

The SS “Rivne NPP” is an enterprise with a number of auxiliary production facilities. The enterprise is registered in the State Air Pollution Protection Register. The enterprise’s fleet is of 290 vehicles, including 142 diesel and 148 gasoline and 7 units of rail transport. There are 2 certified testing stations to monitor the vehicle health check, toxicity level and exhaust smoke capacity [20].

There were registered 164 stationary emission points and 40 polluting non-radioactive substances (pollutants). The main emission point is the auxiliary boiler room, designed to burn sulphur fuel oil. Since 1994, the auxiliary boiler is not in operation; its boilers can be launched once per year to its minimum capacity for personnel training and equipment testing. The stationary emission points in the territory of the Rivne NPP are concentrated on 7 production sites. The emission of pollutants from stationary points are released on the basis of separate permit (Annex A), namely:

- the rehabilitation and health complex "Bile Ozero" near the village of Bilskaya Volya, the Volodymyrets district, the permit validity period is not limited;
- the motor transport enterprise in the industrial zone No. 2 (southern), in the town of Varash, validity period - 5 years;
- the vocational school and the sports complex in urban district Peremoha, in the town of Varash, validity period - unlimited;
- the stations, ARMS (Automated Radiation Monitoring System), the warehouse - refrigerator on the streets: Teplychna, Runkova, Comunalna, Energetykiv, in the town of Varash, validity period - unlimited;
- the station, asphalt plant in the construction site of Varash, the term of validity is 10 years;
- the wastewater treatment facilities of the industrial site on the Dachna street, in the town of Varash, the validity period is not limited.

In compliance with the permit conditions, the Rivne Oblast State Administration developed, approved and carried out the scheduled plan aim to monitor the due diligence of the permissible emissions of pollutants and compliance with the permits conditions of the stationary emission points.

The state monitoring of the atmosphere is carried out in Ukraine by the Hydro-meteorological Committee of Ukraine (Hydrometcom). This monitoring is based on the sanitary-hygienic principles of air protection of Hydrometcom and it is realized with the help of measurements taken at the points located in all regional centres and in the most contaminated cities. The nearest point of monitoring the atmospheric air pollution in the area of the Rivne NPP is located in the city of Rivne and Lutsk. At these points, the following concentrations are measured:

- suspended solids;
- sulphur dioxide, dioxide and nitrogen oxide, carbonic monoxide;
- without pyrene;
- heavy metals (zinc, copper, chromium, iron, lead, nickel, cadmium);
- specific impurities (formaldehyde, ammonia, phenol, hydrogen sulphide).

Based on the results of the numerical modelling of impurities transfer and the mathematical models recommended by the IAEA, we can estimate that the industrial emission sources located outside the monitoring zone of the Rivne NPP (in the cities of Rivne and Lutsk) have a slight effect on the environmental pollution of the 30-kilometer zone of the Rivne NPP. The quality of atmospheric air is determined by emissions from enterprises that provide environmentally safe operation of the Rivne NPP.

3.1 Effects of non-radiation (chemical) emissions

As the separate subdivision, the Rivne NPP may affect the environment by atmospheric emissions released in the process of power plant operation. Such emissions include [6]:

- radioactive gas releases;
- non-radioactive (chemical) emissions;
- heat and moisture emissions from external cooling systems.

There are both radioactive and chemical substances, which are considered as part of emissions polluted the surface layer of atmospheric air in the 30-kilometer zone of the Rivne NPP.

The first include radioactive elements that are sources of ionizing radiation, to the other belong gas releases of carbon, sulphur, nitrogen, as well as solid impurities, organic substances, etc.

The considerable part of radioactive atmospheric isotopes associates with the aerosol particles. The airflow and turbulent exchange favour the distribution of aerosols and gases, whereas the impurities associate with the drops of clouds and fogs, wash out by precipitation and reach the land surface. There is also a dry sedimentation along the land surface with dust and solid aerosols.

In accordance with the estimation results of the surface concentrations of harmful substances in the atmosphere, the maximum surface concentrations of these substances do not exceed the maximum permissible index approved by the current state regulations. This applies both to the sanitary protection area and to the area of the nearest residential settlements. Taking into account the background concentrations approved by the State Department of Environmental Safety in the Volyn Oblast, the total maximum surface concentrations outside the sanitary protection area do not exceed the MPC (Maximal Permissible Concentration). In conclusion, we can estimate that the environmental characteristics of the atmosphere within the 30-kilometer zone around the Rivne NPP have not been deteriorated during the period of the Rivne NPP operation.

3.2 Effects of heat and moisture emissions from cooling towers and spray ponds on air environment

In the process of water cooling by cooling towers and spray ponds, a considerable amount of heat and moisture is emitted in the atmosphere. Concentrated on a limited area near the NPP, the heat and moisture emissions negatively affect the microclimatic conditions, since the heat and moisture are the passive impurities in the atmosphere. Under their influence, the following powerful upward and downward streams are developed in the air surrounding the cooling towers:

- transformation of meteorological fields (air temperature and air humidity, atmospheric turbulence characteristics) and, in general, the parameters of the boundary layer of the atmosphere in the area of the Rivne NPP and in its surrounding area;
- formation of steam-condensate plume of condensed water and liquid droplets formed during the destruction of jets emitted from the cooling tower mouth at a speed of 4-6 m/s.

The heat and moisture streams and the steam-condensate plumes negatively affect the thermal air pollution observed in the plume areas:
- disruption of microclimate regime in the surrounding area (air temperature and air humidity);
- dimming of the underlying surface in the plume areas and, as a result, decrease of solar radiation supply (insolation);
- reduction of meteorological visibility;
- increase in frequency of fogs, ice glazing and mist;
- overmoistening of the landscapes cased by frequent precipitation of local nature and the associated corrosion destruction of the buildings and infrastructure facilities;
- transfer, washout and deposition of chemical and radioactive contaminants in the air and deterioration of radiation and sanitary-epidemiological situation, mainly in the sanitary protection zone of the NPP.

3.2.1 Assessment of cooling towers and spray ponds effects on microclimate and justification of measures to limit these effects

The cooling towers are used for water cooling in the circulating system of technical water supply for condensers and auxiliary equipment of turbine generators of the Rivne NPP. The spray ponds are used for water cooling in the system of technical water supply for the essential consumers (group "A") and non-essential consumers (group "B"). The technical characteristics of the cooling sources are given in Tables 3.1 and 3.2. The output of water loss during evaporation and winding from the cooling tower is given in the Table 3.3. The type of cooling tower is the identical for all power units [22].

Table 3.1. Technical characteristics of cooling tower

Characteristic		Dimensions
1. Type of cooling tower – tower, evaporative:	tower height	150 m
	diameter of the tower shell	124 m
	diameter of the tower outlet	75 m
	height of air-duct inlets	10 m
2. Hydraulic load:	maximum	100000 m^3/per year
	nominal	95000 m^3/per year
3. Thermal load	nominal	0,9×10^9 Kcal/per year
4. Liquid spray area		10000 m^2
5. Liquid spray rate	nominal	9,5 m^3/m^2 × per year
6. Temperature difference/drop	nominal	9,5 ^{0}C
7.Number of cooling tower: 6 towers, including 4 towers of the NPP Unit № 1–3; 2 towers of the NPP Unit № 4		

Table 3.2. Technical characteristics of spray ponds

Characteristic	Dimensions
Design cooling water discharge for each spray pond: power units № 1+№ 2 power units № 3+№ 4	 3200 m^3/per year 6240 m^3/per year
Water temperature in the nominal conditions: thermally enriched water cooled water	7 – 35 ^{0}C 5 – 33 ^{0}C
Thermal load in the nominal conditions from one power unit*): maximum minimum	 20×10^6 Kcal/per year 2,5×10^6 Kcal/per year
Heat release in the planned cooling down*): during 1 – 3 hours next 7 hours after next 8 hours	 60×10^6 Kcal/per year 37×10^6 Kcal/per year 23×10^6 Kcal/per year
Estimated output of water loss for additional evaporation power units № 1 – № 4 Including power units № 3 – № 4	 82,4 m^3/hour 60,0 m^3/hour
Estimated output of water loss for dropping: power units № 1 – № 4 including power units № 3 – № 4	 212 m^3/hour 140 m^3/hour
8. Number of spray ponds for the essential consumers (group "A") – 7 ponds, including: power units № 1 and № 2 – 1 pond, power unit № 3 and № 4 – 1 pond, emergency – 1 pond	
Number of spray ponds for the non-essential consumers (group "B") – 3 ponds, including: power units № 1 and № 2 – 3 ponds, power units № 3 – 1 pond and power unit № 4 – 1 pond *) – The indicated heat release can be distributed among the channels by all means, including total load on one channel	

Table 3.3. Estimated average monthly output of water loss during evaporation and winding (dropping) transfer

in thousand m^3/per year

Month											
01	02	03	04	05	06	07	08	09	10	11	12
The estimated value of evaporation loss											
0,84	0,85	0,93	1,07	1,20	1,26	1,30	1,26	1,20	1,07	0,97	0,88
The estimated value of evaporation loss											
0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05

3.2.2 Nature of microclimate formation

The microclimate in the area of the Rivne NPP region was formed under the effect of additional heat and moisture emitted by cooling towers and spray ponds in the atmosphere. The air, which passes from cooling tower, contains the moisture by itself, both in the liquid-spray and water vapour form. The data on the amount of total water losses in the cooling towers and cooling ponds (Tables 3.2 and 3.3) indicate the inevitability of certain effects of cooling systems on the microclimatic conditions of the surrounding area. These effects cause the development of vertical streams, which lead to the transformation of meteorological fields (air temperature and humidity, wind), increase the turbulence in the boundary layer of the atmosphere and form the steam condensate plumes.

The microclimate in the area of the Rivne NPP is formed under influence of the regional climate characterized by a relatively long cold period (~210 days), relatively cooler summer (average July temperature is 18.1°C), low winter temperatures and high humidity during the winter period. In summer, at the high temperatures and low humidity, the impact of the cooling units on the microclimate is much lower than in the autumn-winter period with low temperatures and high air humidity.

The steam condensate plumes have a strong impact on the microclimatic conditions and affect the atmospheric precipitation, meteorological visibility, insolation, fog, and ice glazing in the area of the Rivne NPP.

To give more detailed information about the impact of cooling towers on the microclimate formation in the area of the Rivne NPP and on the surrounding territory, the brief description of the processes and the operating principle of cooling towers are given below

3.2.2.1 Physical processes in the cooling towers and the steam condensate plumes

The water heated in the turbine condensers (at 9,5˚C) enters the irrigation devices of the cooling towers. Running along the fillers with a thin jet, the warm water contacts the oncoming stream of cold air and transmits air a part of its thermal energy due to convective heat transfer. The atmospheric air after heating becomes more "dry", it means that its relative humidity decreases, creating a lack of moisture. The water jets, which are flowing down the filler, saturate the air streams with moisture and then “evaporation cooling” cools the water.

The air heated and saturated with the water vapour, becomes lighter than the atmospheric air (the water vapour is almost twice lighter than the atmospheric air). Thus, the pressure produced by the vapour-air mixture inside the cooling tower is below the atmospheric pressure. This process cause the drafting in the cooling tower and its height, geometric shape and the interior surface contribute to the activation of air flow and increase the cooling capacity of cooling tower.

The air-vapour stream coming from the cooling tower, contact and mix with the cold air, is intensively cool down.

In many cases, especially with high humidity of the atmospheric air, the water vapours condense, creating a visible part of the steam-air cloud that runs from the mouth of cooling tower.

With low relative humidity of the atmospheric air, the vapour-air mixture is coming out of the tower shell and after mixing with the atmospheric air, may not provide full saturation with moisture. In these cases, usually the visible part of the plume will be invisible.

The droplets of condensate water presented in the vapour-air mixture associate with each other, enlarge and finally sedimentate partially in the form of a mist. In the case of the adverse meteorological conditions (high humidity, surface inversions and low temperatures), the particles of the condensate water reach the surface layers and settle on the land surface, trees, buildings and other facilities in the form of a dew, black ice, frost, crystalline ice. These phenomena do not occur in the warm period (except dew).

3.2.3 Estimation of microclimate main characteristics under effects of cooling towers and spray ponds

The experts from many foreign countries, like Germany, Switzerland, France, etc., were engaged in the research of the effects of existing cooling towers of the NPP (TPP) on the environment (microclimate).

This report covers the results of estimation of the thermal and humidity impact on the microclimate of the Rivne NPP area, conducted by the Ukrainian Research Hydrometeorological Institute (UkrNDGMI), directly in the area. The estimation was carried out during the period of 1983-1986, when two cooling towers were in operation, and in the period of 1987-1989, when four cooling towers were in operation. The UkrNDGMI report included the observations from the aircraft and helicopter equipped with the meteorological laboratories, the observations of the land-based mobile laboratories and the microclimatic observations. In total, during 1983 -1989, 234 complex land-based and helicopter (aircraft) observations of the plume structure were performed.

The UkrNDGMI observation report allowed to determine the disbalance degree of the microclimatic regime in the area of heat and humidity emissions of the NPP and to study the structural features of steam-condensate plume.

In order to assess the thermal pollution of the air environment in the zone of the steam-condensate plume distribution of the Rivne NPP, the UkrNDGMI performed the following examinations:

- measurement of temperature and humidity parameters in the plume and its perimeter zones;
- specification of geometrical dimensions of the plume (length, width, strength);
- examination of micro-and macrostructure of steam-condensate plumes.

In addition to the experimental observations, the mathematical modelling of heat and moisture transit processes was performed to assess the impact of the cooling towers on the microclimatic conditions outside the sanitary protection zone.

Based on the conducted examinations, the impact assessment of the cooling towers on the microclimate of the SS "Rivne NPP" is carried out according to the following characteristics:

- changes in temperature and humidity;
- horizontal length, level and vertical thickness of the visible steam-condensate plume;
- changes in the meteorological visibility;
- changes in insolation duration and index of direct solar radiation reaching the land surface;

- probability of formation of additional clouds, fogs, glaze, frost and precipitation.

The assessment of the structural change of the boundary layer of the atmosphere during the operation of four cooling towers of the Rivne NPP is given below. The examination of all six cooling towers in operation have not yet been carried out, however, the environmental impact assessment can be done by the mathematical and physical modelling of processes.

3.2.4 Air temperature and air humidity changes

The Figures 3.1 - 3.4 show the two-dimensional size of temperature and humidity fields near the cooling towers of the Rivne NPP during the cold and warm periods of the year. The four figures illustrate the vaporous part of steam condensate plume and the meteorological parameters changes in it along the height of the boundary layer (H) and the horizontal extension (X). The axis X passes through the centre of the cooling tower system and is directed along the geostrophic wind. For visual clarity, the coolers are depicted as a perturbing body. The moist and warm air emitted from the cooling tower, rises upwards and drifts off by wind and associates with more dry air [23].

In the cold period of the year, the zone of perturbation of humidity field in the boundary layer of the atmosphere in the area of cooling towers location of the Rivne NPP is characterized by the following parameters:

- specific humidity of air emitted by cooling towers is 5,0-5,2 g/kg (relative is close to 100%);
- maximum perturbation of humidity field is observed at an altitude of 200 m and extends 1,5 km from the cooling towers. In total, the zone of perturbation of humidity field is observed up to a height of 500 m and at a distance of 4,0 – 4,5 km from the centre of the cooling tower system.

The zone of maximum warming in the cold period of the year is formed at an altitude of 150-300 m and extends to 2,5-3,0 km from the cooling tower system. The air temperature in the zone of temperature perturbation is in the range from minus 2,0˚C to 2,8-3,0˚C.

In the warm period (Figures 3.3 and 3.4), the zone of perturbation of humidity field in the boundary layer of the atmosphere is characterized by the following parameters:

- specific humidity of air emitted from the cooling tower is 8,3 – 11,2 g/kg;
- maximum perturbation of humidity field is observed at an altitude of 150-250 m (11,2 g/kg) and extends to 1,5 km from the cooling towers. In total, the zone of perturbation of humidity field in summer is observed up to a height of 350 m and extends to 3,0 – 4,0 km from the centre of the cooling tower system.

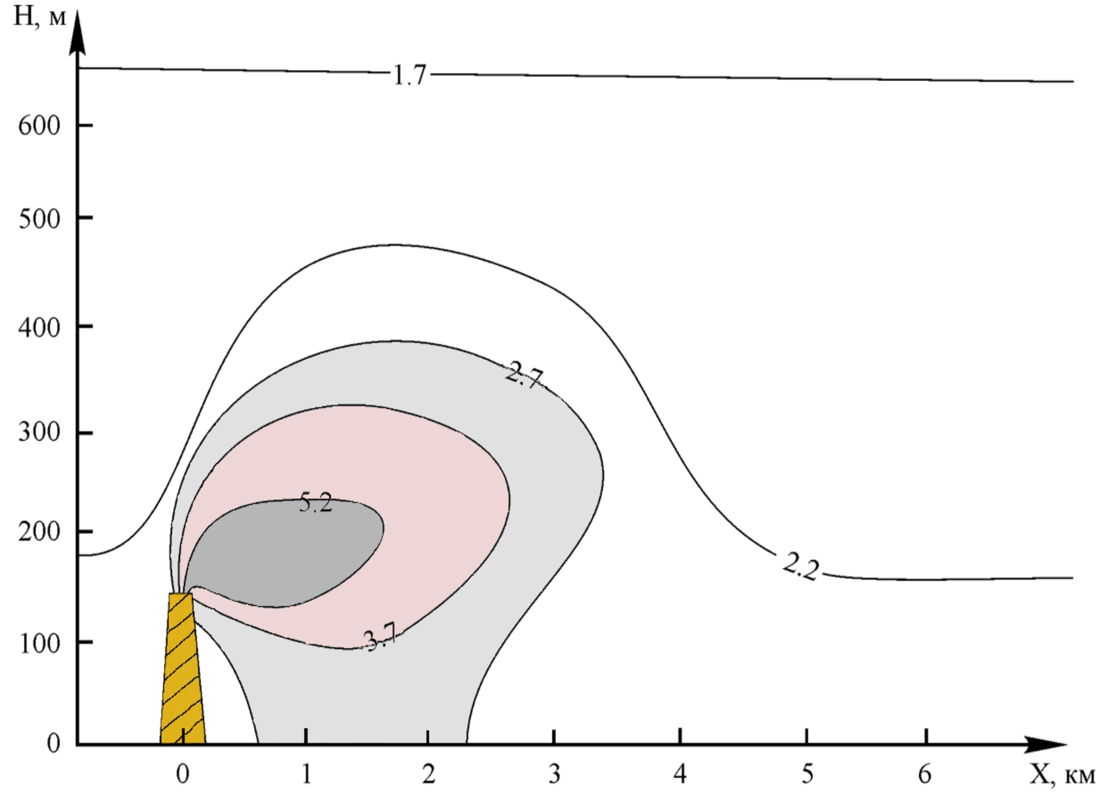


Fig. 3.1. Vertical cross-sections of specific humidity near the cooling towers, g/kg. Winter

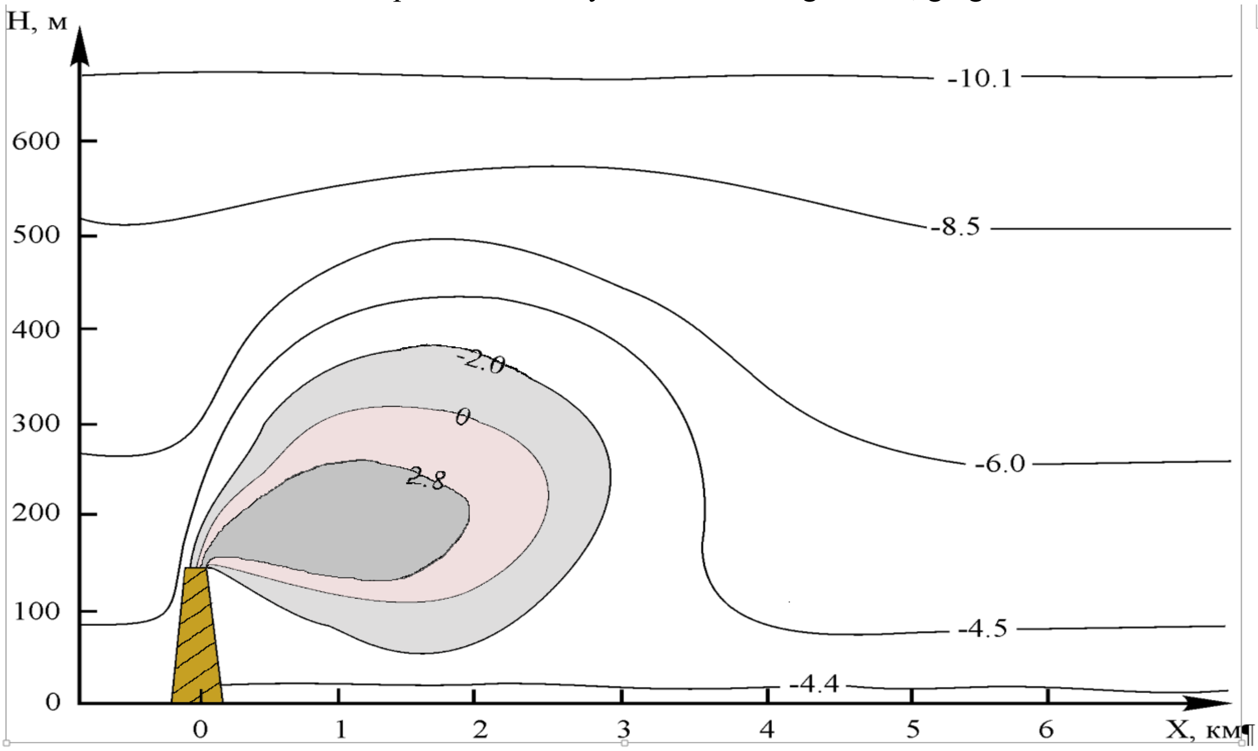


Fig. 3.2. Vertical cross-sections of air temperature near the cooling towers, ^{0}C. Winter

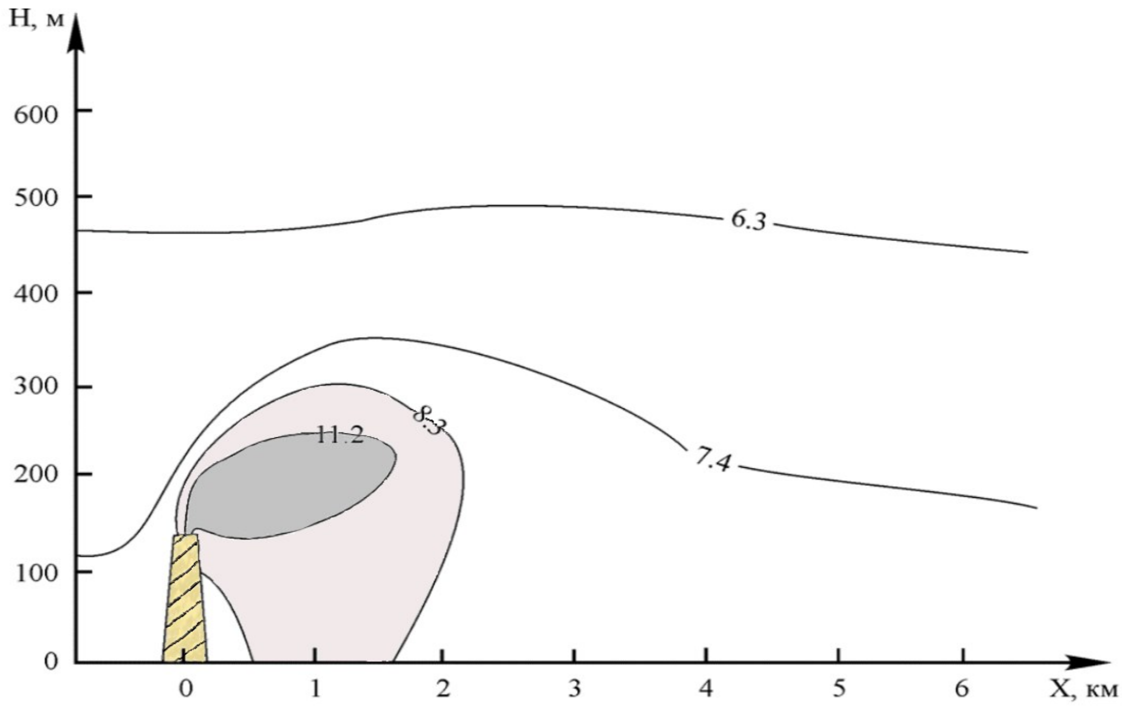


Fig. 3.3. Vertical cross-sections of specific humidity near the cooling towers, g/kg. Summer

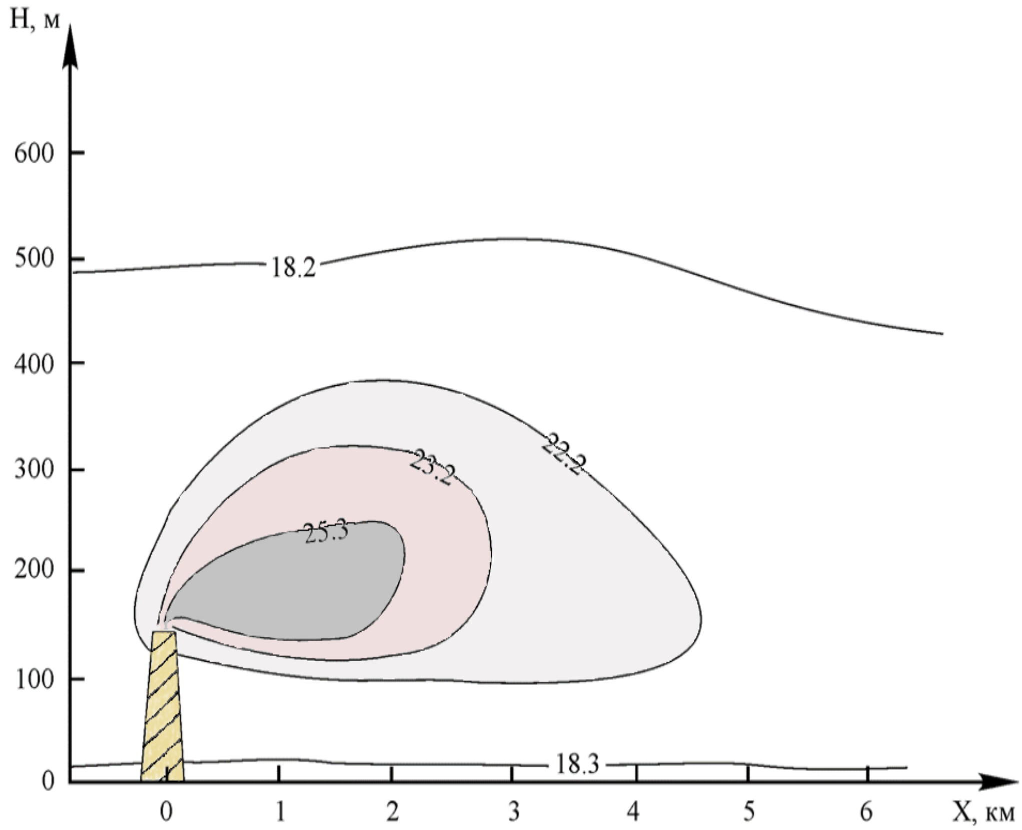


Fig.3.4. Vertical cross-sections of air temperature near the cooling towers, ^{0}C. Summer

The zone of maximum warming in the summer period is formed at an altitude of 150-350 m. The maximum air temperatures in this zone are within the limits of 23,2-25,3˚C and extend to 3 km from the cooling towers system.

To analyse the distribution of heat and humidity from the cooling system in the boundary layer of atmosphere, the average January and mid-July meteorological parameters were taken as an input data for the mathematical modelling (the data of the reference Manevichi meteorological station (Table 3.4)).

Table 3.4. Average monthly air temperatures, air humidity and wind speed. Manevichi meteorological station.

Characteristics	Winter (January)	Summer (July)
Air temperature	minus 4,4^{0}C	18,3^{0}C
Air humidity	86 %	69 %
Wind speed	5 m/s	3,5 m/s

According to the estimated data, the "perturbation zones" of air temperature and humidity fields near the land surface during the cold period (winter) extends from the source of emissions in the wind direction (Figures 3.5 and 3.6). The maximum surface air temperature in this case at an altitude of 800 to 1500 m from the cooling towers is around 1˚C above the background (ΔT = 0,89˚C), that is equal to minus 3,4˚C. At an altitude of 2,5-3,0 km from the cooling towers, the air surface temperature decreases by 0,1°C (ΔT = 0,08˚C) and can be minus 4,3˚C, that is nearly equal to the background temperature.

The maximum humidity at the land surface in winter is observed at a distance of 300-500 m from the cooling tower system. The specific air humidity in this area is 0.03 g/kg different from the background one. At an altitude of 2,0 km from the cooling towers, the surface air humidity is equal to the background.

In the summer, the temperature and humidity perturbation in the surface air layer are practically not observed.

The plume formation occurs as a result of the synchronizing activity of several processes: - condensation of water vapour;

- droplet extract from the cooling towers;
- coalescence of drops (drops merging).

The observations in the zone of plumes and the calculations indicate that in the context of macrophysics, the plumes represent a source of balanced liquid droplets and solid particles of air and have a heterogeneous structure.

After dispersion in air flow, the plume particles are modified: they enlarge in the process of coalescence, settle down and intensively evaporate. The interrelation processes, which contribute to humidity accumulation and dispersion, determine the macrophysical characteristics of the plumes, their structure, the precipitation intensity and eventually the environmental changes. The macrophysical structure of plumes is determined by:

- degree of air saturation;
- atmospheric stratification;
- air temperature;
- wind speed.

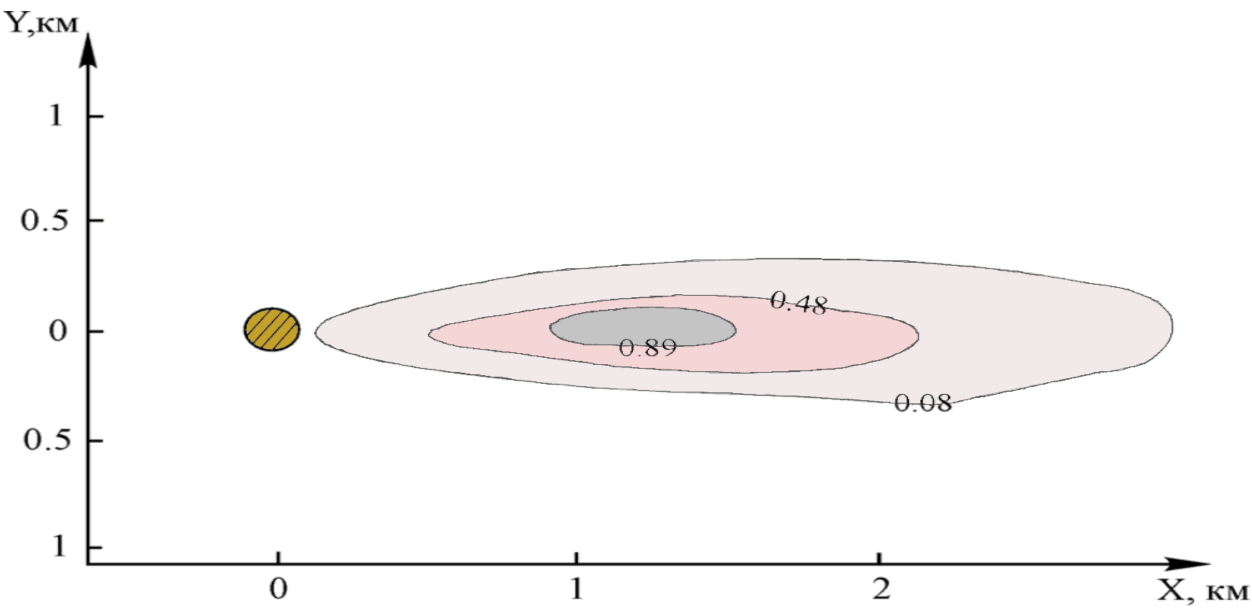


Fig. 3.5. Horizontal cross-sections of perturbation temperature fields, ΔT ^{0}C, at the land surface under effect of emissions from cooling tower. Winter.

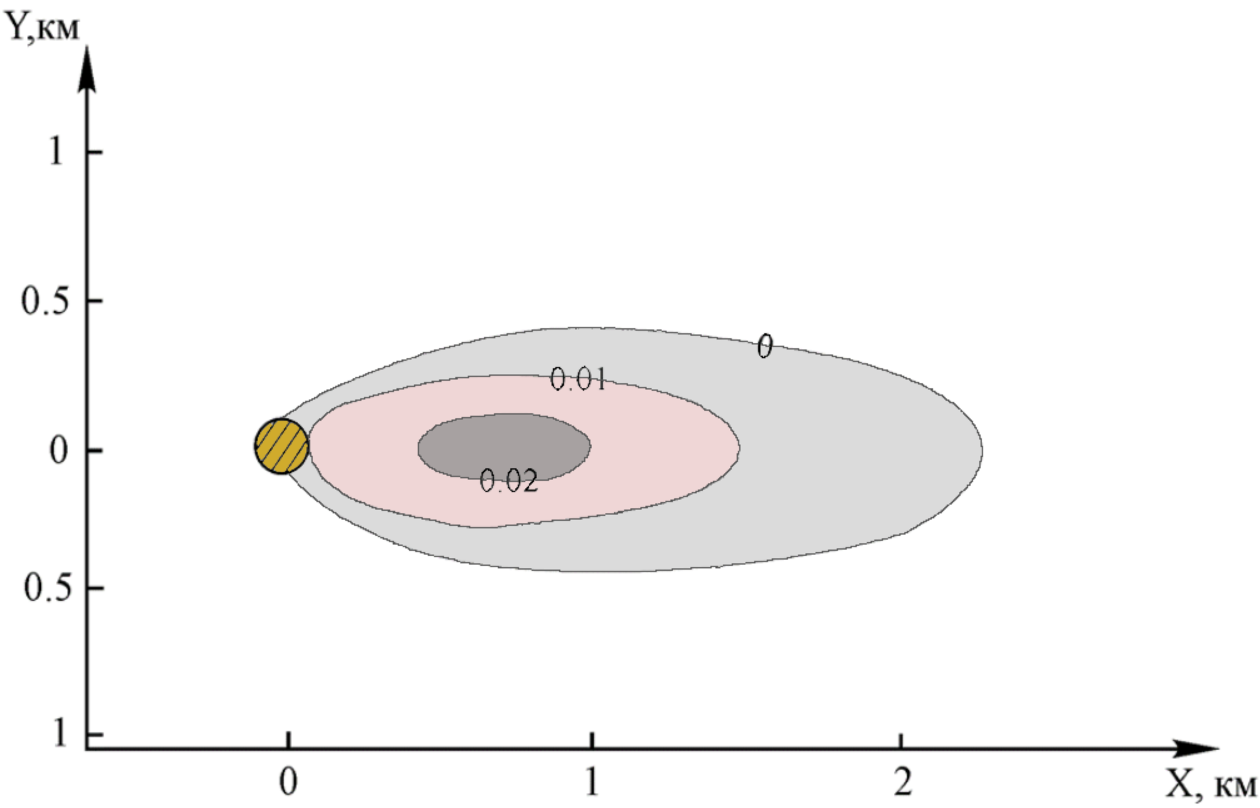


Fig. 3.6. Horizontal cross-sections of specific air humidity fields, ΔR g/kg, at the land surface under effect of emissions from cooling tower. Winter.

Depending on air temperature, the structure of the plumes has the following features:

- the plumes are liquid-droplet at air temperature above minus 6,0˚C and minus 8,0˚C;
- at air temperature below minus 8,0 ˚C and minus 10,0˚C and the length ≥ 2,5-4,0 km – the plumes are crystalline, with the length ≤ 500 m - liquid-droplet, in the range from 2,5 to 0, 5 km - mixed.

The geometric parameters of the plumes depend on both the temperature and humidity of the air and on the atmospheric stratification.

The plumes can achieve the considerable length (L ≥ 5000 m) at the air temperature below minus 10-12˚C, weak winds (3-4 m/s), cloudy weather and very high humidity (> 76%), as well as in the presence of inversions.

The shortest plumes (L <300 m) are formed with a high humidity deficit, cloudy weather and specifically during hot summer days.

Under ground and low raised inversions, the length of the plumes (at the negative temperatures and high humidity) does not exceed 1.0 km.

In the isotherm layer extended to a height of 300-400 m, the length of plumes does not usually exceed 1.5-2.0 km.

In the "stagnation" cases, the humidity emitted by the cooling towers condenses and accumulates in the area of the Rivne NPP site in the form of an isolated "dome". The cases of the intensive humidity accumulation in the zone of the Rivne NPP are also observed at the temperatures close to 0˚C, 100% relative humidity, weak winds, low clouds, in the case of ground or low raised inversions.

The thickness of plumes is one of the important macrophysical characteristics. The thickness and the microstructure parameters are determined by the visibility in the plumes, their "shading" ability. The horizontally oriented plumes have a low thickness (100-300 m), in short plumes – the thickness is less than 100 m. In the certain subinversive plumes, when the plumes are "drawing" into the clouds and the humidity is accumulating in the "stagnant" conditions, the thickness of the plume increases to 300- 500 m and more. The vertically oriented plumes are formed under unstable stratified atmosphere and they rise to 800-1000 m. Their zone of influence is limited to the sanitary protection zone of the NPP. The thickest plumes are formed in the cold period

The width of the plume depends on the temperature stratification of the atmosphere. With neutral atmospheric stratification and wind speed >4-6 m/s, the plumes are limited (<100m).

According to the micro and macrophysical characteristics of the steam-condensate plumes, three areas of the plume can be distinguished:

- area "A" - is characterized by high water content and volumetric concentration of droplets. It borders with the mouth of the cooling tower and is clearly visible. This area of the plume has a strong impact on the intensity of precipitation, decreases the visibility and creates intense shading on the land surface, and, consequently, decreases the insolation (direct solar radiation is often absent);
- area "B" - is characterized by a less dense structure. The plumes are more stratified, the precipitation is low and the insolation is less than in the area "A";
- area "C" - is invisible and it is manifested only in the changes of the microclimatic parameters and falls out in the form of liquid (or solid) particles carried by the air flow.

3.2.5 Meteorological visibility changes

The steam condensate plumes in most cases have a slight effect on the meteorological visibility, especially in the remote zone. The visibility index usually exceeds 5-10 km, and only with the subinversive plumes formation and slow plume flowing into the low clouds there can be some periods with the visibility less than 2-4 km. The lowest visibility index are observed in the "stagnation" conditions, when a "dome" of humidity is formed above the industrial area of the NPP caused by high air humidity and weak wind. Such areas are usually localized in the nearest zone with intense fogs and visibility of less than 300-500 m.

The performed visibility calculation, which is based on estimation of homogeneity and isotropy of plume, showed that with the observed parameters of microstructure of visibility zone in the plumes (at a distance of 500-1000 m), the visibility is 300-600 m. The measurements were taken from a helicopter and are as follows:

- 100-200 m in the nearest zone of the thick plume;
- more than 500-1000 m in the remote zone of the thick plume;
- formation of short and medium length plume did not significantly deteriorate the visibility.

3.2.6 Insolation duration changes and changes in amount of direct solar radiation reaching the land surface

The results of analysis of solar radiation regime in the area affected by four cooling towers of the Rivne NPP [20-23] were summarized to estimate the losses of direct solar radiation caused by formation of steam condensate plumes in the area of the Rivne NPP.

Based on the analysis of these materials, the considerable decrease in the flow of solar energy to the underlying surface is observed in the area of steam condensate plumes formation, in particular:

- 40-80% or more at a distance of 200 m from the cooling towers;
- 10-20% at a distance of 1000 - 2000 m from the cooling towers;
- with "stagnation" phenomenon and under formation of strong local layer of fog over the area of cooling towers, there is no access to direct solar radiation. The area of absolute shading can extend to a distance of 0,5-1,0 km around the NPP.

The potential number of days when fog can cause the absolute shading is approximately 3 days during the warm period and 5 days in the cold period. The partial shading from plumes will always exist, but there are no quantitative characteristics about the duration of this phenomenon in the area of the Rivne NPP. Based on the data, in particular, on the results of calculations performed for West Berlin for spring and autumn, the average duration of shading in the underlying surface of the plumes is 30 min/day (~ 5% of the average duration of sunshine in the clear days). The maximum average duration of shading is observed in winter and equals to 100 min/day at a distance of 1,2 km from the cooling towers and 70 min/day at a distance of 2 km.

Taking into account the fact that the duration of sunshine at the latitude of Berlin and the Rivne NPP is nearly the same, the reference information on partial shading of the underlying surface may be indicative in this issue;

- decrease in insolation is not so significant - up to 10-12% in the crystalline part of the plume.

In the area of the Rivne NPP, in the cold period of the year, which is characterized by a small number of clear days, the factor of insolation reduction during few sunny days is quite important for estimation of the sanitary and hygienic quality of air.

3.2.7 Probability of extra clouds, fogs, ice glaze and precipitation

The heat and humidity emissions from the cooling system of the NPP, as well as the steam condensate plumes, cause the probability of extra clouds, fogs, ice glaze and frost during the cold season.

The precipitation in the area of the cooling system characterized by the following features:

- in the immediate proximity to the cooling towers, precipitation from steam condensate plume falls in the form of large droplets, the average diameter of drops reaches 0,7 – 1,5 mm. In the nearest area (within a radius of 300-500 m) from the cooling towers, the maximum index of precipitation intensity (up to 0,6-1,0 mm/h) and cloudiness (up to 0,6-0,8 mg/m3) are recorded. The maximum annual amount of precipitation falling from steam condensate plumes in the nearest surrounding area is 10-15 mm, which equals to less than 2-3% of the annual amount of precipitation;
- at the distance of ≥ 500 m from the cooling towers, the average diameter of the drops decreases to 0,1-0,4 mm, the precipitation intensity decreases by 1-2 degree.

The precipitation in the cold period of the year contributes to the formation of ice glaze, frost and fog. Usually, the ice glaze and frost are formed by emissions from the cooling towers and observed in the nearest and middle area of steam condensate plumes within a radius of 300-500 m to 1,5-1,7 km from the cooling system. The most unfavourable situations are observed under the "stagnation" of the air, when the entire sanitary protective area of the "Rivne NPP" is in the zone of influence of thick fogs and mist.

The annual number of fog days is 27, according to the Manevichi meteorological Station (7 days in the warm period and 20 days in the cold period), and the number of fog days in the sanitary protective zone may increase by an average of 10 days in the warm period and up to 25 days in the cold period.

In some cases, under formation of the thick long-term subinversive plumes, the ice glaze and frost extends up to 4 to 6 km from the cooling towers, causing ice on the roads and makes the travel of vehicles dangerous. The number of days with ice and frost may increase by 30-50% and make an average of 8-9 days per year, maximum - 25-40 days.

3.2.8 Predictive impact assessment of cooling towers and spray ponds on the microclimate during operation of power units

The impact of cooling towers and spray ponds on the microclimate in the Rivne NPP zone should be considered as an integrated effect of the cooling sources of the heated water, since the entire cooling system is located within the boundaries of the monitoring area.

The cooling towers, which are accompanied by a "dome" of heat and humidity and the spray ponds, are the main sources of microclimate change in the NPP area.

The thermal emissions from spray ponds do not exceed 2% of the similar emissions of the cooling towers. Approximately, their impact on the microclimate of the Rivne NPP area is identical to the cooling towers.

The spray ponds mainly affect the microclimate of the surface air layer due to the humidity dropping. This effect is most pronounced in the strong wind and only in the immediate proximity of the spray ponds (100-500 m). In the cold period of the year, the drops transit can increase the formation of rime and ice deposits in the area of the site. Taking into account the fact that in the cold season, the spray devices in the ponds are switched off; the impact of the spray ponds during this period is reduced to zero.

The scope and limits of impact of the thermal emissions by the cooling towers and the spray ponds and the forecast of their impact on microclimate is based on the following results:

- observation of the microclimatic conditions in the NPP area and the conditions of the steam condensate plumes formation by the cooling towers of the Rivne NPP, the micro- and macrophysical structure of the plumes;
- mathematical modelling of heat and moisture transit processes in the Rivne NPP area and the plume formation based on the three-dimensional non-stationary microphysical mathematical model of the Central Aerology Observatory (Moscow, Russia).

In the case of six cooling towers operation, the zone of maximum "perturbation" of temperature and humidity will reach a height of 300-350 m and will extend to 2,5-3,5 km from the coolers in the winter and up to 1,0-1,5 km in the summer period. The maximum surface air temperature is forecasted at a distance of 0,8-1,5 km and exceeds the background temperature by 1,0˚C in the winter. The maximum air humidity in the winter will be above the background of 0,03 g/kg at a distance of 0,5-1,0 km from the cooling towers.

The mouth steam condensate plumes. This is the thickest part of the plume with 500-700 m in width and up to 0,7-1,5 km in length in the summer, and up to 3,0-4,0 km in length in the winter. The maximum length of the visible part of the plume is mostly determined by the atmospheric conditions: long and thick plumes (5-7 km long) will be formed at inversions, moderate winds, and high humidity and air temperature below minus 10˚C.

The intensity of humidity deposition on the land surface is (~ 10-2 mm/h). The area of the vapour and liquid-droplet transfer from the NPP can cover a territory with a radius of 5-7 km and, consequently, the thermal processes and moisture have a considerable impact on microclimate and environment in this monitoring area.

The formation of ice and frost increased by 30-50% in the area with extra humidity at the minus temperatures. The maximum deposit is observed in 0,5-1,0 km from the coolers. In some cases, these phenomena can extend to 4-6 km.

The increase of vapour volumes emitted in the atmosphere is accompanied by an increase of maximum shading in the area. In winter, this area reaches 0,8-1,2 km in length and 0,8-1,0 km in width, in the summer its dimensions are limited to a distance of 0,3-0,5 km.

The zone of meteorological visibility in the winter period is 1,5-2,0 km (from the centre of the cooling system).

To summarise the results of analysis and impact assessment of the cooling towers and spray ponds on the microclimate in the area of Rivne NPP, we can conclude that the cooling towers and their steam-condensate plumes are the main sources of microclimate change.

The increase of air temperature and humidity due to the steam condensate emissions of the cooling towers occurs mainly in the boundary layer of the atmosphere, at an altitude of 200 -

500 m. In the surface layer, the heat and humidity impact of the cooling towers is observed only in the immediate proximity. The increase of air temperature by about 0,5-1,0˚C in winter against the background temperature of January at a distance of up to 1 km from the cooling towers and the increase of annual amount of precipitation by 2-3% are inconsiderable. Actually, the impact of the cooling towers on the microclimate and environment outside the sanitary protective zone is not expressed. As an exception, there can be observed some occasional ice glaze and frost.

3.3 Chemical pollution of the Rivne NPP air environment

The main sources of air chemical pollution in the area of the Rivne NPP and in the surrounding areas are auxiliary facilities of the NPP. These include [21, 23]:

- a boiler house (BH);
- a centralized repair workshop (CRW): a forge and the welding stations;
- a repair and construction workshop (RCW): woodworking and sandblasting stations;
- a motor-road transport department (MRTD): a forge, welding stations, a paint spray booth, gas station.

The auxiliary facilities are located on two industrial sites: BH, CRW, RCW - at the main industrial site (No. 1); MRTD - at the industrial site number 2, 4 km north of the main industrial site [21].

Each of auxiliary facilities is equipped with the purification system of atmospheric discharges (dust collectors at the repair and construction workshop, hydrofilters at the motor-road transport department, gas cleaning devices for absorption of aerosol emissions at the boiler house).

The auxiliary facilities are stationary sources of air pollution in the area of the industrial site of the Rivne NPP and directly in the surrounding area. In total, these facilities eject into the atmosphere more than 20 types of pollutants.

Fourteen sources of air emissions are equipped with the gas treatment units (GTU). The passports are developed for all gas treatment units. The gas treatment equipment is operated in accordance with the "Rules of Technical Operation of Gas Purification Units". According to the Order of the Rivne NPP General Director, the responsible persons for the technical operation of gas treatment units are appointed. Following the design documentation and working conditions, each operating manual of GTU has been developed and approved. The units are marked with the registration numbers according to the passport. Each gas treatment unit has a logbook for time records.

The annual reports in the form 2-TP (annual air) are submitted on a regular basis to the Central Statistics Office and Department of Ecology and Natural Resources of the Rivne Oblast State Administration. The reports are prepared in accordance with the calculation method and are based on data on the use of raw materials, fuel materials and equipment operating hours.

Annually, the stationary sources of the Rivne NPP eject from 33 to 37 tons of pollutants into the atmosphere: non-metallic volatile inorganic compounds - from 18 to 25 tons, nitrogen compounds - from 5 to 9 tons, suspended solids (micro particles and fibers) - from 1,4 to 2,7 tons, sulphur compounds - from 1,4 to 2,7 tons, etc. The emissions of air pollutants of the nuclear power plant are 2-3 thousand times less than that of the coal-steam power station with a similar installed power capacity [20-23].

3.3.1 Monitoring results of chemical pollution of the Rivne NNP

The emissions of air pollutants from the stationary sources are carried out on the basis of the permits issued by regional representatives of the Ministry of Environmental Protection of Ukraine No. 5620881201-1 and permits issued by the Department of Ecology and Natural Resources of the Rivne Oblast State Administration: № 5610700000-8 dated 23.09.2013 (validity period – 5 years), 5610700000-11 dated 27.12.13 (validity period - 5 years), 5610700000-12, 5610700000-13 dated 24.10.2014 (validity period is not limited), 5610700000-14 dated 24.10.2014 (validity period - 10 years) and permit number 5610700000-16 dated 24.10.2014 (validity period is not limited) [21].

164 stationary sources of air pollution emissions have been inventoried in the Rivne NPP; 14 of them are equipped with gas treatment units. The biggest sources of air pollution of the Rivne NPP are the auxiliary facilities: a boiler house (BH), the diesel generators and the transport. The Rivne NPP includes 142 diesel and 148 carburant vehicles, as well as 4 diesel locomotives, 1 rail crane, 1 rail motorcar and 1 motor trolley. The transport department is equipped with a testing station to monitor the vehicle health check, the toxicity level and the exhaust smoke capacity The testing is conducted quarterly with corresponding records in the register journals.

The data on air pollution emissions from stationary sources in 2016 are given in Table 3.4 according to the form of the statistical reporting No. 2-TP (air).

The total emissions from stationary sources amounted to 34,785 tons in 2017.

Table 3.4. Air pollution emissions from stationary sources

Code of pollutants, greenhouse gases and groups	Pollutants	Emitted from the beginning of the year, t
00000	Total enterprise (excluding carbon dioxide)	34,785
01000	Metals and their compounds	0,203
03000	Substances in the form of suspended solid particles (micro particles and fibers)	2,237
04000	Nitrogen compounds	8,582
05000	Dioxide and other sulphur compounds	1,510
06000	Carbon oxide	3,356
11000	Nonmethane volatile organic compounds	18,810
12000	Methane	0,004
15000	Chlorine	0,012
16000	Fluorine and its compounds (calculated as fluorine)	0,034
18000	Cryofluorane	0,037
07000	Carbon dioxide	109,691

In compliance with the permit conditions, there was developed and approved the scheduled plan to control the established maximum permissible emissions of air pollutants and the emissions from stationary sources. According to the agreement between the Rivne NPP and the state institution "Rivne Oblast Laboratory Centre" of the Ministry of Health of Ukraine, the monitoring of the emissions ejected from stationary sources was conducted at the Rivne NPP during the reporting period (Protocol No. 45 dated 07.06.2016).

In 2017, the transport facilities of the Rivne NPP utilized 507,072 tons of diesel fuel and 397,989 tons of unleaded gasoline.

The volumes of air pollution emissions over the past 6 years are given in the Table 3.5., on the basis of which the dynamics pattern of air pollution emissions (Fig. 3.7) was performed.

Table 3.5. Dynamics pattern of air pollution emission from stationary sources.

Pollutant description	Air pollution emissions, t/per year				
	2013	2014	2015	2016	2017
Total enterprise (excluding carbon dioxide)	37,283	37,799	35,359	33,827	34,795
Metals and their compounds	0,099	0,332	0,146	0,307	0,203
Substances in the form of suspended solid particles (micro particles and fibers)	2,697	2,425	1,765	1,380	2,239
Nitrogen compounds	5,668	5,690	6,698	6,574	8,582
Dioxide and other sulphur compounds	2,652	1,819	1,744	1,417	1,510
Carbon oxide	2,649	2,365	2,723	2,561	3,356
Nonmethane volatile organic compounds	23,428	25,037	22,181	21,463	18,815
Chlorine	0,012	0,005	0,006	0,003	0,004
Methane	0,011	0,012	0,014	0,0120	0,012
Fluorine and its compounds (calculated as fluorine)	0,034	0,067	0,043	0,076	0,035
Cryofluorane	0,026	0,044	0,039	0,0342	0,037
Carbon dioxide	212,985	125,435	159,696	88,565	109,219

The volumes of air pollution emissions (dynamics) over the past 6 years are graphically depicted in Fig. 3.7. The Figure is based on the data of Table 3.5 [21].

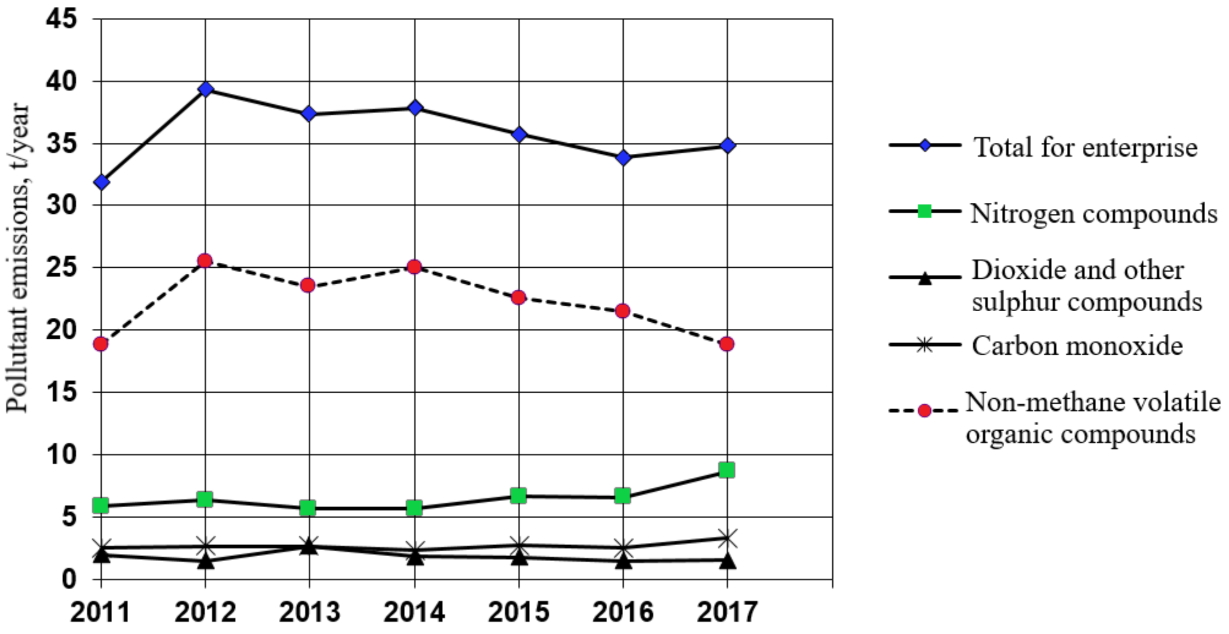


Fig. 3.7. Dynamics pattern of air pollution emissions from stationary sources

The rehabilitation and health complex «Bile ozero» worked in the summer period, where 1 source of air pollution emissions was inventoried - a woodworking machine equipped with a shaving separator. The emissions are ejected on the basis of the permit number 5620881201-1 (issued on 28.11.2011, expired on 28.11.20016). According to Clause 1 of Section IX of the Law of Ukraine "On Atmospheric Air Protection", the validity period of the permit is extended and it is unlimited.

The air pollution emissions from RHC "Bile Ozero" were not monitored in 2017.

The number of pollutants emitted in the atmosphere from the stationary source of the RHC "Bile Ozero" in 2017 is given in the Table 3.6. The dynamics pattern of emissions for 2010-2017 is presented in the Table 3.7.

Table 3.6. Air pollution emissions from stationary source, the rehabilitation and health complex «Bile ozero»

Code of pollutant, greenhouse gas and groups	Pollutants	Emitted 1 quarter, t	Emitted 2 quarter, t	Emitted 3 quarter, t	Emitted 4 quarter, t	Emitted from beginning of the year, t
00000	Total enterprise (excluding carbon dioxide)	0,000	0,000	0,000	0,00	0,000
03000	Substances in the form of suspended solid particles (micro particles and fibers)	0,000	0,000	0,000	0,000	0,000

Table 3.7. Dynamics pattern of air pollution emissions from stationery source of RHC "Bile ozero", SS "Rivne NPP"

Pollutant description	Air pollution emissions, t/per year						
	2011	2012	2013	2014	2015	2016	2017
Total enterprise (excluding carbon dioxide)	0,023	0,009	0,005	0,003	0,003	0,001	0,000
Metals and their compounds	0,000	0,000	0,000	0,000	0,000	0,000	0,0000
Substances in the form of suspended solid particles (micro particles and fibers)	0,023	0,0087	0,005	0,003	0,003	0,001	0,000
Nitrogen compounds	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dioxide and other sulphur compounds	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Carbon oxide	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Nonmethane volatile organic compounds	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Methane	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Fluorine and its compounds (calculated as fluorine)	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Cryofluorane	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Carbon dioxide	0,000	0,000	0,000	0,000	0,000	0,000	0,000

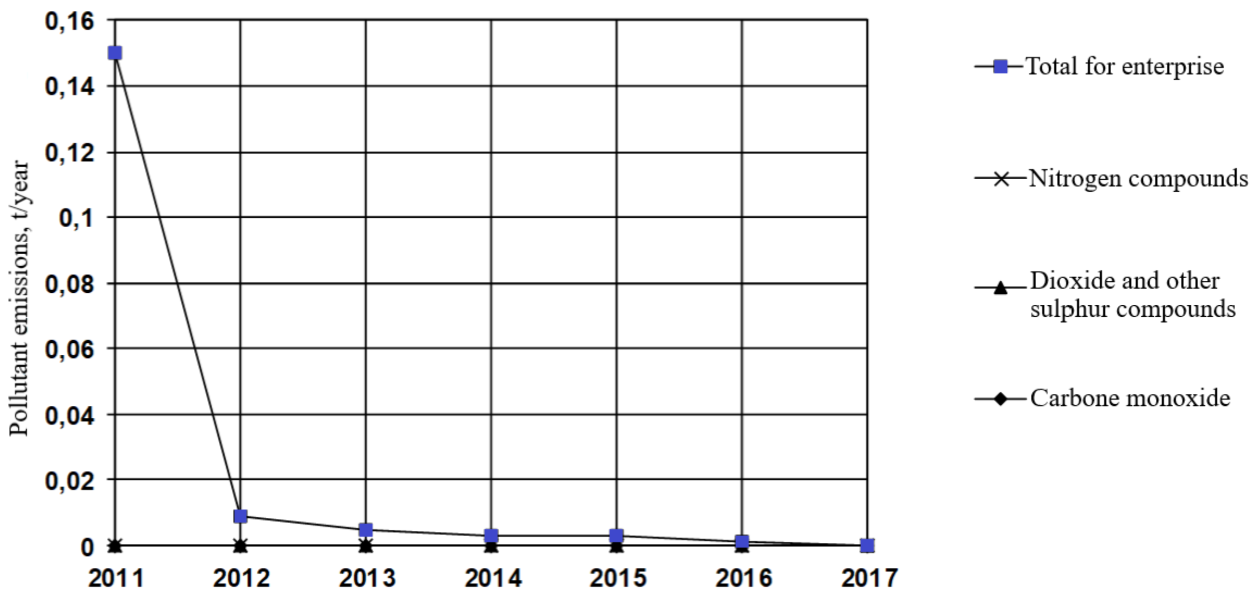


Fig.3.8. Dynamics pattern of air pollution emissions from stationery source of RHC "Bile ozero", SS "Rivne NPP"

The decreased amount of air pollution emissions in the area of RHC "Bile Ozero" of the Rivne NPP was due to the replacement of the coal boilers by the electric heater since 2012.

The Rivne NPP releases the air pollutant emissions in accordance with the emission permit conditions (Attachment A). The amount of raw materials and other materials used in 2017 does not exceed the values established in the provided documents.

3.3.2 Justification of maximum permissible non-radioactive emissions and the measures aim to reduce the Rivne NPP impact on the environment

In accordance with the "Calculation methodology of air pollutant concentration in the emissions from enterprises", OND-86 [16], the values of maximum permissible emissions (MPE) are set in the way that the emissions of polluted substances from one and other sources do not form the surface concentration of polluted substances and don't exceed the maximal permissible concentration (MPC). According to the conducted estimation, the surface concentrations of all substances in the emissions within the sanitary protection zone (SPZ), and, especially, in the residential area outside the SPZ, are less than the MPC (or even less for certain substances).

In addition, it should be noted that the estimated value of annual gross emissions of the Rivne NPP by main substances is much lower than the currently established values and the calculated values of emissions per second are not increased, as the sources capacity remains unchanged.

This allows concluding that the calculation values given in the Table 3.8 can be submitted for approval as the MPC.

Table 3.8. Proposed MPC (chemical) values of air pollution emissions from the sources of the Rivne NPP

Substance description		Established values of gross emissions		Estimated values of gross emissions, the Rivne NPP	
		t/per year	g/s	t/per year	g/s
1	Nitrogen dioxide	77,94	3,7891	0,1728	0,0189
2	Sulphur dioxide	1607,66	78,0286	0,613	0,1241
3	Carbon oxide	253,25	12,3978	1,586	0,1440
4	Charcoal black (soot)	40,005	1,9404	0,006	0,0015
5	Inorganic dust	0,2307	0,1780	0,2768	0,1780
6	Wood dust	0,8822	0,1441	0,7352	0,1441
7	Manganese and its compounds	0,00098	0,00076	0,0137	0,00076
8	Hydrocarbons saturated C_{12}-C_{19}	0,2955	0,0231	0,3546	0,0231
9	Hydrogen fluoride	0,00048	0,00061	0,00066	0,00061
10	Welding aerosol	0,0105	0,0135	0,0144	0,0135
11	Butanol	0,0621	0,0689	0,0745	0,0689
12	Butyl acetate	0,0761	0,1102	0,0913	0,1102
13	Toluene	0,2102	0,2103	0,1752	0,2103
14	Ethanol	0,0401	0,2664	0,04812	0,2664

Substance description		Established values of gross emissions		Estimated values of gross emissions, the Rivne NPP	
		t/per year	g/s	t/per year	g/s
15	Ethyl acetate	0,0561	0,0908	0,0673	0,0908
16	Ethyl cellosolve	0,0196	0,0202	0,0235	0,0202
17	Ashes	0,9	0,2321	1,242	0,2321
18	Acetone	0,0172	0,0123	0,0206	0,0123
19	Petrol (vapour)	0,6121	0,8708	0,7345	0,8708
20	Sulphuric acid (vapour)	0,000025	0,00005	0,00003	0,00005
21	White spirit (vapour)	0,2246	0,1560	0,2695	0,1560
22	Sodium carbonate	0,0184	0,0064	0,0221	0,0064
23	Calcium oxide	-	-	1,469	0,0583
Total:		1982,592	98,56042	8,6136	2,75132

Taking into account the low values of chemical pollutants released in the atmosphere, it is inappropriate to provide any additional measures for emissions reduction, except for existing gas treatment units (GTUs).

3.3.3 Estimation of chemical (non-radioactive) pollution level during normal operation of the Rivne NPP power units and accidents

3.3.3.1 Quantitative estimation of chemical (non-radioactive) pollution during normal operation of the Rivne NPP power units

The air pollution within the sanitary protective zone and the 30-kilometer zone of the Rivne NPP from the NPP sources is characterized by gross emissions per year and per second and the surface concentration of these emissions in the air.

The estimated annual gross emissions in total by all substances equal to 9,044 ÷ 10,335 tons/per year, which is 0,7% of the currently established values. In the absolute values these emissions are estimated in some grams (compound of manganese, fluoride hydrogen) and 120 ÷ 150 kg (gasoline, wood dust). Consequently, the low values of these emissions do not have a significant impact on environment. This conclusion is confirmed by estimation of maximum surface concentration of all above-mentioned substances in the atmosphere.

The estimation of the surface concentrations of harmful substances were performed on the basis of the emission values per second from all sources of the Rivne NPP, the volume and temperature of the exhaust gas emissions, the heights and diameters of the ventilation pipes, the emission source positions, etc.

The measurements were carried out using the software complex "EOL", taking into account the combination of the most adverse meteorological and temperature conditions for the dispersion of harmful emissions in the atmosphere [23].

The obtained values of the surface concentrations of harmful substances were compared with the maximal permissible concentrations of these substances (MPC) for residential areas [12].

The estimations were carried out for all organized and unorganized emissions, except emissions of substances under the following condition:

$$\frac{M}{MPC} < 0{,}01\ H \text{ at } H > 10 \text{ м}$$

$$\frac{M}{MPC} < 0{,}1\ H \text{ at } H < 10 \text{ м}$$

where M – emission of harmful substances per second, g/s;
MPC – maximal permissible concentration of this substance, mg/m^3;
H – average height of the emission source, m.

whereas H was determined by the formula

$$H = \frac{5M_{0-10}+15M_{1120}+25M_{21-30}}{\Sigma M}$$

where M_{0-10}, M_{11-20}, M_{21-30} – total amount of emissions from the sources which have the height of up to 10 m, from 11 to 20 m, from 21 to 30 m (consequently);

ΣM – total amount of emissions.

Based on this criterion, 13 (acetone, inorganic dust, manganese and its compounds, saturated hydrocarbons, hydrogen fluoride, welding aerosol, ethanol, ethyl cellosolve, calcium sulphate, sulphuric acid, white spirit, petrol and charcoal black (soot)) are excluded from the total number of substances in the estimation of surface concentrations.

However, the estimation of surface concentrations is made for the following substances: sulphur dioxide, carbon oxide, nitrogen dioxide, ashes, wood dust, butanol, ethyl acetate, butyl acetate, calcium oxide, toluene.

Due to the fact that in the submitted documents of the Rivne NPP cornering the harmful emissions there is no clarification about the composition of certain substances (inorganic dust, coal ash, welding aerosol), the most conservative conditions were accepted in the estimation:

- inorganic dust with SiO_2 > 70 % content MPC=0,15;
- coal ashes MPC =0,05;
- welding aerosol MPC=0,04.

In addition, according to the DSP-201-97 [10], the estimation of the cumulative effect of sulphur dioxide and nitrogen dioxide (total chemical reactivity) has been performed.

The estimation results are presented in the Figures 3.9 - 3.18, with the isoline reference to the map of the sanitary protection zone.

Based on the attached figures, the following conclusions can be made:

- sulphur dioxide - the maximum surface concentrations are 0,15 MPC and they are concentrated at a distance up to 100 m from the source (Figure 3.9); nitrogen dioxide - respectively, 0,05 MPC at the same distance from the source (Figure 3.10); butanol, butyl acetate and ethyl acetate, the release of these occurs only on the site No. 2, the maximum surface concentrations are from 0,12 to 0,17 MPC at a distance not exceeding 100 m (Figures 3.12, 3.15 and 3.16, respectively);

- after summation of these values and comparison with background ones (nitrogen dioxide and ethyl acetate – 0,8 MPC, butyl acetate – 0,7 MPC) the maximum permissible concentrations are not exceeded (Figure 3.17). It should be noted that the established background values do not take into account the share of active sources of nuclear power plant. The actual concentrations will be at the background level, as there is no provision for additional sources of air chemical emissions.

In addition, the estimated values of maximum surface concentrations were taken in comparison with the MPC for residential area, and, in our case, the concentrations may exceed MPC within the sanitary protection zone (SPZ).

According to the estimation of SO_2 and NO_2, the maximum values of 0,21 MPC are recorded within the SPZ.

Therefore, the estimation performed in this section allows us to conclude that the future operation of all 4 power units of the Rivne NPP and introduction of new sources of chemical emissions will not impact the ecological situation of the 30-kilometer zone and will not exceed the normative values of chemical (non-radioactive) pollution for residential areas.

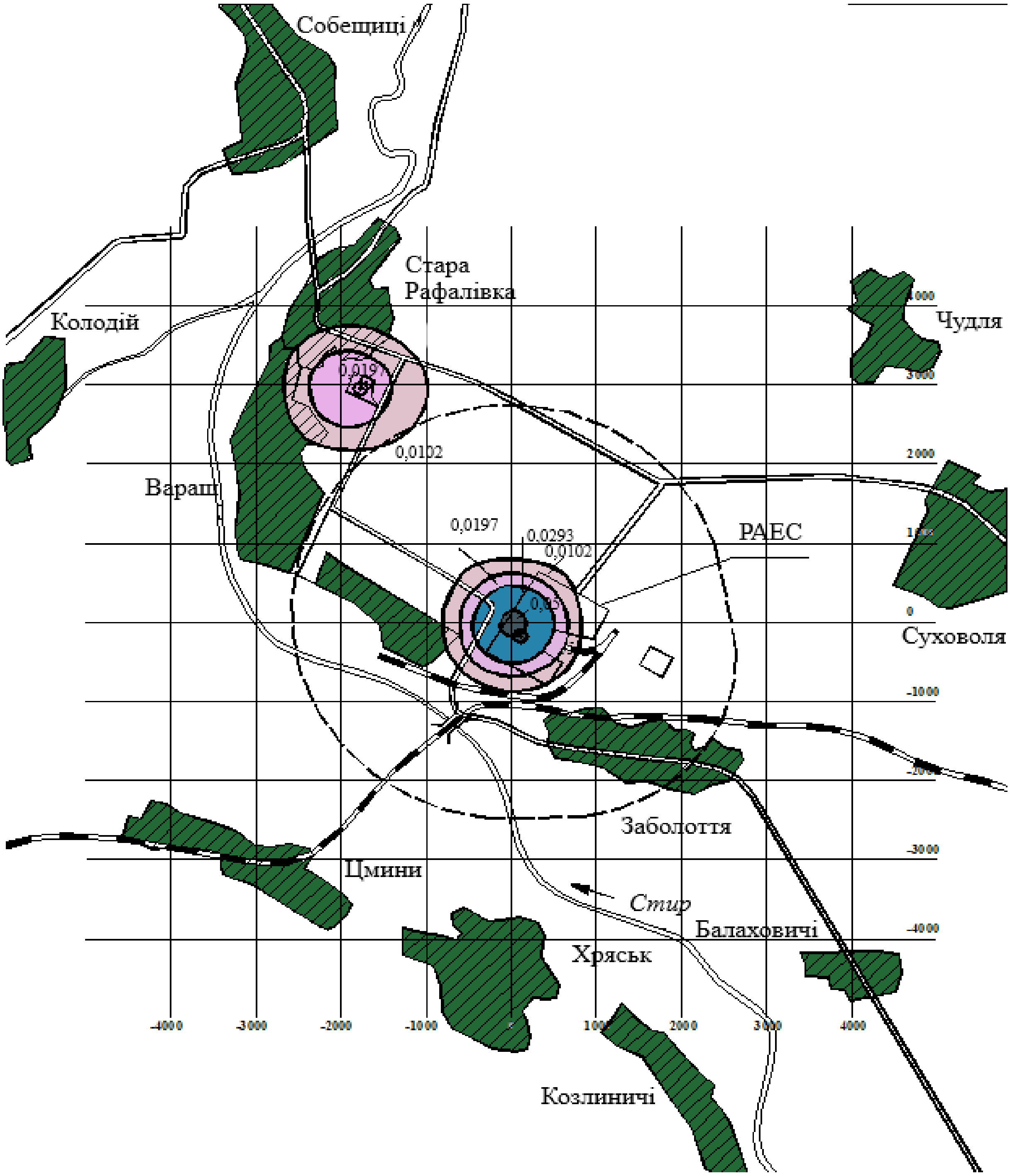


Fig. 3.9. Dispersion modelling of SO_2 emissions

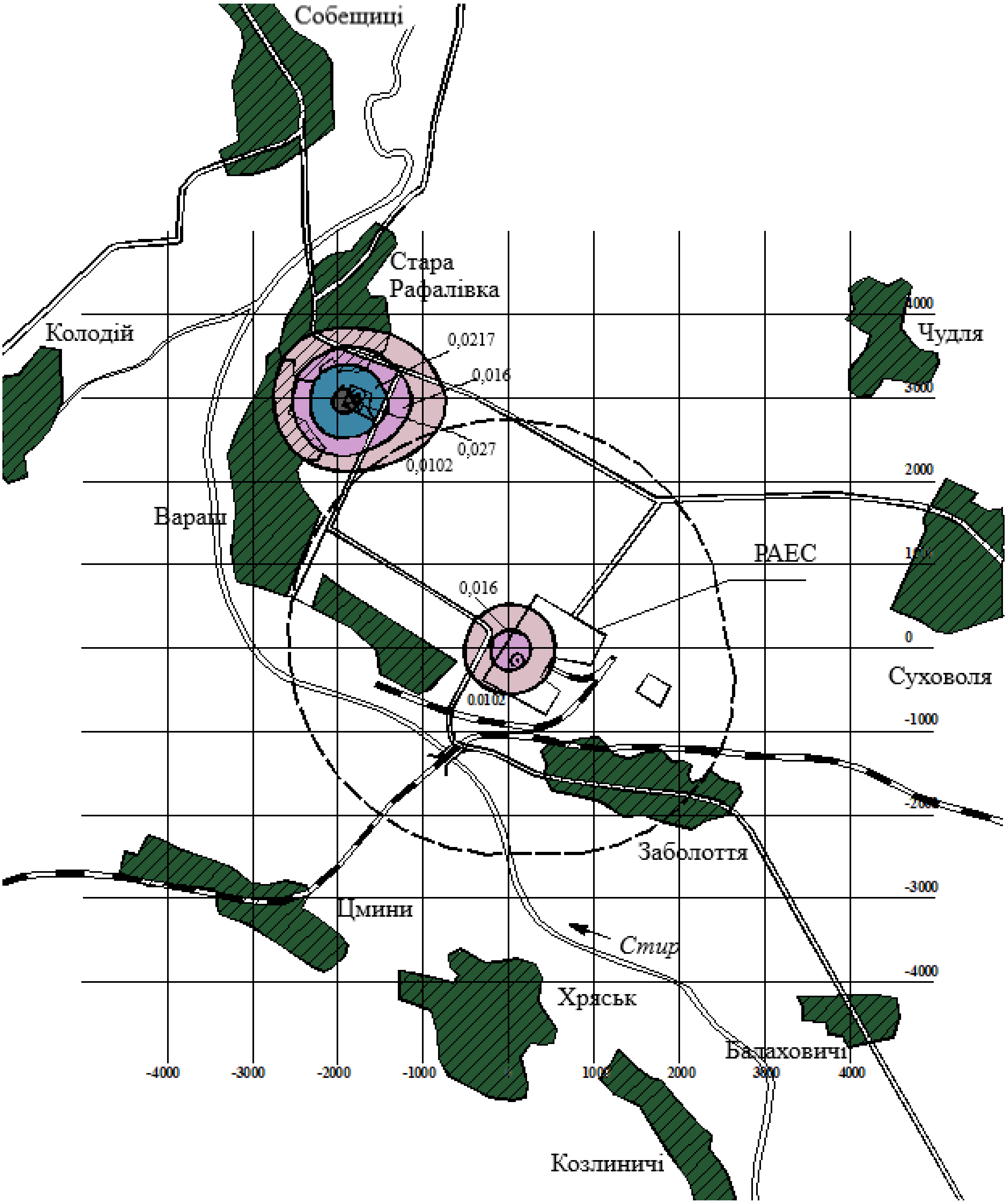


Fig. 3.10. Dispersion modelling of NO_2 emissions

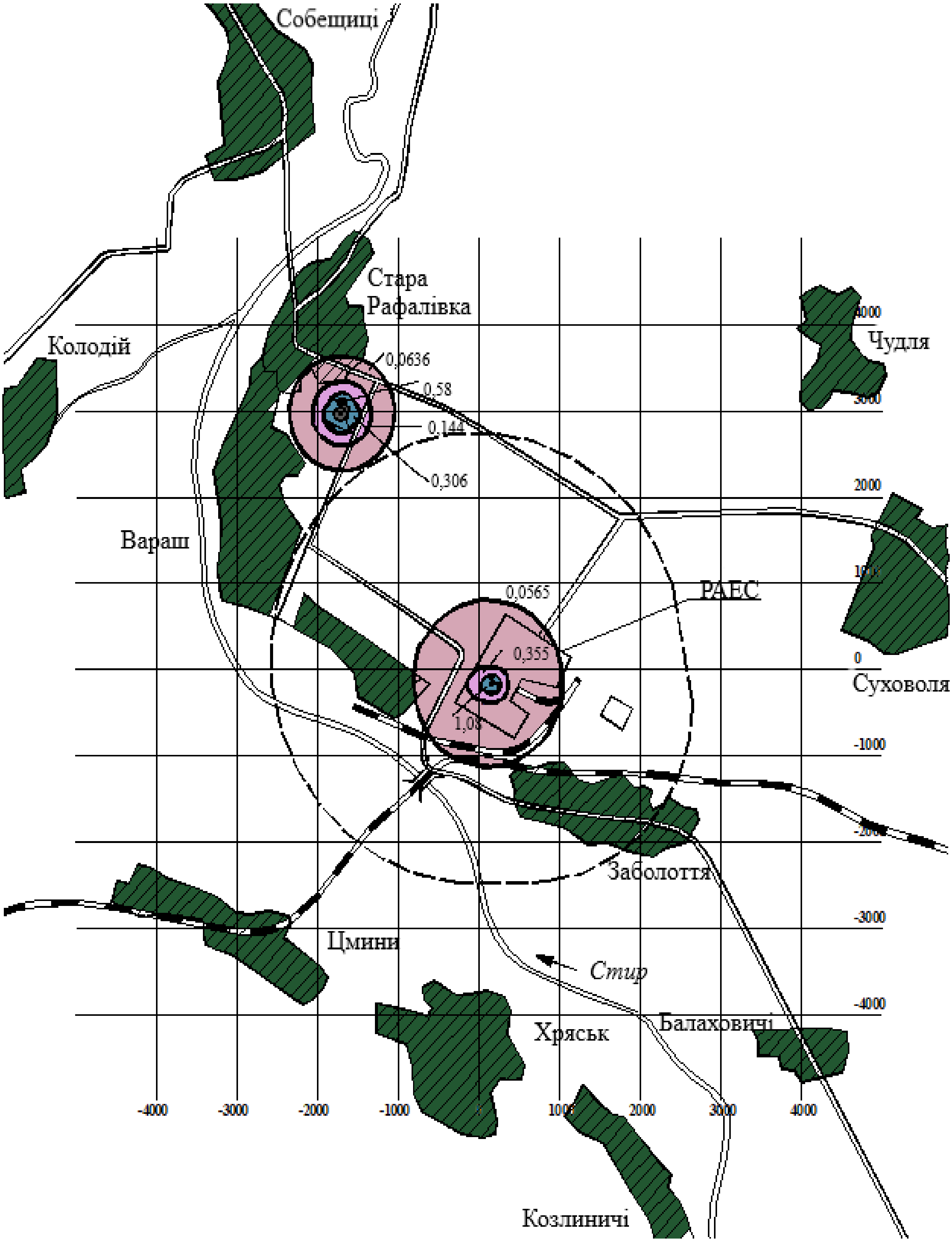


Fig. 3.11. Dispersion modelling of ashes emissions

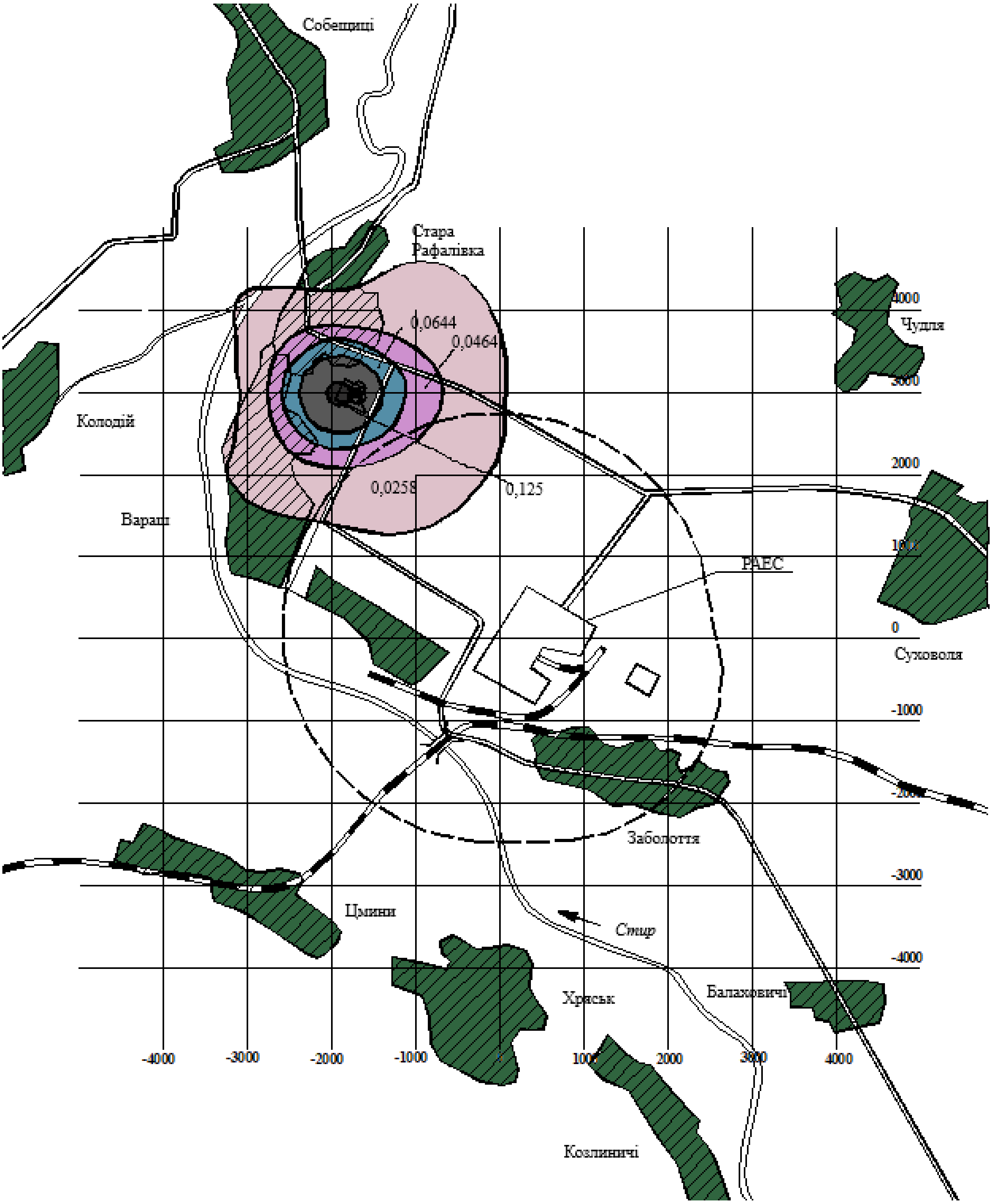


Fig. 3.12. Dispersion modelling of butanol emissions

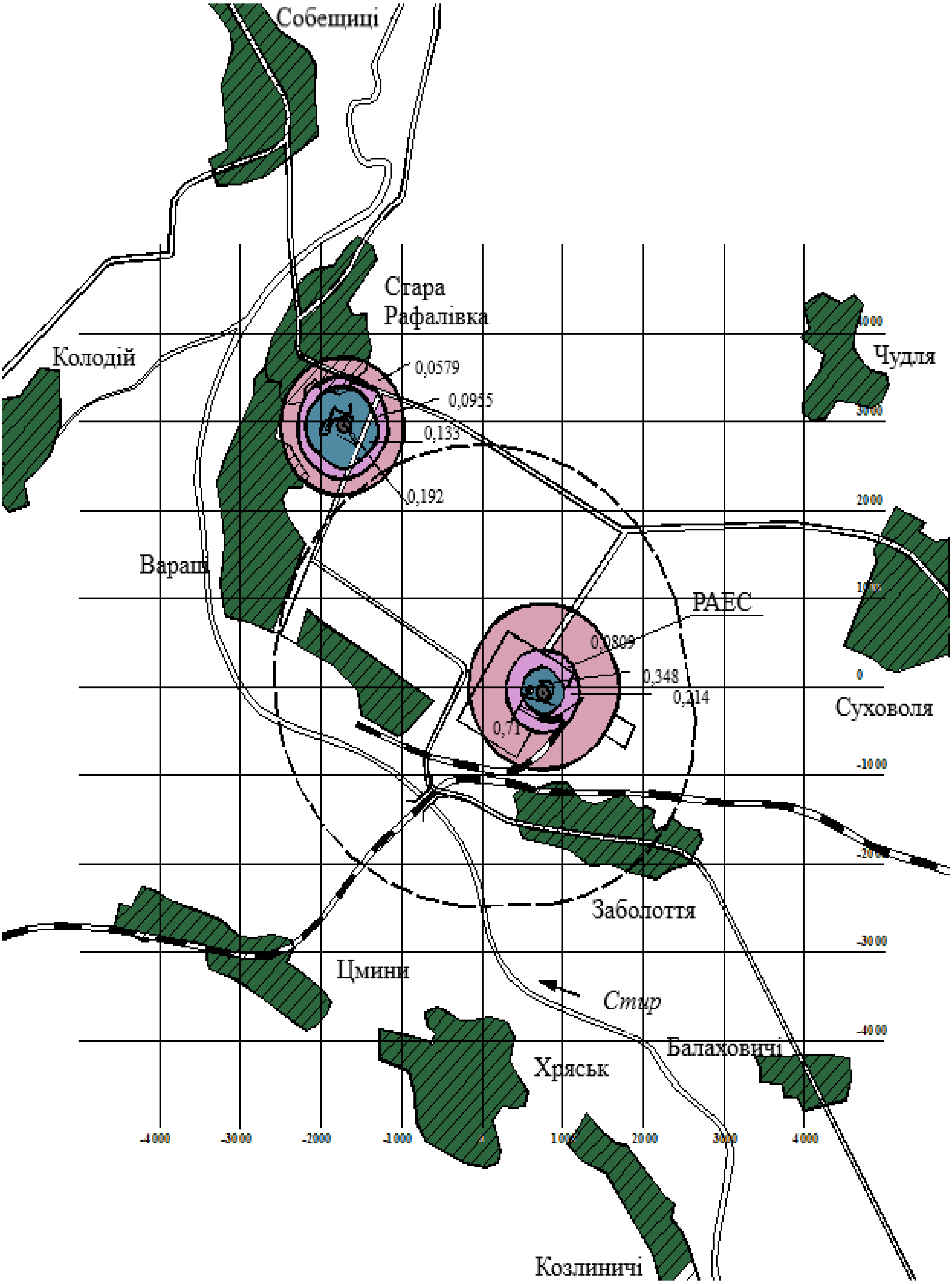


Fig. 3.13. Dispersion modelling of wood dust emissions

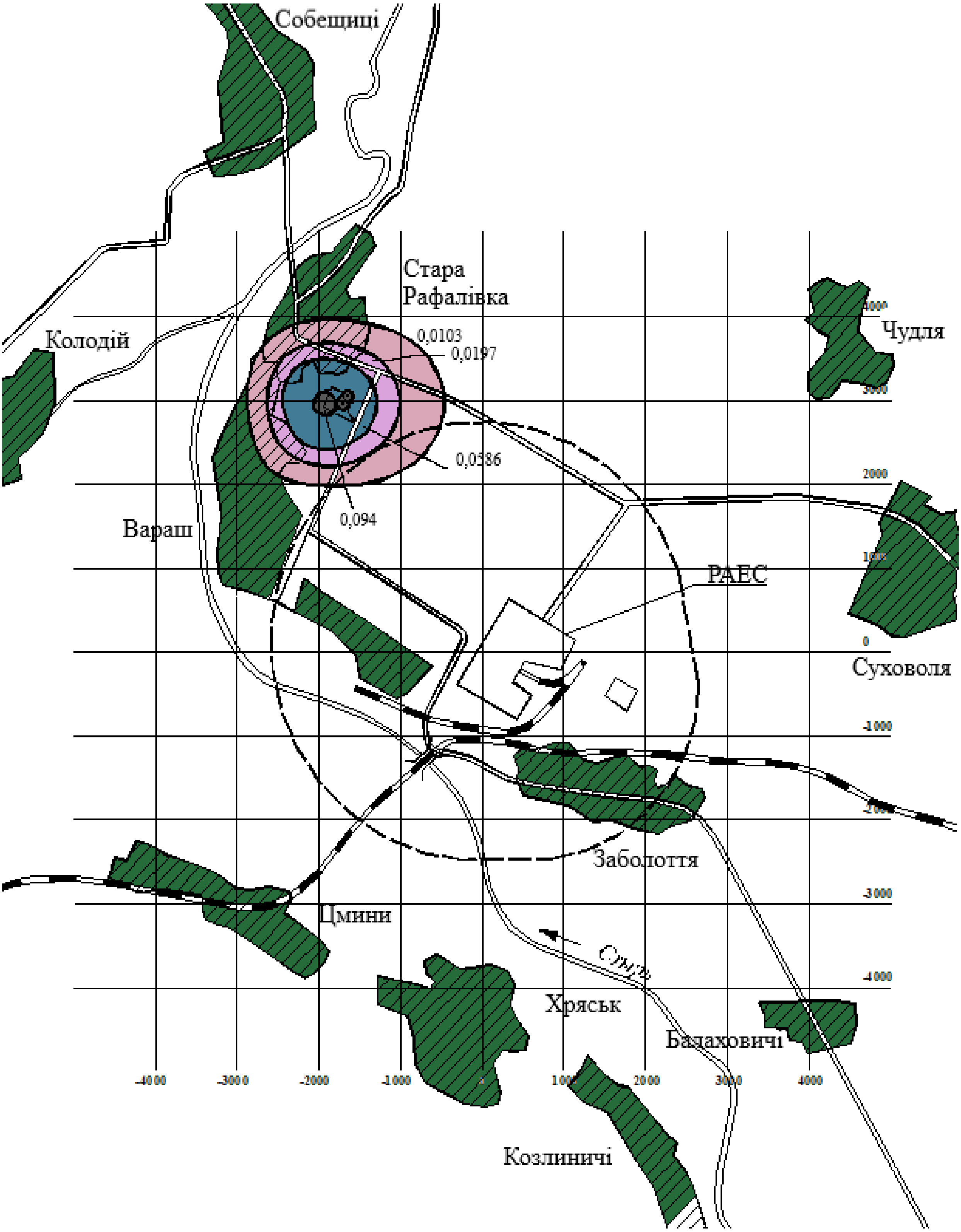


Fig. 3.14. Dispersion modelling of toluene emissions

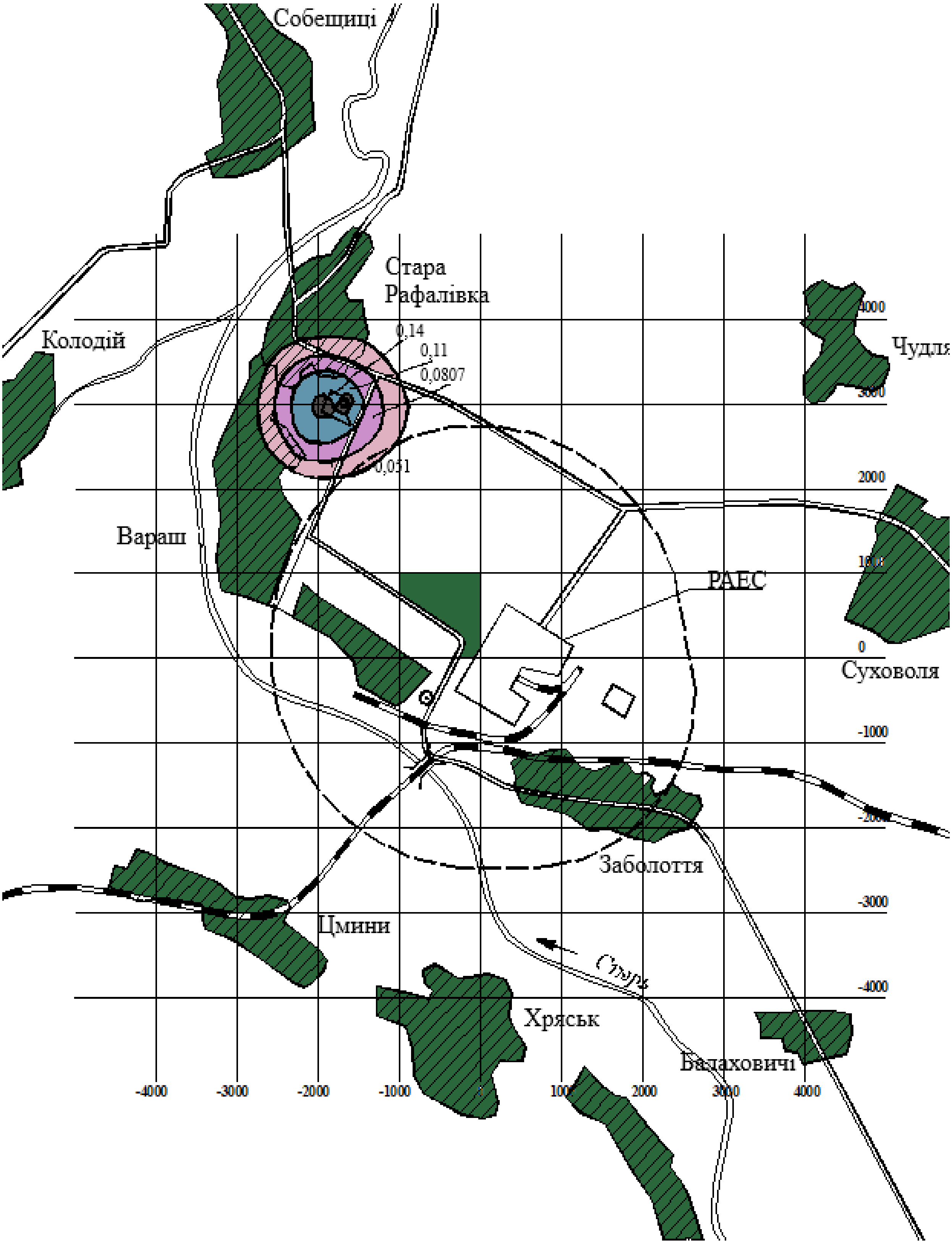


Fig. 3.15. Dispersion modelling of butyl acetate emissions

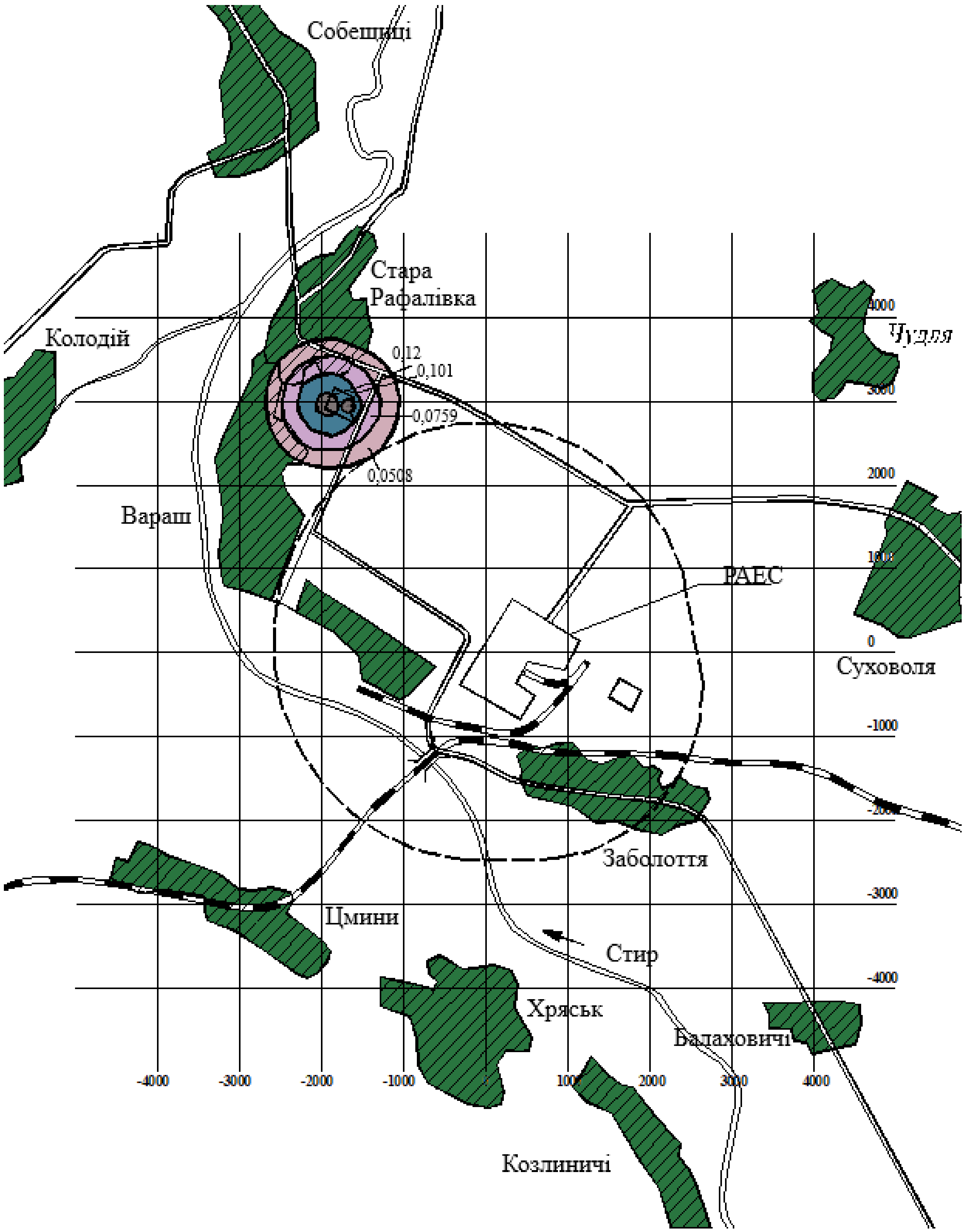


Fig. 3.16. Dispersion modelling of ethyl acetate emissions

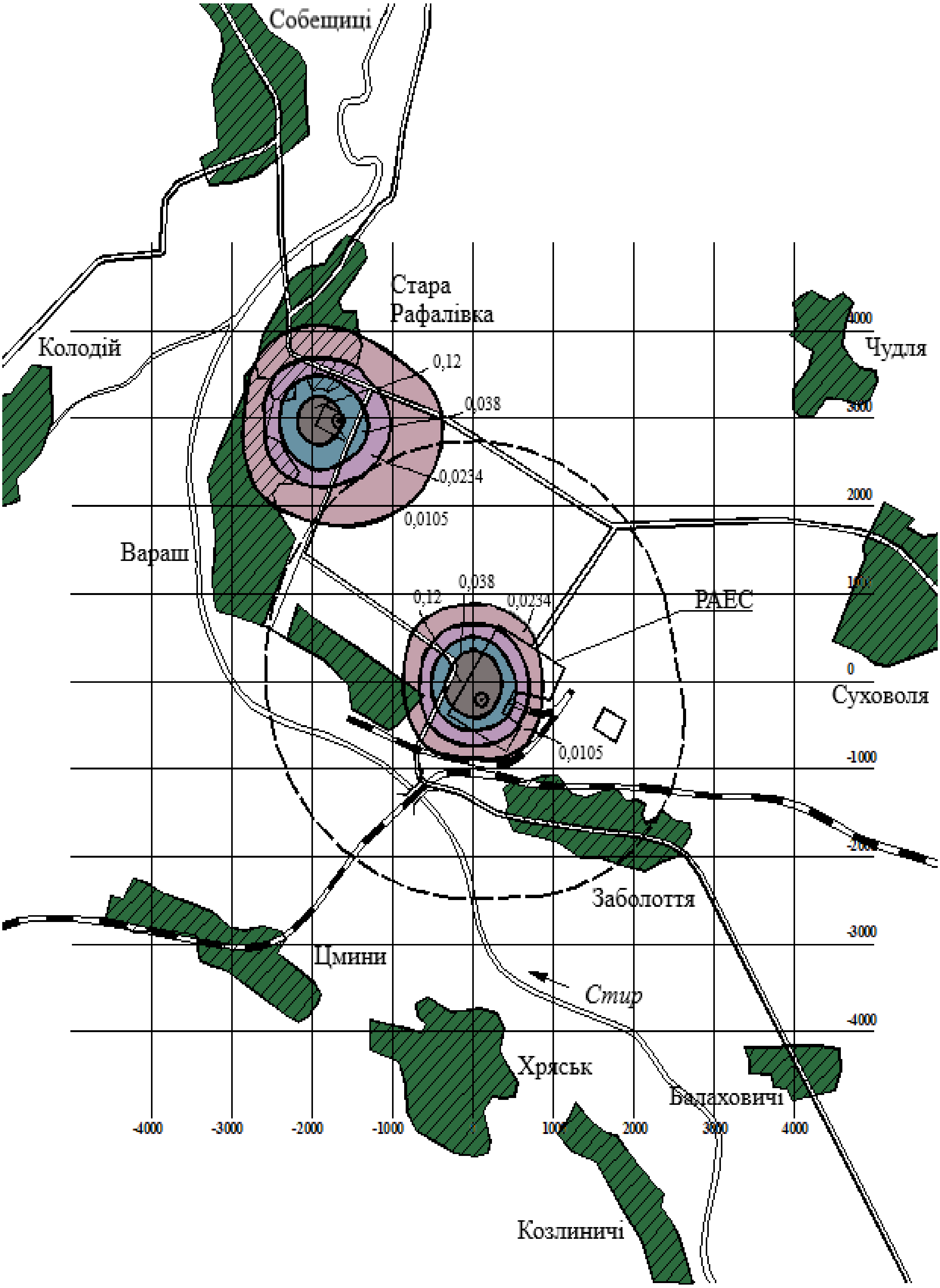


Fig. 3.17. Dispersion modelling of SO_2+NO_2 (total chemical reactivity) emissions

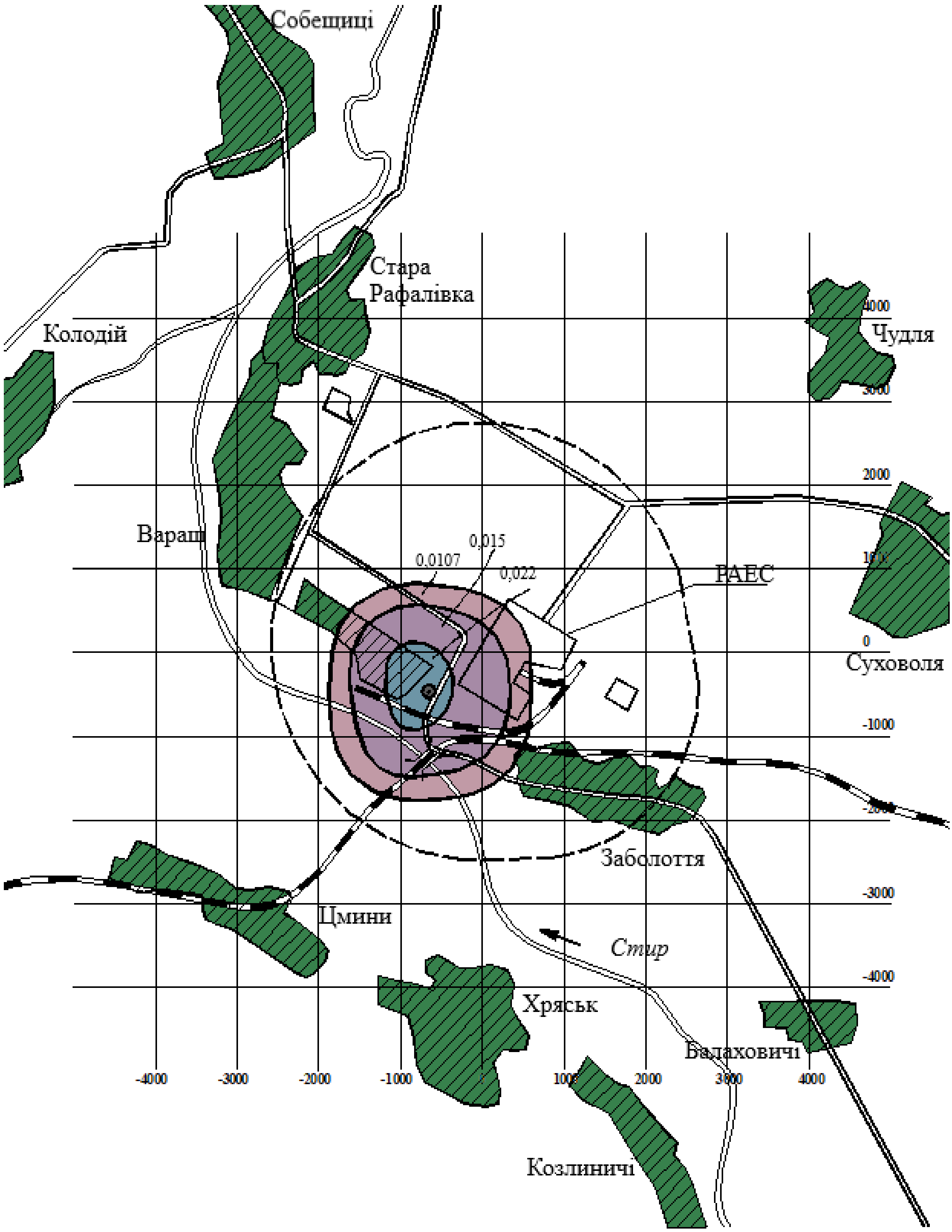


Fig. 3.18. Dispersion modelling of CaO emissions

3.3.3.2 Quantitative estimation of chemical (non-radioactive) pollution during accidents

The nature of environmental pollution by chemical emissions and discharges during accidents may cause the excessive release of chemicals. Hereby, we considerer the following accidents that could lead to excessive chemical emissions in comparison to the emissions during normal operation of the NPP [22, 23]:

- an accident involving the discharging of one of the power units or the entire NPP (the last one is very unlikely), which leads to the launch of the emergency diesel-run power plant (EDPP) and the general emergency diesel-run power plant (GEDPP);
- an accident related to the cut of water supply from power units due to its radioactive contamination or emergency works at the heat point, which leads to the launch of the steam boiler (SB);
- an accident related to the shutdown of gas treatment facilities at one of chemical emissions sources.

The gross annual emissions and maximum surface concentrations of harmful substances in the atmosphere during the first two accidents are within the permissible limits.

The local accidents at the gas treatment units of auxiliary facilities, which operate occasionally, are not taken into account, as these technological units can be stopped before performing repair and maintenance works.

3.4 Chemical pollution of air environment in the region (Rive Oblast)

The environmental conservation is one of the most challenging issue in society development. The dynamic growth and production expansion increase the anthropogenic impact on the environment [6].

The current trends determine the objective need for development and implementation of economic strategy aim to improve the nature management system and to reduce the negative effects of anthropogenic load on the environment and its components. The realization of this objective should be facilitated by comprehensive study and integrated analysis of all factors and consequences of environmental pollution in order to collect all necessary information about the environment health.

However, in spite of numerous researches and developments, the issue of statistical monitoring of anthropogenic load both on the environment and on the human being remains essential. In the process of transition of Ukraine to sustainable (balanced) development, the statistical assessment of air pollution and air protection plays a significant role in the research concerning pollution and protection of human life space.

A large amount of pollutants ejected in the atmosphere is potentially dangerous for environment, but also for human health. The various gases, airborne small particles and liquid substances, which negatively affect the living beings and the conditions of their existence, pollute the atmospheric air. The sources of pollution can be natural and anthropogenic. The natural pollution of the atmosphere, in the majority, is not dangerous for a human being, because they occur under certain biological laws and are regulated periodically by a circuit of substance. The anthropogenic pollution of the atmosphere occurs due to changes in its composition and properties under the influence of human activity. The stationary sources and mobile vehicles cause the anthropogenic pollution of atmospheric air by harmful substances.

3.4.1. Air pollution dynamics

According to the Head Department of Statistics in the Rivne Oblast, the total amount of pollutants released into the atmosphere in 2016 from stationary sources amounted to 9,1 thousand tons, which is 1,1 thousand tons (or 12.1%) less than in 2015 [21].

Table 3.9. Air pollution dynamics, th. t.

Years	Air pollution emissions, ths. t			Emission density per 1 km^2, kg	Emissions per person, kg
	Total	including			
		stationary source	mobile source		
2000	49,7	14,1	35,6	2478,7	42,0
2005	57,7	17,3	40,4	2877,2	49,9
2006	59,2	17,9	41,3	2952,5	51,3
2007	66,2	18,5	47,7	3301,6	57,5
2008	61,3	16,2	45,1	3057,2	53,3
2009	52,7	10,0	42,7	2628,3	45,7
2010	56,2	12,9	43,3	2805,5	48,8
2011	62,5	17,1	45,4	3114,7	54,1
2012	60,4	14,9	45,5	3012,2	52,3
2013	56,1	12,0	44,1	2801	48,5
2014	56,7	11,6	45,1	2828,5	48,9
2015	52,2	10,2	42,0	2602,1	44,9
2016	*	9,1	*	*	*

Note:* - the estimation of air pollution emissions was not foreseen in the plan of state statistical monitoring in 2016

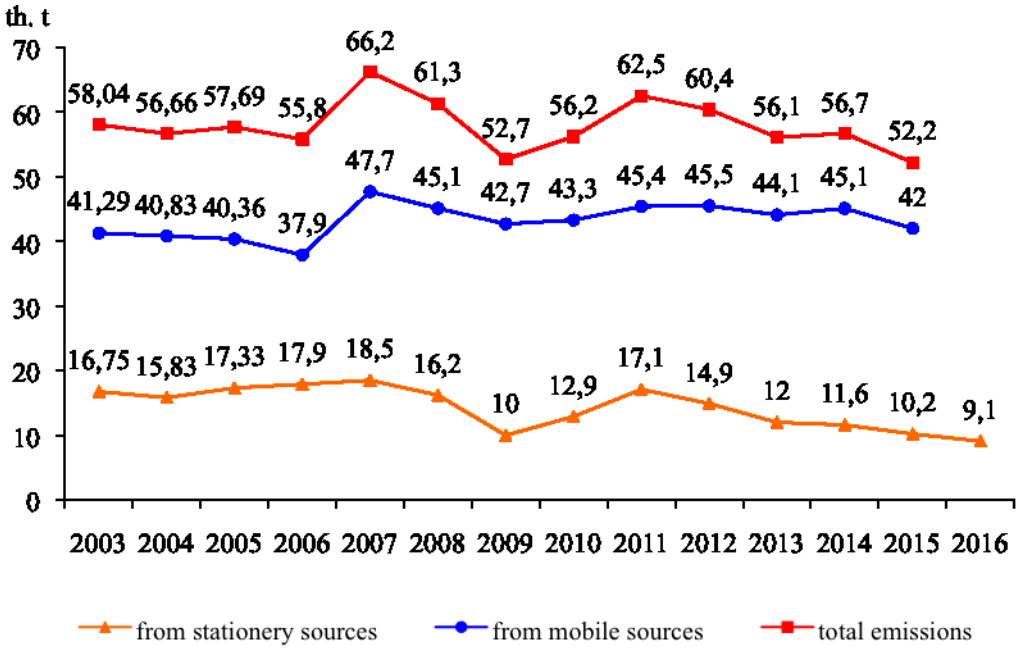


Fig. 3.19. Dynamics of air pollution emissions from stationary and mobile sources

The chemical composition of pollutant emissions from stationary sources in 2016 is shown in Figure 3.20 [6].

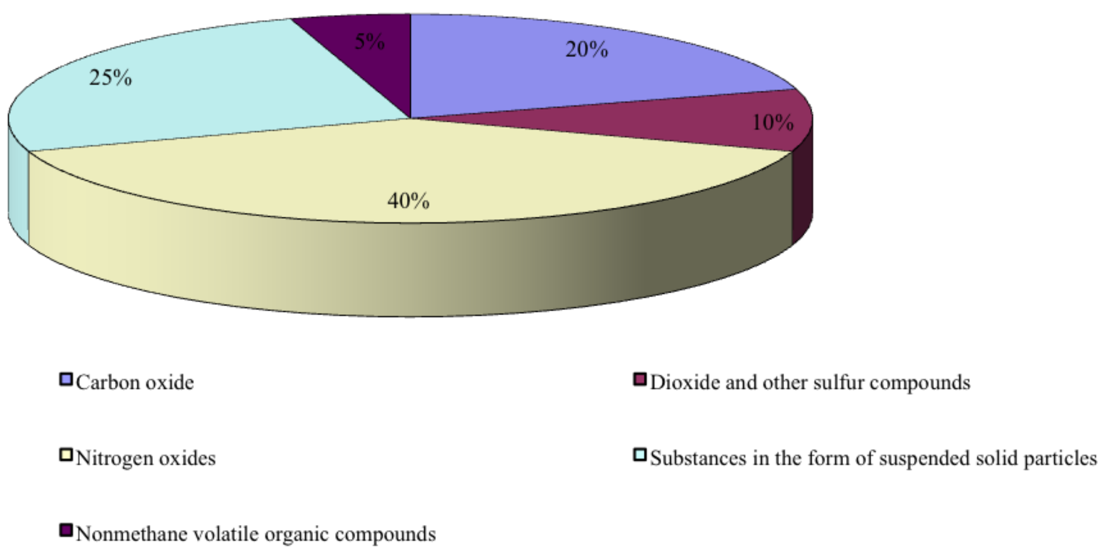


Fig. 3.20. The chemical composition of pollutant emissions from stationary sources in 2016

The density of air pollution emissions by stationary sources in the territory of the Rivne Oblast amounted to 454.2 kg per square kilometre in 2016 against 510.2 kg in 2015, in estimation per person - 7.8 kg in 2016 against 8.8 kg in 2015. The stationary sources ejected 1.3 million tons of carbon dioxide, which significantly affect the climate change.

Table 3.10. Air pollution missions from stationary sources (per administrative unit).

Administrative unit	Emission volumes total, t		Emission density, kg/km^2		In estimation per person, kg	
	2015	2016	2015	2016	2015	2016
Total in Rivne Oblast	10229,4	9106,9	510,2	454,2	8,8	7,8
Rivne	3711,6	3164,5	63992,3	54561,2	14,9	12,8
Dubno	60,0	78,4	2221,4	2902,3	1,6	2,1
Varash	36,5	34,6	3320,3	3147,1	0,9	0,8
Ostroh	11,9	12,7	1085,1	1155,4	0,8	0,8
Berezne district	102,3	120,9	59,6	70,5	1,6	1,9
Volodymyrets district	120,1	98,2	61,9	50,5	1,9	1,5
Hoshcha district	102,9	121,5	148,9	175,9	2,9	3,4
Demydiv district	-	6,1	-	16,2	-	0,4
Dubno district	492,4	522,4	410,0	435,0	10,8	11,4
Dubrovytsia district	156,6	134,7	86,1	74,0	3,3	2,8
Zarichne district	247,5	93,3	171,6	64,7	7,0	2,6

Administrative unit	Emission volumes total, t		Emission density, kg/km^2		In estimation per person, kg	
	2015	2016	2015	2016	2015	2016
Zdolbyniv district	2727,6	2342,3	4139,0	3554,3	47,7	41,0
Korets district	9,5	4,0	13,1	5,5	0,3	0,1
Kostopil district	477,3	488,7	318,9	326,5	7,4	7,6
Mlyniv district	70,3	69,5	74,4	73,6	1,9	1,8
Ostroh district	55,1	42,1	79,5	60,7	1,9	1,5
Radyvyliv district	46,8	73,1	62,8	98,1	1,3	2,0
Rivne district	1092,1	1146,2	928,7	974,6	12,0	12,4
Rokytne district	347,5	242,7	147,9	103,3	6,2	4,3
Sarny district	361,4	311,0	183,3	157,7	3,5	3,0

The air pollution dynamics depends on the economic activity in the region. The main factor to decrease the air pollution emissions by stationary sources is to reduce the production volumes.

The principal causes of atmospheric pollution are the use of technologies, most of which do not meet the current environmental requirements, physically worn out equipment, failure to meet the established deadlines for atmospheric and protective measures to reduce harmful emissions, low level of exploitation of the dust and wastewater treatment units.

The increase of air pollution emissions was observed in Berezne, Hoshcha, Dubno, Radyvyliv, Rivne, Kostopil districts, in the towns of Dubno and Ostroh. In other districts and towns of the region the decrease of emissions was recorded.

The primary sources of air pollution in 2016 were the enterprises in the city of Rivne (3,2 thousand tons), Zdolbuniv (2,3 thousand tons), Rivne (1,1 thousand tons), Kostopil (0,5 thousand tons), Dubno (0,5 thousand tons) and Sarny (0,3 thousand tons) districts.

The most polluted territories are the city of Rivne (54561,2 kg/km2), Varash (3147,1 kg/km2), Dubno (2902,3 kg/km2), Zdolbuniv district (3554,3 kg/km2) and Rivne district (974,6 kg/km2).

3.4.1.1 Dynamics of the most common air pollutant emissions in the towns of the region (Rivne Oblast)

The primary contributors to air pollution in the region are the PJSC «Rivneazot» and the branch of «Volyn-cement» of PJSC «Dyckerhoff cement Ukraine» [6].

The maximum dust emissions were observed in the city of Rivne and Zdolbuniv, Sarny, Rivne, Kostopil districts; sulfur dioxide - in Rivne, Dubno districts and in the city of Rivne; nitrogen dioxide - in Zdolbuniv, Rivne districts and in the city of Rivne; carbon oxide - in the city of Rivne and Zdolbuniv, Rivne, Kostopil districts (Table 3.11).

3.4.1.2 Primary contributors to air pollution (by types of economic activity)

The primary contributors to environmental pollution in the region (Rivne Oblast) are the enterprises of the processing industry (71% of the total amount of pollutants). The Table. 3.11. represents the air pollution emissions by types of economic activity.

Table 3.11. Air pollution emissions by types of economic activity in 2016

№	Type of economic activity	Number of enterprises ejected the emissions	Emission volumes in the region (Rivne Oblast)		Average ejected emissions per enterprise, t
			t	in % from total	
1	All types of economic activity	199	9107,0	100	45,8
	including:				
1.1	Agriculture, forestry and fish industry	29	771	8,5	26,6
1.2	Mining industry and quarrying	16	379	4,2	23,7
1.3	Food and pharmaceutical industries	80	6468	71,0	80,9
1.4	Electricity, gas, steam and air conditioning supply	18	623	6,8	34,6
1.5	Water supply, sewerage, waste management	5	5	0,1	1,0
1.6	Construction industry	2	13	0,1	6,5
1.7	Wholesale and retail trade; repair and maintenance of motor vehicles and motorcycles	6	219	2,4	36,5
1.8	Transport, warehousing, postal and courier services	14	362	4,0	25,9
1.9	Temporary accommodation and catering services, information and telecommunications; financial and insurance activities; real estate operations; administrative and auxiliary services activities	4	13	0,1	3,3
1.10	Professional, scientific and technical activities; education	6	19	0,2	3,2
1.11	Public administration and defence; compulsory social insurance	5	96	1,1	19,2
1.12	Public health service and social assistance; art, sports, entertainment and recreation; other types of services	14	139	1,5	9,9

The primary contributors to air pollution in Rivne Oblast are PJSC Rivneazot, LLC "Svispan Limited", LLC "ODEK" Ukraine, PrJSC Consumers-Sklo-Zorya, branch of "Volyn-cement" PJSC "Dyckerhoff Cement Ukraine" (Table 3.13).

Table 3.12. Dynamics of air emissions including the most common substances (dust, sulphur dioxide, nitrogen dioxide, carbon oxide) in the Rivne Oblast and in the administrative units, ths. t

Administrative units	2015							2016							(+/-) 2016 till 2015					
		including							including							including				
		stationary source							stationary source							stationary source				
			including							including							including			
	total	total	dust	sulphur dioxide	nitrogen dioxide	carbon oxide	mobile source	total	total	dust	sulphur dioxide	nitrogen dioxide	carbon oxide	mobile source	total	total	dust	sulphur dioxide	nitrogen dioxide	carbon oxide
Rivne	14,92	3,71	0,67	0,08	0,62	0,53	11,21		3,17	0,67	0,09	0,51	0,40	*		-	-	+0,01	-0,11	-0,13
Dubno	1,26	0,06	0,01	0,006	0,03	0,01	1,20		0,08	0,02	0,01	0,04	0,01	*		+0,02	+0,01	+0,004	+0,01	-
Varash	1,32	0,04	0,002	0,002	0,007	0,003	1,28		0,04	0,002	0,001	0,007	0,003	*		-	-	-0,001	-	-
Ostroh	0,48	0,01	0,002	0,0008	0,004	0,004	0,47		0,01	0,002	0,0002	0,005	0,005	*		-	-	-0,0006	+0,001	+0,001
Berezne district	1,94	0,10	0,04	0,006	0,02	0,02	1,84		0,12	0,04	0,009	0,03	0,03	*		+0,02	-	+0,003	+0,01	+0,01
Volodymyrets district	1,88	0,12	0,04	0,053	0,002	0,004	1,76		0,10	0,04	0,04	0,001	0,003	*		-0,02	-	-0,013	-0,001	-0,001
Hoshcha district	1,27	0,10	0,005	0,006	0,008	0,02	1,17		0,12	0,005	0,01	0,004	0,002	*		+0,02	-	+0,004	-0,004	-0,018
Demydiv district	0,41	-	-	-	-	-	0,41		0,006	0,003	0	0,001	0,002	*		+0,006	+0,003	-	+0,001	+0,002
Dubno district	2,07	0,49	0,12	0,10	0,03	0,076	1,58		0,52	0,12	0,10	0,03	0,078	*		+0,03	-	-	-	+0,002
Dubrovytsia district	1,58	0,16	0,08	0,006	0,02	0,039	1,42		0,13	0,07	0,03	0,01	0,02	*		+0,03	-0,01	+0,024	-0,01	-0,019
Zarichne district	1,21	0,25	0,08	0,08	0,007	0,07	0,96		0,09	0,02	0,04	0,003	0,03	*		-0,16	-0,06	-0,04	-0,004	-0,04
Zdolbuniv district	5,55	2,73	0,44	0,053	1,63	0,56	2,82		2,34	0,31	0,04	1,34	0,61	*		-0,39	-0,13	-0,013	-0,29	+0,05
Korets district	1,09	0,0095	0,005	0,001	0,001	0,001	1,08		0,004	0,003	0	0,0003	0,0004	*		-0,0055	-0,002	-0,001	-0,0007	-0,0006
Kostopil district	2,45	0,48	0,16	0,004	0,089	0,17	1,97		0,49	0,16	0,002	0,098	0,17	*		+0,01	-	-0,002	+0,009	-
Mlyniv district	2,51	0,07	0,002	-	0,003	0,001	2,44		0,07	0,002	0	0,004	0,003	*		-	-	-	+0,001	+0,002
Ostroh district	0,95	0,06	0,0003	-	0,001	0,007	0,89		0,04	0	0	0,001	0,007	*		+0,02	+0,0003	-	-	-
Rivne district	3,96	1,09	0,21	0,37	0,22	0,22	2,87		1,15	0,23	0,4	0,21	0,22	*		+0,06	+0,02	+0,03	-0,01	-

Administrative units	2015							2016							(+/-) 2016 till 2015					
		including							including							including				
		stationary source					mobile source		stationary source					mobile source		stationary source				
			including							including							including			
	total	total	dust	sulphur dioxide	nitrogen dioxide	carbon oxide		total	total	dust	sulphur dioxide	nitrogen dioxide	carbon oxide		total	total	dust	sulphur dioxide	nitrogen dioxide	carbon oxide
Rokytne district	2,05	0,35	0,16	0,008	0,051	0,12	1,70		0,24	0,12	0,008	0,058	0,05	*		-0,11	-0,04	-	+0,007	-0,07
Sarny district	3,80	0,36	0,23	0,068	0,022	0,02	3,44		0,31	0,21	0,038	0,02	0,03	*		-0,05	-0,02	-0,03	-0,002	+0,01
Radyvyliv district	1,47	0,05	0,023	-	0,007	0,02	1,42		0,07	0,03	0	0,01	0,008	*		+0,02	+0,007	-	+0,003	-0,012
Total in Oblast	52,16	10,23	2,28	0,84	2,77	1,89	41,93		9,1	2,057	0,82	2,38	1,68	*		-1,13	-0,223	-0,02	-0,39	-0,21

Note: * - the estimation of air pollution emissions was not foreseen in the plan of state statistical monitoring in 2016

Table 3.13. Main contributors to air pollution in 2016

№	Enterprise	Pollutant	Percentage of pollutant emissions			Percentage of emission sources equipped with gas treatment equipment, %	Efficiency of gas treatment equipment,%	Measures aim to reduce emissions			
			Total emissions, t/per year	Total emission of the enterprise, %	Total emissions of the residential unit, %			Estimated costs, th. UAH	Actually invested from the beginning of measures, th. UAH	Emissions reduced after the measures, t/per year*	
										Expected	Actual
1	PJSC "Rivneazot"	Substances in the form of suspended solid particles (micro particles and fibers)	576,2	24,8	-	-	-	-	-	-	-
		Nitrogen compounds	1400,4	60,2	-	-	-	-	-	-	-
		Dioxide and other sulphur compounds	0,4	-	-	-	-	-	-	-	-
		Carbon oxide	307,7	13,2	-	-	-	-	-	-	-
		Total	2327,7	100	-	-	-	27848,5	6252,1	3,67	3,67
2	LLC "Svispan Limited"	Substances in the form of suspended solid particles (micro particles and fibers)	61,6	43,0	-	-	-	-	-	-	-

№	Enterprise	Pollutant	Percentage of pollutant emissions			Percentage of emission sources equipped with gas treatment equipment, %	Efficiency of gas treatment equipment,%	Measures aim to reduce emissions			
			Total emissions, t/per year	Total emission of the enterprise, %	Total emissions of the residential unit, %			Estimated costs, th. UAH	Actually invested from the beginning of measures, th. UAH	Emissions reduced after the measures, t/per year*	
										Expected	Actual
		Nitrogen compounds	22,3	15,5	-	-	-	-	-	-	-
		Carbon oxide	44,3	30,9	-	-	-	-	-	-	-
		Nonmethane volatile organic compounds	15,2	10,6	-	-	-	-	-	-	-
		Total	143,4	100	-	-	-	-	-	-	-
3	LLC "Odek" Ukraine	Substances in the form of suspended solid particles (micro particles and fibers)	45,7	17,9	-	-	-	-	-	-	-
		Nitrogen compounds	95,4	37,4	-	-	-	-	-	-	-
		Carbon oxide	107,0	42,0	-	-	-	-	-	-	-
		Total	255,0	100	-	-	-	-	-	-	-
4	PJSC "Consumers-Sklo-Zorya"	Substances in the form of suspended solid particles (micro particles and fibers)	87,3	31,7	-	-	-	-	-	-	-

№	Enterprise	Pollutant	Percentage of pollutant emissions			Percentage of emission sources equipped with gas treatment equipment, %	Efficiency of gas treatment equipment,%	Measures aim to reduce emissions			
			Total emissions, t/per year	Total emission of the enterprise, %	Total emissions of the residential unit, %			Estimated costs, th. UAH	Actually invested from the beginning of measures, th. UAH	Emissions reduced after the measures, t/per year*	
										Expected	Actual
		Nitrogen compounds	88,2	32,1	-	-	-	-	-	-	-
		Carbon oxide	70,5	25,6	-	-	-	-	-	-	-
		Total	275,0	100	-	-	-	-	-	-	-
5	Branch “Volyn-cement” of PJSC of “Dyckerhoff Cement Ukraine”	Substances in the form of suspended solid particles (micro particles and fibers)	311,7	13,7				-	-	-	-
		Nitrogen compounds	1331,2	58,5		-	-	-	-	-	-
		Dioxide and other sulphur compounds	9,0	0,4		-	-	-	-	-	-
		Carbon oxide	600,1	26,4		-	-	-	-	-	-
		Total	2275,1	100		-	-				

3.4.2 Protection of the Rivne NPP air environment

The emissions of air pollutants from stationary sources are carried out on the basis of permits issued by regional representatives of the Ministry of Environmental Protection of Ukraine No. 5620881201-1 and the permits issued by the Department of Ecology and Natural Resources of the Rivne Oblast State Administration №№ 5610700000-8, dated 23.09.2013 (validity period - 5 years), 5610700000-11 dated 27.12.2013 (validity period - 5 years), 5610700000-12, 5610700000-13 dated 24.10.2014 (validity period is not limited), 5610700000-14 dated 24.10. 2014 (validity period - 10 years) and No. 5610700000- 16 dated 24.10.2014 (validity period is not limited) [6, 18, 21].

164 stationary sources of air emissions have been inventoried in the Rivne NPP; 14 of them are equipped with gas treatment units. The biggest sources of air pollution of the Rivne NPP are the auxiliary facilities: a boiler house (BH), the diesel generators and the transport. The Rivne NPP includes 142 diesel and 148 carburant vehicles, as well as 4 diesel locomotives, 1 rail crane, 1 rail motorcar and 1 motor trolley. The transport department is equipped with a testing station to monitor the vehicle health check, the toxicity level and the exhaust smoke capacity The testing is conducted quarterly with corresponding records in the register journals.

The data on air pollution emissions from stationary sources in 2016 are given in Table 3.14 according to the form of the statistical reporting No. 2-TP (air).

The total amount of air pollutant emissions from stationery sources in 2017 equalled to 34,785 t.

Table 3.14. Air pollution emissions from stationery sources

Code of pollutants, greenhouse gases and groups	Pollutants	Emitted from the beginning of the year, t
00000	Total enterprise (excluding carbon dioxide)	34,785
01000	Metals and their compounds	0,203
03000	Substances in the form of suspended solid particles (micro particles and fibers)	2,237
04000	Nitrogen compounds	8,582
05000	Dioxide and other sulphur compounds	1,510
06000	Carbon oxide	3,356
11000	Nonmethane volatile organic compounds	18,810
12000	Methane	0,004
15000	Chlorine	0,012
16000	Fluorine and its compounds (calculated as fluorine)	0,034
18000	Cryofluorane	0,037
07000	Carbon dioxide	109,691

In compliance with the permit conditions, there was developed and approved the scheduled plan to control the established maximum permissible emissions of air pollutants and the emissions from stationary sources. According to the agreement between the Rivne NPP and the state institution "Rivne Oblast Laboratory Centre" of the Ministry of Health of Ukraine, the monitoring of air pollutant emissions ejected from stationary sources was conducted at the Rivne NPP during the reporting period (Protocol No. 45 dated 07.06.2016).

In 2017, the transport facilities of the Rivne NPP utilized 507,072 tons of diesel fuel and 397,989 tons of unleaded gasoline.

3.5 Radiation pollution of air environment

In 2016, the Rivne Regional Hydrometeorological Centre carried out the radiometric analysis of samples of atmospheric depositions at 19 observation points in 9 western oblasts, two of them are located in the Rivne Oblast – Sarny and AMCS Rivne (Table 3.15).

Table 3.15. Average monthly, maximum daily and monthly total beta activity of atmospheric precipitation, Bq/m^2 × day [6, 14]

Month	AMCS Rivne			Sarny		
	Average	Maximum	Total	Average	Maximum	Total
January	1,7	3,5	52,4	2,0	3,3	61,6
February	1,9	3,1	55,2	1,9	3,2	55,4
March	1,8	3,2	57,3	1,9	3,2	59,4
April	1,8	2,6	52,6	1,9	3,0	57,9
May	1,8	2,9	54,8	1,9	3,1	58,7
June	1,8	2,6	52,6	1,8	3,0	54,4
July	1,8	2,9	54,8	1,9	3,3	59,9
August	2,0	3,1	60,8	1,9	2,9	59,1
September	1,9	2,9	56,7	1,9	2,8	56,7
October	1,8	2,8	56,7	2,0	2,9	61,1
November	2,0	3,1	59,3	1,8	2,8	54,7
December	1,8	3,0	56,8	1,9	2,8	57,6
Total 2016	-	-	670,0	-	-	669,5

The sharp fluctuations of total beta activity index were not observed during the year. The maximum index differs from the average monthly by 1,5-2 times. The annual total beta-activity of atmospheric precipitation at the monitoring points exceeds the pre-emergency levels approximately by 1,2 times (584 Bq/m^2 is the average pre-emergency index of the annual total beta-activity of atmospheric precipitation in the former USSR). The cases of above-limit total beta activity of 110 Bq / m^2 per day were not detected at the monitoring points.

A monthly gamma-spectrometric analysis of sample of atmospheric precipitation for ^{137}Cs was carried out at the observation points of the AMCS Rivne and Sarny. The cases of above-limit maximal permissible concentration of ^{137}Cs in samples were not detected. The results of gamma-spectrometric analysis of atmospheric precipitation samples at the observation points located on the territory of the Rivne Oblast are given in Table. 3.16.

Table 3.16. Results of gamma-spectrometric analysis of atmospheric precipitation samples, Bq/m^2 × day

Meteoro-logical station	Month												Year	
	January	February	March	April	May	June	July	August	September	October	November	December	min.	max.
AMCS Rivne	0,05	0,09	0,04	0,05	0,07	0,08	0,06	0,06	0,12	0,07	0,08	0,04	0,04	0,12
Sarny	0,05	0,09	0,12	0,10	0,05	0,05	0,05	0,09	0,05	0,10	0,07	0,07	0,05	0,12

The daily monitoring of gamma exposure rate was carried out at 4 observation points: the city of Rivne (radiological laboratory), AMCS Rivne, Sarny and Dubno. The increase of gamma exposure rate at the observation points was not detected; the appearance of "new" radioactive products was not registered. The detailed analysis of the radiation situation in 2016 at the monitoring points of the Rivne Hydrometeorological Centre is given in Table. 3.17 and on Fig. 3.20.

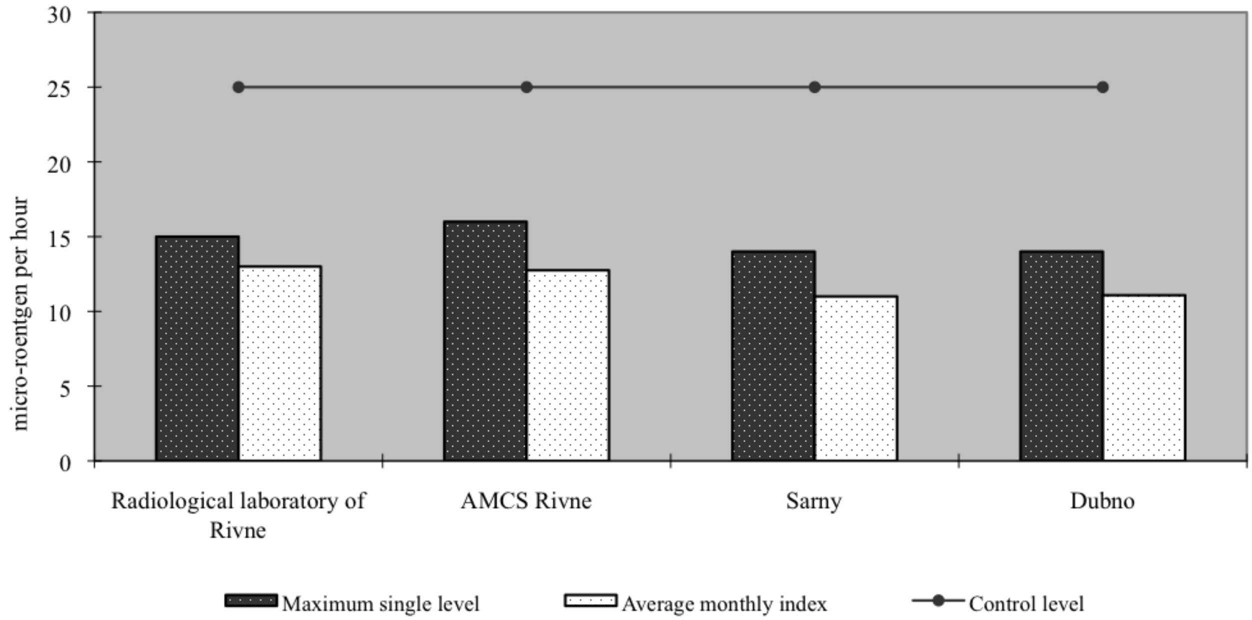


Fig. 3.20. Radiation pollution of air environment in the Rivne Oblast in 2016

Table 3.17. Gamma exposure rate, micro-roentgen per hour

Month	Radiological laboratory of Rivne			AMCS Rivne			Sarny			Dubno		
	min	max	aver	min	max	aver	min	max	aver	min	max	aver
January	11	14	13	11	14	12	10	11	11	10	11	11
February	11	14	13	11	14	13	10	11	11	10	12	11
March	11	14	13	11	14	13	10	12	11	10	12	11
April	12	14	13	11	16	13	10	12	11	10	13	11
May	11	14	13	11	14	13	10	12	11	10	12	11
June	12	15	13	11	15	13	10	12	11	9	13	11
July	11	14	13	11	15	13	10	12	11	10	13	11
August	11	14	13	11	15	13	10	14	11	10	14	12
September	12	14	13	12	16	13	10	12	11	10	13	11
October	12	14	13	10	15	12	10	13	11	10	13	11
November	11	14	13	11	14	13	10	13	11	10	12	11
December	11	15	13	10	14	12	10	12	11	10	13	11
Total 2016			13			13			11			11

The atmosphere has the potential for self-purification from pollutants. The aerosols are washed away from the atmosphere by precipitation, the ions deposit under effect of the electric field and the gravity. In the absence of atmospheric precipitation, the aerosols fall out as a result of the collision of the lower atmospheric layer with the land surface and other land objects. Therefore, the air streams containing the polluted substances are cleaned out, in contact with the green plantings. The trees absorb not only solid particles, but also the volatile substances. Particularly, the chemicals have potential to penetrate into plant tissues; the green plantings are able to minimize the impact of pollutants and many other negative factors (noise, vibration) on the human being. In the urban settlements with industrial facilities and intensive vehicles traffic, the existence of green and park areas has not only the aesthetic effect, but also a great benefit. Consequently, the priority in the urban settlements is to increase the green areas and create the green spaces of the natural-reserved fund protected by the legislation, namely the parks-monuments of garden art, the arboretums and the protection of age-old trees, etc.

3.6 Measures aim to improve air quality in the Rivne Oblast and in the Rivne NPP

The enterprises, the main contributors to air pollution, have implemented the following measures to reduce air pollution emissions [6,14,2,21] in the region in 2016:

- at the branch of “Volyn-Cement” PJSC “Dyckerhoff Cement Ukraine”, an investment project on the reconstruction, installation of filters for the refrigerator and brick conveyors of the rotary kiln No. 5, in particular, the installation and adjustment of the sack filter manufactured by RD42 company (Italy) at the cost of 5,5 UAH million;
- at PJSC Rivneazot, the renovation works of liquid ammonia storage facilities in the ammonia workshop № 1 and nitric acid workshop and the upgrading of pneumatic chamber pumps in the workshop of compound fertilizers;
- at LLC “Svyspan Limited” the sack filter BF-100 manufactured by the German company "Bison" was installed on the dry sorting line of the DSP-1 shop, the air blast and the batchbox of the pneumatic system of the Palman mill were replaced in the DSP-2 workshop, the air blast of the pneumatic system of the Palman mill was replaced in the DSP-1 workshop, the cyclone collector of the Bütner dryer № 2 was replaced in the DSP-1 workshop.

In order to reduce the emission of chemical pollutants into the atmosphere, the following technical and organizational measures are foreseen at the Rivne NPP:

- none of the permitted emissions should not exceed the maximum permissible emission level;
- the technological operation of the equipment must be carried out in accordance with the technological instructions;
- the repair and maintenance works must be carried out according to the schedules; - the technological equipment must be in proper condition;
- the application of hermetic, technological, gas treatment equipment and systems;

- timely and regular cleaning-out of gas treatment equipment;
- constant control over the health index of air discharge purification systems;
- installation of reservoirs with acids, ammonia, sodium hydroxide and lime on the pallets;
- wet cleaning in the industrial premises.

To reduce emissions of pollutants into the atmosphere, a number of stationary sources were equipped with dust and gas treatment equipment.

The main dust and gas treatment equipment used at the Rivne NPP include dry cleaning cyclones, wet dust collectors, spray gas scrubbers, various types of filters. The efficiency of air cleaning is 79,06 ÷ 99,0%.

According to the performed estimation, the dispersion of pollutants in the atmospheric air within the sanitary protection zone does not exceed the maximal permissible concentration and the emitted volumes do not exceed the permissible values, consequently, there is no need to provide additional measures aim to reduce emissions of air pollutants.

CONCLUSIONS

The Rivne Oblast is located in the northwest of Ukraine. The area of the Oblast is 20051 km^2, which is 3.1% of the total territory of Ukraine.

There are 16 administrative districts and four cities of regional subordination: Rivne, Dubno, Varash, Ostroh. In total there are 1027 urban settlements, including 11 towns, 16 urban-type settlements and 1000 rural settlements. As of 01.01.2017 the population of the region is 1162,7 thousand people.

The climate is moderately continental: a mild winter with frequent thaw periods, a warm summer, an average annual precipitation is 600-700 mm. The winter comes at the end of November and a steady snow cover is formed in the last days of December - the first decade of January. The summer is coming in late May and lasts until September. This is the period of the maximum air and soil temperatures, precipitation, and crop maturation. The rainless, cool early autumn weather is set in early September.

The Rivne Oblast is geomorphologically divided into three parts: Polissya, Volyn Forest Plateau and Male (Small) Polissya, located in the south, between the towns of Radyvyliv and Ostroh, including the spurs of the Podolian Upland with its altitudes of more than 300 meters above the sea.

The review of the meteorological and aeroclimatic parameters of the climate allows us to determine the climatic conditions of the NPP zone including the conditions that favour or slow down the process of self-purification of atmospheric air in the area of the Rivne NPP.

According to the map of climatic zonation for construction, the area of the Rivne NPP and its 30-kilometer zone are located in the second climatic region (subarea II-B), in the zone of moderate-continental climate with a positive water balance, a mild and wet winter, a relatively cool and rainy summer, a long-lasting wet autumn and an unstable weather in the transitional seasons.

The climate of the area is formed under the influence of both maritime and continental air masses. The nature and intensity of the main climatogenic factors significantly differ depending on the seasons of the year.

The climate main characteristics in the 30-kilometer zone of the Rivne NPP presented in this section are based on the records from the meteorological stations (Hydrometerological Committee of Ukraine) the nearest to the NPP and located in the perimeter of the zone at various distances from the site of the Rivne NPP :

- Lyubeshiv meteorological station - 54 km to the northwest;
- Manevichi meteorological station - 26 km to the west;
- Sarny meteorological station - 50 km to the east;
- Rivne meteorological station - 80 km to the south-southeast;
- Lutsk meteorological station - 78 km to the southwest.

The Manevichi meteorological station is the nearest station to the Rivne NPP. This meteorological station is located in a 30-kilometer zone of the NPP and it is determined as the reference station for evaluation of the principal climatic characteristics for construction and technological design of the NPP. Its representative function was established during the site screening based on the synchronic inspections performed in 1968-1970 at the temporary meteorological station located in the village of Stara Rafalivka, 9 km north of the construction site.

The aerological climate characteristics are based on the data of Shepetivka meteorological station [12], which is a reference station for the north-western territory of Ukraine. All above listed meteorological stations have long-term observation periods that ensure the reliability of the multi-year climate parameters.

The metrological conditions of the northern part of the NPP zone are recorded by Lyubeshiv meteorological station, the central and western (including the industrial area of the Rivne NPP) - Manevichi meteorological station, the eastern - Sarny meteorological station, the south-eastern and southern - Rivne meteorological station and the southwest – Lutsk meteorological station. This conditional zonation of the territory of the 30-kilometer zone helped to identify the influence of local factors of individual parts of the territory on the distribution of meteorological characteristics in the NPP zone.

The analysis of the temperature regime in the zone of the Rivne NPP shows that the temperature conditions of the eastern and southern parts of the monitoring area are somewhat different from the rest of the territory, there is some continentality here.

The air humidity parameters within the monitoring area are nearly identical:

- average annual relative humidity is 78-79%;
- average annual partial water vapour pressure - 8,7-8,9 hPa;
- saturation deficit - 3,2-3,5 hPa.

The soil temperature at a depth in the northern part of the zone is slightly lower than in the rest of the territory (0.4-0.5˚C at all levels of standard depths). In general, the average annual soil temperature at the depth of 0,4 m is 8.3-8.7˚C, at the depth of 1,6 m - 8.5-8.9˚C, at the depth of 2,4 -3,2 m - about 9˚C which was recorded on the territory of the 30-kilometer zone of the Rivne NPP.

In the cold season, the negative soil temperature remains at the depth of 0,4 m and equals to minus 0.3-1.6˚C. The soil temperature remains positive in the deep layers, but continues to decrease until March-April.

The maximum index of soil temperature at the depth of 2,4-3,2 m is observed in August-September (12.3-13.8°C), while the maximum temperature of the surface layer is recorded in July-August.

The highest index of solar radiation is observed in June-July, the lowest – in November-December. The annual amount of normal beam solar radiation in the area of the Rivne NPP is 1650 MJ/m^2, the scattered - 1870 MJ/m_2.

In the context of the year, the maximum cloudiness is observed during the cold period (8,0 – 8,1 points in general cloudiness). The lower cloudiness is mostly observed in November-December (6,0-6,8 points). The minimum cloudiness, both general and lower, is observed in August (5,0-5,2 general and 2,9-3,2 lower points). The diurnal variation of cloudiness is feebly marked in the cold period of the year; in the warm period – the maximum cloudiness is observed in the middle of the day under influence of the convection processes and less at the night.

The review of atmospheric precipitation data of the monitoring area of the Rivne NPP showed the following:

- the maximum annual amount of precipitation falls in the western, central and eastern part of the area (64-627 mm);
- to the north and south of the central part the precipitation decreases to 588 mm in the north and 579 mm in the south;
- the maximum daily precipitation is 103-119 mm;
- the prevailing wind direction during precipitation – the western and the northwest;
- the maximum long-term daily amount of precipitation in the territory of the 30-kilometer zone was not exceeded during the years of the NPP operation,
- the intensity of precipitation at different time intervals is identical for the entire zone.

The density of the snow cover depends on the weather conditions. According to the Sarny, Lutsk and Rivne meteorological stations (snow measuring records), the average density of snow cover in the first decade of January, when the fresh snow is not yet settled, equals to 98 kg/m^3 on the east and 143-150 g/m^3 on the north. By the end of January, the density of snow cover reaches its maximum (133 kg/m^3 on the east and 159-165 kg/m^3 on the south), remaining at this level almost to the loss of snow. At the maximum ten-day depth, the average density is 216 kg/m^3 on the east and 238-240 kg/m^3 on the south of the 30-kilometer zone.

The average annual amount of evaporation from the water surface in the ice-free period is 602 mm, the maximum is 946 mm and the minimum is 419 mm. During the ice-free period, the maximum average monthly amount of evaporation occurs in the summer months (110-120 mm in June-July). In the dry rain-free years, the evaporation in the summer months can increase to 198-213 mm.

The wind is a horizontal movement of air relative to the surface of the earth. The principal wind characteristics are wind speed and wind direction. Both of these characteristics are determined by the preassure (baric) area, which in our case is specific for entire Ukraine and for the irregular surface of the monitoring area.

The wind regime is the main factor determining the distribution of impurities. The wind causes the horizontal dispersion of pollutants, removes them from the source of emissions and transfer outside of the 30-kilometer zone limits.

According to the performed observations, we can estimate that the maximum wind speeds, in the mentioned gradients, in the territory of the 30-kilometer zone of the Rivne NPP, are mostly frequent in the western and north-western directions and rarely in the southwest direction (with wind speed ≥ 25 m/s). The extreme wind speeds were recorded in the southern part of the zone and reached 38 m/s (Rivne meteorological station) and 40 m/s (Lutsk meteorological station) in the north-western direction. The maximum wind speeds are usually observed during cyclone activity.

The probability of potentially dangerous tornado risk phenomenon in the limited area, which is the 30-kilometer zone of the Rivne NPP, according to [8], is estimated on the basis of the annual probability of tornado and its intensity rate. These characteristics are as follows:

- an annual probability of tornado passing through any point of the 30-kilometer zone of the Rivne NPP NP is 9.25 x 10^{-7} reactor/per year;
- an estimated intensity rate of the potential tornado is 1,92. The probability that the intensity rate of tornado will exceed is equal to 0.90 (in 90 of 100 cases the estimated intensity rate will not be exceeded).

The probability of intensive spontaneous dust storms in the northern and western regions of Ukraine (where the Rivne NPP is located) is about 5%, it means that they can occur one time in 20 years.

The fogs with visibility ≤ 100 m are observed in 7% cases in the western part of Ukraine, whereas the heavy fogs were not observed on the territory of Rivne and Khmelnytsky Oblasts.

It should be noted that the meteorological disasters have a multiple effect on the nuclear power plant - from surcharge load on the plant's facilities (strong wind, tornadoes, ice, snowfall) to creating the favourable conditions for both distribution of impurities and pollutants transfer at large distances (heavy rainfall and flood, strong wind, dust storms).

During the operation of the station, the meteorological disasters did not cause any emergency situations at the Rivne NPP.

In total, the annual capacity of the mixed layer in this area is only 540 m (the average of 800-900 m on the territory of Ukraine) which reduces the mechanism of natural self-purification of the atmospheric air in the area of the Rivne NPP.

The height frequency of the mixed layer ≤ 500 m is maximum in winter (85-92%). In this period, the mechanism of air mixing is the most complicated. In the warm period, the frequency of thin mixed layers is reduced to 32-42%, which characterizes a more intense mixing in the lower layers of the atmosphere.

In the cold period of the year, the cloud cover is observed more often (due to the cyclonic nature of the weather). In November-February, in 51-60% of cases, the cloud base is observed in the layer of up to 1.0 km and in the upper layers above1 km and equals to 40-49%. In the cold period of the year, the cloud base has the maximum frequency in the layer of 0.2-0.4 km (from 17-18% in January-February to 20-26% in November-December).

In summer, the maximum frequency of cloud base is observed in the layers of above 1 km. In the layer up to 1 km, the cloud base is extremely rare. From May to September, the cloud base at a height of 0.4-1.0 km was not observed.

The stratification of the atmosphere basically determines the height of the mixed layer. Under neutral atmospheric stability, the height of the mixed layer with an edge of less than 500 m is most frequent. The interdependency between the height of the mixed layer and the atmospheric stability can be proximately estimated by the data on the seasonal frequency of the categories (classes) of the atmospheric stability and the data on the frequency of the height of the mixed layer ≤ 500 m.

The prevalence of the stable classes of atmospheric stability and the low-strength mixed layers in the area of the Rivne NPP determines the less intense mechanisms of natural self-purification of the atmosphere in the monitoring area.

Based on the results of numerical modelling of impurities transfer and the mathematical models recommended by the IAEA, we can estimate that the industrial emission sources located outside the monitoring zone of the Rivne NPP (in the cities of Rivne and Lutsk) have a slight effect on the environmental pollution of the 30-kilometer zone of the Rivne NPP. The quality of atmospheric air is determined by emissions from enterprises that provide environmentally safe operation of the Rivne NPP.

From all above said, we can conclude that the environmental characteristics of the atmosphere within the 30-kilometer zone around the Rivne NPP have not been deteriorated during the period of the Rivne NPP operation.

The microclimate in the area of the Rivne NPP is formed under influence of the regional climate characterized by a relatively long cold period (~210 days), relatively cooler summer (average July temperature is 18.1°C), low winter temperatures and high humidity during the winter period. In summer, at the high temperatures and low humidity, the impact of the cooling units on the microclimate is much lower than in the autumn-winter period with low temperatures and high air humidity.

The steam-condensate plumes have a strong impact on the microclimatic conditions and affect the atmospheric precipitation, meteorological visibility, insolation, fog, ice glazing in the area of the Rivne NPP.

In the cold period of the year, the zone of perturbation of humidity field in the boundary layer of the atmosphere in the area of cooling towers location of the Rivne NPP is characterized by the following parameters:

- specific humidity of air emitted by the cooling towers is 5,0-5,2 g/kg (relative is close to 100%);
- maximum perturbation of a humidity field is observed at an altitude of 200 m and extends 1.5 km from the cooling towers. In total, the zone of perturbation of the humidity field is observed up to a height of 500 m and at a distance of 4,0 – 4,5 km from the centre of the cooling tower system.

The zone of maximum warming in the cold period of the year is formed at an altitude of 150-300 m and extends 2,5-3,0 km from the cooling tower system. The air temperature in the zone of temperature perturbation is in the range from minus 2,0˚C to 2,8-3,0˚C.

In the warm period, the zone of perturbation of humidity field in the boundary layer of the atmosphere is characterized by the following parameters:

- specific humidity of air emitted from the cooling tower is 8,3 – 11,2 g/kg;
- maximum perturbation of the humidity field is observed at an altitude of 150-250 m (11,2 g/kg) and extends to a distance of 1,5 km from the cooling towers. In total, the zone of perturbation of humidity field in summer is observed up to a height of 350 m and at a distance of 3.0 - 4.0 km from the centre of the cooling tower system.

According to the calculation data, the "perturbation zones" of air temperature and humidity fields near the land surface during the cold period (winter) extends from the source of emissions in the wind direction (Figures 3.5 and 3.6). The maximum surface air temperature in this case at the level of 800 to 1500 m from the cooling towers is around 1˚C above the background (ΔT = 0,89˚C), that is equal to minus 3,4˚C. At the altitude of 2,5-3,0 km from the cooling towers, the air surface temperature decreases by 0,1°C (ΔT = 0,08˚C) and can be minus 4,3˚C, that is nearly equal to the background temperature.

After dispersion in the air flow, the plume particles are modified: they enlarge in the process of coalescence, settle down and intensively evaporate. The interrelation processes, which contribute to humidity accumulation and dispersion, determine the macrophysical characteristics of the plumes, their structure, the precipitation intensity and eventually the environmental impact.

The performed calculations of visibility which are based on estimation of homogeneity and isotropy of the plume, showed that with the observed parameters of the microstructure of visibility zone in the plumes (at a distance of 500 - 1000 m), the visibility is 300 - 600 m. The measurements were taken from a helicopter and are as follows:

- 100-200 m in the nearest zone of the thick plume;
- more than 500 - 1000 m in the remote zone of the thick plume;
- formation of short and medium length plume did not significantly deteriorate the visibility.

The potential number of days when fog can cause the absolute shading is approximately 3 days during the warm period and 5 days in the cold period. The partial shading from plumes will always exist, but there are no quantitative characteristics about the duration of this phenomenon in the area of the Rivne NPP.

In the area of the Rivne NPP, in the cold period of the year, which is characterized by a small number of clear days, the factor of insolation reduction during few sunny days is quite important for estimation of the sanitary and hygienic quality of air.

The increase of air temperature and humidity due to the steam-condensate emissions of the cooling towers occurs mainly in the boundary layer of the atmosphere, at an altitude of 200 - 500 m. In the surface layer, the heat and humidity impact of the cooling towers is observed only in the immediate proximity. The increase of air temperature by about 0,5-1,0˚C in winter against the background temperature of January at a distance of up to 1 km from the cooling towers and the increase of annual amount of precipitation by 2-3% are inconsiderable. Actually, the impact of the cooling towers on the microclimate and environment outside the sanitary-protective zone is not expressed. As an exception, there can be observed some occasional ice glaze and frost.

Annually, the stationary sources of the Rivne NPP eject from 33 to 37 tons of pollutants into the atmosphere: non-metallic volatile inorganic compounds - from 18 to 25 tons, nitrogen compounds - from 5 to 9 tons, suspended solids (micro particles and fibers) - from 1.4 to 2.7 tons, sulphur compounds - from 1.4 to 2.7 tons, etc. The emissions of air pollutants of the nuclear power plant are 2-3 thousand times less than that of the coal-steam power station with a similar installed power capacity.

The SS “Rivne NPP” releases the air pollutant emissions in accordance with the emission permit conditions (Attachment A). The amount of raw materials and other materials used in 2017 does not exceed the values stipulated in the provided documents.

Taking into account the small values of chemical pollutants released in the atmosphere, it is inappropriate to provide any additional measures for emissions reduction, except for existing gas treatment units (GTUs).

The estimated annual gross emissions in total by all substances equal to 9,044 ÷ 10,335 tons/per year, which is 0,7% of the currently approved values. In the absolute values these emissions are estimated in some grams (compound of manganese, fluoride hydrogen) and 120 ÷ 150 kg (gasoline, wood dust). Consequently, the above-mentioned values do not have a significant impact on environment. This conclusion is confirmed by estimation of maximum surface concentration of these substances in the atmosphere.

Therefore, the estimation justified in this section allows us to conclude that the future operation of all 4 power units of the Rivne NPP and introduction of new sources of chemical emissions will not impact the ecological situation of the 30-kilometer zone and will not exceed the normative values of chemical (non-radioactive) pollution for residential areas.

According to the performed estimation, the dispersion of pollutants in the atmospheric air within the sanitary protection zone does not exceed the maximal permissible concentration and the emitted volumes do not exceed the permissible values, consequently, there is no need to provide additional measures aim to reduce the air pollutant emissions.

The results of Environmental Impact Assessment of the power units and the industrial site of the Rivne NPP indicate that the environmental impact of the Rivne NPP will continue to be at the same level and there are no prerequisites for the deterioration of ecological environment around the Rivne NPP.

LIST OF REFERENCES

1. The Law of Ukraine "On Environmental Impact Assessment", News of Verkhovna Rada of Ukraine (VVR), 2017, No. 29, p.315.
2. DBN A.2.2-1-2003 "Composition and Content of Environmental Impact Assessment Materials (EIA)".
3. DBN A.2.2-1-2003 "Advancement Material Guidelines on Environmental Impact Assessment".
4. Law of Ukraine "On Protection of Human Health Against the Effect of Ionizing Radiation", News of the Verkhovna Rada of Ukraine (VRU), 1995, No. 12, p.81.
5. Law of Ukraine "On Protection of Human Health Against the Effect of Ionizing Radiation", News of the Verkhovna Rada of Ukraine (VRU), 1998, No. 22, p.115.
6. Report on Environment Situation in the Rivne Oblast in 2016 / Department of Ecology and Natural Resources of Rivne Oblast State Administration, Rivne. - 2017 -224 p.
7. Physical and Geographical Zoning of the Ukrainian SSR. Edited by V.Popov, A.M. Marinin, A.I.Lanko. Edition of Kiev University, 1968.
8. Lanko AI, Marynych O. M., Shcherban M.I. Physical Geography of the Ukrainian SSR. Soviet school. K., 1969.
9. DSTU-N B V.1.1-27-2010 "Construction Climatology".
10. Scientific and Applied Reference Book on Climate of the USSR. Series 3 Long-term data. Parts 1-6. Issue 10 Ukrainian SSR. Books 1 and 2. - Leningrad: Gidrometeoizdat, 1990.
11. Archive materials of meteorological observations 1945-1997 performed by the meteorological stations of Manevichi, Sarny, Rivne, Lutsk and Lyubeshiv: air temperature and humidity, atmospheric precipitation, wind, snow cover, soil freezing, evaporation, fog, atmospheric phenomena, natural meteorological disasters. - Kyiv: Sectoral State Archive of the Central Geophysical Observatory of the State Committee of Ukraine on Hydrometeorology, 2000.
12. Report on Academic Research Work “Analysis of the Upper-air Regime of the Territory of the Khmelnytsky and Rivne NPPs. Location” - Kiev: NASU, Research Centre for Fluid Mechanics, 1999.
13. Archive materials of meteorological observations 1945-1997 performed by the Kovel meteorological station: air temperature and humidity, atmospheric precipitation, wind, snow cover, soil freezing, evaporation, fog, atmospheric phenomena, natural meteorological disasters. - Kyiv: Sectoral State Archive of the Central Geophysical Observatory of the State Committee of Ukraine on Hydrometeorology, 2000.
14. Reports on the Radiation Situation in the Area of the Rivne NPP 1981–1999. Laboratory of External Radiation Control of the Rivne NPP.– Kuznetsovsk, 2000. Letter of the Rivne Nuclear Power Plant No. 147/3276 dated 23.08.2000.

15. Basic Sanitary Standards of Radiation Safety of Ukraine (BSSU-2005).
16. OND-86 Calculation of Air Pollutant Concentrations Emitted by the Enterprises. Goskomgidromet.-Leningrad: Gidrometeoizdat, 1987.
17. DSP 201-97 State Sanitary Rules of Air Protection in the Residential Settlements against Chemical and Biological Pollution. - Kyiv: MHU, 1997.
18. Annual Report on Results of Meteorological Observations in 2017 in the Area of the Rivne NPP. 132-09-3B-18-TRB. Varash 2018, -206 pp.
19. Manual of Individual and Collective Dose Calculation for Population Caused by Radionuclides Emissions Released by the NPP. Set of Rules and Regulations on Radiation Safety in Nuclear Energy. M: 1989, T. 3, p. 19-315.
20. Non-technical Summary. Materials on the safety justification for the extension of the lifetime of the power unit № 3 of the SS "Rivne NPP" in an over-projection period./ Ministry of Energy and Coal Industry of Ukraine. State Enterprise "National Atomic Energy Generating Company" Energoatom", Rivne NPP, 2018 - 58 p.
21. Report on Impact Assessment of Non-Radiation Factors of the Rivne NPP SE NNEGC "Energoatom" on the Environment in 2017/ Ministry of Energy and Coal Industry of Ukraine. State Enterprise "National Atomic Energy Generating Company" Energoatom ", Rivne NPP, 2018 - 25 p.
22. 22.3.133. OB.02.04. Rivne NPP. Power Unit №3. Safety Analysis Report. Chapter 5 "Analysis of Non-project Emergency (ANPE)". Part 1. Additional Justifications and Development of Final Reports on ANPE. Book 4.
23. Rivne NPP. Power Unit № 4. Environmental Impact Assessment. Volume 4. Environment Characteristics and Envoronmental Impact Assessment. Book 3. Air environment and microclimate./Kiev State Institute of Engineering Survey and Research "Energoproekt", 2001. -83 p.

Attachment A

№	Document description	Date of issue	Validity terms	Permit/ licence issued by
	Air Protection			
1	Permit No. 5610700000-8 on air pollutant emissions by stationary sources of the Rivne NPP in Kuznetsovsk (TSEC RNPP)	23.09.13	23.09.18	Department of Ecology and Natural Resources* of Rivne Oblast State Administration
2.	Permit No. 5610700000-11 on air pollutant emissions by stationary sources of the Rivne NPP in Kuznetsovsk (industrial zone)	27.12.13	27.12.18	
3.	Permit No. 5610700000-12 on air pollutant emissions by stationary sources of the Rivne NPP in Kuznetsovsk (vocational school number № 12, Sports Complex, Palace of Culture)	24.10.14	unlimited	Letter of Department of Ecology and Natural Resources of Rivne Oblast State Administration №2754/04/1-09/16 dated 06.12.2016
4.	Permit No. 5610700000-13 on air pollutant emissions by stationary sources of the Rivne NPP in Kuznetsovsk (URP, ASKRO, TSGO)	24.10.14	unlimited	
5.	Permit No. 5610700000-14 on air pollutant emissions by stationary sources of the Rivne NPP in Kuznetsovsk (asphalt plant, CSR)	24.10.14	24.10.24	
6.	Permit No. 5610700000-16 on air pollutant emissions by stationary sources of the Rivne NPP in Kuznetsovsk (wastewater treatment facilities of the industrial site of the Rivne NPP)	24.10.14	unlimited	
7.	Permit No. 5620881201-1 on air pollutant emissions by stationary sources of RHC "Bile Ozero" of the Rivne NPP	28.11.11	unlimited	
	Water Resources Protection			
8.	Permit Ukr № 1/RVN on special water use of the Rivne NPP	06.08.15	06.08.20	Department of Ecology and Natural Resources of Rivne Oblast State Administration
9.	Permit Ukr № 454 / RVN on special water use of RHC "Bile Ozero" of the Rivne NPP (extended)	15.01.14	extended, unlimited	
10.	License № 458 on management of hazardous waste as per list, determined by the Cabinet of Ministers of Ukraine	02.12.15	unlimited	Ministry for Natural Resources of Ukraine
	Land and Mineral Resources Protection			
11.	Special permit on mineral resources use № 2263 (Rafalivka-1 deposit)	9.10.2000	20 years	Ministry for Natural Resources of Ukraine

APPROVED BY

________________R.V. Maraikin

Director of NT-Engineering

«25» December 2018

REPORT
ON
SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 3

Volume 2

Atmospheric air.

Radiation factor impact on atmospheric air.

Version 2

Technical Project Manager
Ph. D. I. O. Poliakova

Deputy Director
for Departmental Supervision A. H. Uskov

2018

УДК 621.039:504.064.3

МІНІСТЕРСТВО ЕКОЛОГІЇ ТА ПРИРОДНИХ РЕСУРСІВ УКРАЇНИ

НАУКОВО-ДОСЛІДНА УСТАНОВА «УКРАЇНСЬКИЙ НАУКОВО-ДОСЛІДНИЙ ІНСТИТУТ ЕКОЛОГІЧНИХ ПРОБЛЕМ» (УКРНДІЕП)

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«___» ___________ 2018 р.

ЗВІТ

За темою **«Проведення оцінки впливу на довкілля майданчику ВП «Рівненська АЕС»**

Етап 3

Вплив радіаційного фактору на атмосферне повітря (остаточна редакція)

за договором № 0709/849/2.4 от 12.04.2018 р.

Науковий керівник,
зав. лабораторії радіоекологічної
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Abstract

This report contains calculations and justification of radiation impact of radioactive releases from SS Rivne NPP on the environment and the population during normal operation and in emergency cases.

All calculations have been performed for conservative conditions of impurity propagation and radiation dose formation (at maximum doses).

It has been shown that maximum permissible values of radiation criteria for equivalent and absorbed doses in body organs and the entire body at the border and outside the sanitary protection zone, as defined by documents СП АС 88 (recommendation type of document) and НРБУ 97 (SP AS-88 and NRBU-97), are met during normal operation of power units or in case of design basis accidents.

It has been justified that in case of a beyond design basis accident, the levels of unconditional justification for urgent countermeasures are not exceeded, therefore no countermeasures of any type are necessary.

The report contains 262 pages, including 77 figures and 162 tables.

Keywords: NPP, radiation dose, volumetric activity in the air, soil surface fallout, radiation accident.

CONTENTS

ABBREVIATIONS

ES	design basis accident “Steam generator header cover lift-up - Emergency spike”
SFP	Spent fuel pool
SS	Separate Subdivision
LLN	long-lived nuclides
RNPP	Rivne Nuclear Power Plant
BDBA	beyond design basis accident
IRG	inert radioactive gases
IAEA	International Atomic Energy Agency
MDA	minimum detectable activity
ICRP	International Commission on Radiological Protection
MDBA	maximum design basis accident
BSRRS	Basic Sanitary Rules on Radiation Safety
DBA	design basis accident
PES	design basis accident “Steam generator header cover lift-up - Pre-emergency spike”
HLD-SFP	design basis accident “Hydraulic lock drop in the spent fuel pool”
FAD-SFP	design basis accident “Fuel assembly drop on the reactor core and FA top nozzles in the spent fuel pool”
SFCD	design basis accident “Spent fuel container drop from a height of more than 9 meters”
FADR	design basis accident “Fuel assembly drop on the reactor core in the rector”
ITR	design basis accident “Impulse tube rupture beyond the containment”
PCDLR	design basis accident “Planned cool down line rupture”
PBPR	design basis accident “Rupture of the process blow off pipeline for cleaning in the process blow off system of the reactor building”
SPZ	sanitary protection zone
RAWT	radioactive water treatment

INTRODUCTION

This report is aimed at assessing the impact of air radioactive releases from SS Rivne NPP on the environment and population. The assessment is performed for both normal operation and for design basis accidents. The study method selected is mathematical modelling, which is based on actual operating conditions at SS Rivne NPP and on territorial specifics of the region under study.

Safety assessment of SS Rivne NPP activities is based on the requirements of the laws and regulations of Ukraine, namely limit human radiation doses as set forth in documents НРБУ 97 and СП АС-88 (NRBU-97 and SP AS-88) [1, 2].

1 MODELS USED TO ASSESS IMPACT OF RADIOACTIVE ATMOSPHERIC RELEASES FROM SS RIVNE NPP

1.1 Models used for normal operation

Modelling of atmospheric propagation of radioactive substances and formation of doses dependent on radionuclide releases from SS Rivne NPP during normal operation was carried out using software suites PC CREAM [3, 4] by National Radiological Protection Board (UK) and CAP-88 by Environmental Protection Agency (USA). These software suites are designed for assessing radiation impact of radionuclide releases during normal (accident-free) operation, i. e. impurities transport models are intended for continuous release, while dose factors and risk assessment methods are intended for chronic low-level exposure (significantly below LD_{50} (LD_{50} is radiation dose that causes death of 50 % of radiation-exposed objects; human LD_{50} is ~2-3 Gy [5]).

Codes are based on Pasquill atmospheric stability classes (PC CREAM may also use Durie classification), and so meteorological files have been developed and prepared for use in models based on the available meteorology data [6–10].

The frequency of wind directions for each atmospheric stability class is accounted in PC CREAM and in CAP-88 using the following formula:

$$A_i(x,z) = \sum_j f_{i,j} A_{i,j}(x,z),$$

where $f_{i,j}$ is frequency of wind direction within a specified sector (i) for atmospheric stability class j; x is distance from the source.

1.1.1 PC CREAM

PC CREAM software suite and its separate modules are described in [3, 4]. The system is designed for calculating radiation impact of continuous (accident-free) air releases and river/sea discharges of radioactive substances. The key features of the software suite are:

✓ assessment of individual and collective doses from air releases and sea discharges, as well as individual doses from river discharges;

✓ effective doses (as per ICRP Publication No. 60 [11]) are calculated using dose factors from ICRP Publication No. 72 [12] (ICRP recommendations are also used when developing radiation safety regulations in Ukraine);

✓ three age groups are considered: infants under 1 YOA, children under 10 YOA and adults;

✓ reference data include averaged releases and discharges per year;

✓ the suite allows for choosing from 5 integration times (1, 50, 500, 1000 years and infinity) for collective doses and from 3 integration times (1, 5 and 50 years) for individual doses. The dose integrated by n years for 1 year of release and/or discharge is numerically equal to an average dose on n^{th} year for continuous release and/or discharge;

✓ air release models take into account all irradiation exposure pathways, while water discharge models do not take into account the possibility of water use for agricultural irrigation.

In PC CREAM, atmospheric dispersion is assessed using Gaussian model, dry deposition using source depletion model, wet deposition using washout factors. The atmospheric dispersion model used accounts for sedimentation of a single daughter product during spot motion. Following deposition, radionuclide transport is represented by separate compartment models for soil and food products.

External air radionuclide exposure is calculated in PC CREAM using finite and infinite cloud models for gamma and beta irradiation, respectively.

Plume dispersal

Plume dispersal is modelled by modified Gaussian equation [13]:

$$\overline{A}(x,z) = \frac{Q}{(2\pi)^{\frac{3}{2}} x \sigma_z \mu} \sum_{s=0}^{\infty} \exp\left[-\frac{(2sL \pm h_{эфф} \pm z)^2}{2\sigma_z^2}\right], \qquad (1.1)$$

where

$\overline{A}$ is average activity in air in point (x, z), Bq/m^3

Q is radionuclide stack emission rate, Bq/s;

x is downwind distance, m;

μ is average wind speed, m/s;

σ_z is vertical dispersion factor, m;

h_{eff} is effective stack height, m;

L is mixing height, m;

s is 0, 1, 2, 3, etc.

PC CREAM uses fixed wind rate and mixing height values for each atmospheric stability class in Table 1.1.

Table 1.1 - Wind rate and mixing height values used in PC CREAM

Pasquill stability class	Wind rate at 10 m, m/s	Mixing height, m	Rain
A	1	1300	No
B	2	900	No
C	5	850	No
D	5	800	No
E	3	400	No
F	2	100	No
C	5	850	Yes
D	5	800	Yes

Dispersion factors

Vertical dispersion factor σ_z, which is used to calculate dispersion:

$$\sigma_z = \frac{ax^b}{1+cx^d} F(z_0, x), \quad (1.2)$$

$F(z_0, x)$ is correction for ruggedness:

$$F(z_0, x) = \ln\left(fx^g \left[1 + \frac{1}{hx^j} \right] \right), \text{ at } z_0 > 0.1 \text{ m}, \quad (1.3)$$

$$F(z_0, x) = \ln\left(fx^g \left[\frac{1}{1 + hx^j} \right] \right), \text{ at } z_0 \leq 0.1 \text{ m}, \quad (1.4)$$

where z_0 is soil ruggedness height, m; see values of a, b, c and d factors in equation (1.7) and f, g, h and j in equations (1.8) and (1.9) in Table 1.2.

Table 1.2 - Factors to calculate vertical dispersion factor and factors for ruggedness correction

Pasquill stability class	a	b	c	d
A	0.112	1.06	5.38×10^{-4}	0.815
B	0.130	0.950	6.52×10^{-4}	0.750
C	0.112	0.920	9.05×10^{-4}	0.718
D	0.098	0.889	1.35×10^{-3}	0.688
E	0.0609	0.895	1.96×10^{-3}	0.684
F	0.0638	0.783	1.36×10^{-3}	0.672

Soil ruggedness, m	f	g	h	j
0.01	1.56	0.0480	6.25×10^{-4}	0.45
0.04	2.02	0.0269	7.76×10^{-4}	0.37
0.1	2.72	0	0	0
0.4	5.16	-0.098	18.6	-0.225
1.0	7.37	-0.0957	4.29×10^{3}	-0.60
4.0	11.7	-0.128	4.59×10^{4}	-0.78

Plume depletion

Dry deposition

Dry deposition model is as follows: $R_{dry} = V_r \cdot A$, where R_{dry} is radionuclide deposition rate per unit area (Bq/(m^2·s)); V_r is deposition rate (m/s); A is concentration of radionuclides in the surface air layer (Bq/m^3).

Wet deposition

Fraction of radionuclides deposited from the plume with rain or snow is modelled using the following equation:

$$R_{wet} = \frac{\Phi Q'_{wet}(t)}{x\alpha\mu},$$

where: R_{wet} is surface deposition rate (Bq/(m^2·s)); Φ is washout factor (s^{-1}); $Q'_{вл}$ is radionuclide activity that remains within the plume when a point under consideration is reached (x (m) from the release point) over the entire time (t) (Bq/m^3):

$$Q'_{вл}(t) = \frac{Q_0 f_{wet}}{m_1 - m_2}\left[(m_1 + \Phi)e^{m_2 t} - (m_2 + \Phi)e^{m_1 t}\right],$$

$$2m_1 = -(\Phi + P_{dry} + P_{wet}) - \sqrt{(\Phi + P_{dry} + P_{wet})^2 - 4\Phi P_{dry}},$$

$$2m_2 = -(\Phi + P_{dry} + P_{wet}) + \sqrt{(\Phi + P_{dry} + P_{wet})^2 - 4\Phi P_{dry}},$$

$$f_{wet} = P_{dry}/(P_{dry}+P_{wet}),$$

P_{dry} and P_{wet} are dry and wet weather probabilities, respectively; α is sector angular width, rad; μ is average wind speed.

Depletion factor

Fraction of radionuclides depleted from the plume:

$$F = F_{wet} \cdot F_{dry} \cdot F_{decay}.$$

Fraction of radionuclides depleted with precipitation:

$$F_{wet} = \frac{f_{wet}}{m_1 - m_2}\left[(m_1 + \Phi)e^{m_2 t} - (m_2 + \Phi)e^{m_1 t}\right].$$

Fraction of radionuclides depleted by dry deposition:

$$F_{суу} = \left[\exp F_{0dry}(x)\right]^{V_z/\mu},$$

$$\text{where } F_{0cyx}(\mathrm{x}) = -\sqrt{\frac{2}{\pi}} \int_0^x \frac{1}{\sigma_z} \left\{ \exp\left[-\frac{h_{eff}^2}{2\sigma_z^2} \right] + \exp\left[-\frac{(h_{eff} + 2L)^2}{2\sigma_z^2} \right] \right\} dx$$

at $\sigma_z(x) < L$, and $F_{0dry}(x) = F_{0dry}(x_L)-(x-x_L)/L$ with $\sigma_z(x) \geq L$. x_L here is such that $\sigma_z(x_A) = L$.

Fraction of radionuclides depleted from the plume by radioactive decay:

$F_{decay} = \exp(-\lambda x/\mu)$. Daughter product concentrations are calculated by substituting Q with QR_d in equation (1.6), where:

$$R_{\text{д}} = \frac{\lambda_{\text{д}}}{\lambda_{\text{м}} - \lambda_{\text{д}}} \left[\exp\left\{ -\lambda_{\text{д}} \frac{x}{\mu} \right\} - \exp\left\{ \lambda_{\text{м}} \frac{x}{\mu} \right\} \right],$$

λ_d, λ_m here are decay constants for daughter and mother radionuclides, respectively.

Migration model for agricultural plants

The migration scheme is shown in Fig. 1.1. Link 1 is topsoil with uniformly distributed activity. Link 2 is aerial parts of plants, which are directly contaminated with radioactive fallout, Link 3 is aerial parts of plants, which are contaminated with soil grains during harvesting, Link 4 is root systems of plants, Link 5 is subsoil layer that contains roots. Constants k_{ij} (s^{-1}) correspond to transitions between links, which are due to the following processes: k_{12} - secondary radioactive fallout; k_{21} - sweeping-away with wind and rainwash; k_{13} - contamination of aerial parts of plants with soil grains during harvesting; k_{14} - root absorption; k_{15} - draining out of the root soil layer; k_{22}, k_{33}, k_{44} - periodic harvesting; k_{31}, k_{41} are formal migration constants that provide for nuclides balance within links 1, 3, 4. See values of migration constants in Tables 1.3 and 1.4.

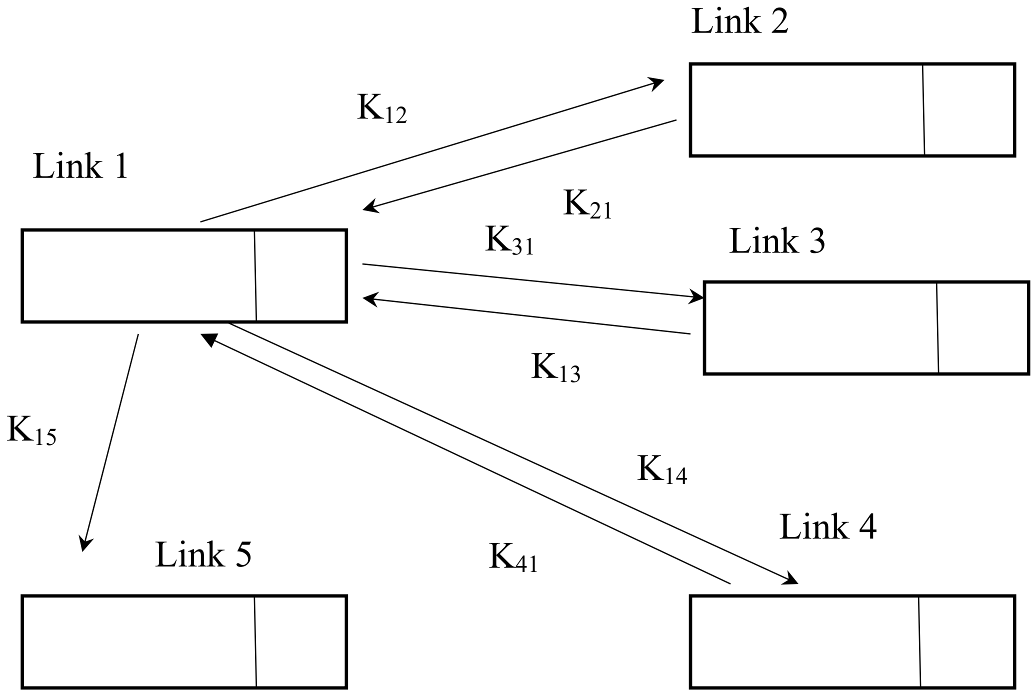


Fig. 1.1 - Radionuclide migration scheme for agricultural plants

Table 1.3 - Migration constants for agricultural plants (common for all chemical elements), s^{-1}

Migration constant	Grain crops	Other agricultural plants	Migration constant	Grain crops	Other agricultural plants
k_{12}	7-9	7-9	k_{41}	1	1
k_{21}	2.7-4	2.7-4	k_{15}	2.2-10	2.2-10
k_{13}	8.9-9	4.4-8	k_{22}, k_{33}	3.2-8	3.2-8
k_{31}	1	1	k_{44}	3.2-8	3.2-8

Table 1.4 - Migration constants for agricultural plants (dependent on chemical elements), k_{14}, s^{-1}

Element	Grain crops	Other agricultural plants	Element	Grain crops	Other agricultural plants
Cr	2.7-7	6.7-7	Ru	5.3-5	8.9-6
Mn	2.7-5	6.7-5	Ag	1.8-4	4.4-4
Fe	3.6-7	4.4-7	Sb	8.9-6	2.2-5
Co	8.9-6	2.2-6	Te	8.9-4	2.2-3
Zn	3.6-4	8.9-4	I	1.8-5	4.4-5
Rb	8.9-5	2.2-4	Cs	5.3-6	4.4-5
Sr	1.8-5	1.6-3	Ba	4.4-6	1.1-5

Element	Grain crops	Other agricultural plants	Element	Grain crops	Other agricultural plants
Y	2.7-6	6.7-6	La	2.7-6	6.7-6
Zr	1.8-7	4.4-7	Ce	2.7-6	1.6-5
Nb	8.9-6	2.2-5	Np, Pu	8.9-10	2.2-7
Mo	8.9-5	2.2-4	Am, Cm	8.9-19	2.2-7
Tc	4.4-2	0.11			

Mathematical models for dose calculation

Individual dose calculation based on food chains

Individual doses based on the food exposure route are calculated assuming that only local food products are consumed. This assessment provides for maximum possible radiation levels under the given conditions. These levels nearly always exceed the actual doses, since a certain share of non-local food products is usually present in food ration. For some of these products, like dairy, leaf vegetables or fruits from private garden plots, these estimates may be quite close to actual values. Based on the above assumption, the average rate for individual annual effective dose $\dot{H}$, Sv/s, of uniform fallout $\dot{A}_S$, Bq/(m^2·s), given the steady balance of environmental radionuclide accumulation/depletion processes, is calculated as follows:

$$\dot{H} = \dot{A}_S K_{fi}^{ind} B_{ig},$$

where B_{ig} is a dose factor of internal radiation exposure when radionuclides are ingested with water or food, Sv/Bq; K_{fi}^{ind} is factor that connects fallout intensity when radionuclides are ingested by a separate person with food, m^2:

$$K_{fi}^{ind} = K_{fi}\overline{S}, \qquad (1.7)$$

where K_{fi} is a dimensionless factor that characterises loss of radionuclides during migration within the food chain, cooking and storage; $\overline{S}$ is agricultural area required for producing certain food products that are consumed individually, m^2. This parameter is calculated in PC CREAM using the following formulas:

for products of plant origin:

$$\overline{S} = \frac{I_{m,}}{P_y},$$

where P_y is annual yielding capacity of the culture under consideration, kg/m^2; I_m is annual individual consumption of this culture, kg;

for products of animal origin:

$$\overline{S} = \left(\frac{I_m}{P_a}\right)\sum_i \overline{S}_{a,i},$$

where I_m is annual individual consumption of meat or milk, kg (l); P_a is annual productivity of one animal (average annual increase in meat or milk per one animal, kg (l); $\overline{S}_{a,i}$ is area of ith feed crop per one animal. This parameter is calculated using the following formula:

$$\overline{S}_{a,i} = \frac{I_{a,i}}{P_{y,i}},$$

where $P_{y,i}$ is annual yielding capacity of ith feed crop, kg/m^2; $I_{a,i}$ is its annual consumption by one animal, kg.

Value K_{fi} in (1.7) is a dimensionless factor that characterises loss of radionuclides during migration within the food chain, cooking and storage. When agricultural areas required to produce certain food products are considered, then this factor is a share of that part of the total total fallout per given area of radionuclides, which will remain in products until consumed. Values of factor K_{fi} vary for different radionuclides, food products, local weather conditions, soil type, and fallout conditions (short-term or continuous).

Individual radiation doses (direct exposure)

Direct exposure means external radiation from photons and β-particles of radionuclides that are found in the air and fall out onto soil, as well as internal radiation by radionuclides that enter the body with air (inhalation route). In these cases individual doses are formed immediately in the release source area.

Photon radiation dose from a radiation cloud

Dispersed radionuclides may be sources of photon radiation. The radiation gas- or aerosol-induced dose in this case largely depends on the physical and chemical form of radionuclides and, naturally, on the radiation type and energy [13].

Source shaped as a semi-infinite space

During continuous release at a variable wind pattern and other weather parameters, a radioactive cloud is simulated by a source shaped as a semi-infinite space with activity A_V, Bq/m^3, uniformly distributed by volume. Effective dose rate, Sv/s, is then calculated using the following formula:

$$\dot{H} = A_V B_{a\gamma}, \qquad (1.8)$$

where $B_{a\gamma}$ is a dose factor of internal photon radiation, Sv·m^3/(s·Bq). For radiation 2π-geometry:

$$B_{a\gamma} = \frac{E1{,}602 \cdot 10^{-13} r}{2w\rho}, \qquad (1.9)$$

where $E = \sum_i n_i E_i$ is photon energy efficiency, MeV/decay (n_i is absolute efficiency in decay scheme, photon/decay; E_i is ith photon energy, MeV/photon); $1.602 \cdot 10^{-13}$ is energy equivalent, J/MeV; r = 1.09 is a factor of conversion from absorbed air dose into equivalent dose in biological tissue, Sv/Gy; $\rho = 1.293$ is air density under normal conditions, kg/m^3. 2 is a factor that takes into account the 2π-geometry of human radiation. w is Gray's energy equivalent per 1 kg of irradiated medium (in this case, air), w = 1 J/(Gy·kg).

Based on the UOM selected, dose factor (1.9) is represented as follows:

$$B_{a\gamma} = 2.13 \cdot E \ \mu Sv \cdot m^3/(year \cdot Bq)$$

Photon radiation dose from radionuclides that fall out on soil

Correlation between release rate $\dot{Q}$ (Bq/s) and effective dose rate $\dot{H}$ (Sv/s):

$$\dot{H} = \dot{A}_S B_{S\gamma} \tau_{ef}, \qquad (1.10)$$

where τ_{ef} is effective period that takes into account radioactive decay and radionuclide soil depletion; it is calculated using the formula $\tau_{ef} = [(T_{1/2}\ T_b)/(T_{1/2} + T_b)]/0,693$, where $T_{1/2}$ and T_b are radioactivity half-life and biological half-life; $\dot{A}_S$ is contamination intensity, Bq/(s·m^2); dose factor $B_{S\gamma}$, Sv·m^2/(s·Bq) characterises effective dose rate of contaminated soil; it depends on the form of contamination and the type photon contamination distribution.

Dose of external β-radiation

Source: contaminated air

Doses in this case are calculated using the "immersion method", simulating source in a shape of a semi-infinite space. 2π radiation geometry shall be always observed for β-radiation. Equivalent dose rate for exposed (not protected by clothes) biological tissue $\dot{H}$, Sv/s:

$$\dot{H} = A_V B_{a\beta}, \qquad (1.11)$$

where A_V is volumetric activity, Bq/m^3; $B_{a\beta}$ is a dose factor of external β-radiation, Sv·m^3/(s·Bq). See $B_{a\beta}$ values in Table 1.5.

Table 1.5 - Dose factors in basal layer, which are induced by β-particles and electrons from radionuclide conversion, which are found in a semi-infinite radioactive cloud, $B_{a\beta}$, Sv×m^3/(hour×Bq)

Nuclide	$B_{a\beta}$	Nuclide	$B_{a\beta}$	Nuclide	$B_{a\beta}$
^{14}C	2.16×10^{-8}	^{99m}Te	1.78×10^{-8}	^{137}Xe	2.78×10^{-6}
^{41}Ar	7.62×10^{-7}	^{103}Ru	7.18×10^{-8}	^{138}Xe	1.10×10^{-6}
^{51}Cr	9.68×10^{-11}	$^{106}Ru/^{106}Rh$	2.19×10^{-6}	^{137}Cs	2.87×10^{-7}
^{54}Mn	4.04×10^{-10}	^{124}Sb	6.46×10^{-7}	^{135}Cs	5.43×10^{-8}
^{59}Fe	1.77×10^{-7}	^{125}Sb	1.48×10^{-7}	^{136}Cs	1.77×10^{-7}
^{58}Co	5.37×10^{-10}	^{125m}Te	1.06×10^{-7}	^{137}Cs	4.16×10^{-7}
^{60}Co	1.36×10^{-7}	^{127m}Te	6.00×10^{-8}	^{138}Cs	1.91×10^{-6}
^{85m}Kr	4.41×10^{-7}	^{127}Te	4.03×10^{-7}	^{140}Ba	5.05×10^{-7}
^{85}Kr	3.89×10^{-7}	^{129m}Te	4.14×10^{-7}	^{140}La	9.31×10^{-9}
^{87}Kr	2.10×10^{-6}	^{129}Te	9.02×10^{-7}	^{141}Ce	2.83×10^{-7}
^{88}Kr	5.85×10^{-7}	^{131m}Te	2.46×10^{-7}	^{144}Ce	1.19×10^{-7}
^{89}Kr	1.93×10^{-6}	^{132}Te	8.68×10^{-8}	^{144}Pr	1.95×10^{-6}
^{86}Rb	1.07×10^{-6}	^{129}I	1.92×10^{-8}	^{147}Pm	6.30×10^{-8}
^{88}Rb	3.06×10^{-6}	^{131}I	3.44×10^{-7}	^{154}Eu	4.31×10^{-7}
^{89}Rb	1.44×10^{-6}	^{132}I	8.79×10^{-7}	^{155}Eu	2.60×10^{-8}
^{89}Sr	9.32×10^{-7}	^{133}I	7.19×10^{-7}	^{239}Np	3.87×10^{-7}
^{90}Sr	3.02×10^{-7}	^{134}I	1.05×10^{-6}	^{238}Pu	9.81×10^{-11}
^{90}Y	1.49×10^{-6}	^{135}I	6.93×10^{-7}	^{239}Pu	8.70×10^{-9}
^{91}Y	9.85×10^{-7}	^{131m}Xe	1.98×10^{-7}	^{240}Pu	9.81×10^{-11}
^{95}Zr	1.91×10^{-7}	^{133m}Xe	3.19×10^{-7}	^{241}Pu	3.69×10^{-13}
^{95}Nb	2.62×10^{-8}	^{133}Xe	1.62×10^{-7}	^{242}Pu	7.56×10^{-10}
^{90}Mo	6.73×10^{-7}	^{135m}Xe	1.80×10^{-7}	^{241}Am	3.17×10^{-10}
^{99}Tc	1.14×10^{-7}	^{135}Xe	5.99×10^{-7}	^{242}Cm	1.01×10^{-14}

Source: skin surface contamination

See values of conversion dose factor $B_{S\beta}$, Sv·cm²/(year·Bq), based on the epidermis thickness, in Table 1.6.

Table 1.6 — Dose factor of external basal layer radiation with β-particles and electrons from radionuclide conversion in case of uniform contamination of skin with radioactive substances, $B_{S\beta}$, Sv×cm²/(year×Bq)

Nuclide	Epidermis thickness Δx, mg/cm²			Nuclide	Epidermis thickness Δx, mg/cm²		
	7	4	40		7	4	40
^{14}C	2.9×10^{-3}	7.9×10^{-3}	0.0	^{135}I	1.8×10^{-2}	2.2×10^{-2}	6.5×10^{-3}
^{32}P	2.1×10^{-2}	2.4×10^{-2}	1.1×10^{-2}	^{134}Cs	1.2×10^{-2}	1.6×10^{-2}	2.7×10^{-3}
^{60}Co	9.9×10^{-3}	1.6×10^{-2}	2.5×10^{-4}	^{137}Cs	1.4×10^{-2}	2.0×10^{-2}	2.3×10^{-3}
^{65}Zn	2.3×10^{-4}	3.3×10^{-4}	1.0×10^{-5}	^{137m}Ba	2.1×10^{-2}	2.4×10^{-3}	1.2×10^{-3}

Nuclide	Epidermis thickness Δx, mg/cm²			Nuclide	Epidermis thickness Δx, mg/cm²		
	7	4	40		7	4	40
^{90}Sr	1.6×10^{-2}	2.4×10^{-2}	3.4×10^{-3}	^{140}Ba	1.7×10^{-2}	2.2×10^{-2}	5.0×10^{-3}
^{90}Y	2.1×10^{-2}	2.4×10^{-2}	1.2×10^{-2}	^{140}La	2.0×10^{-2}	2.4×10^{-2}	9.2×10^{-3}
^{95}Zr	1.2×10^{-2}	1.7×10^{-2}	7.4×10^{-4}	^{144}Ce	8.9×10^{-3}	1.5×10^{-2}	1.7×10^{-4}
^{95}Nb	2.3×10^{-3}	6.4×10^{-3}	1.8×10^{-5}	^{144}Pr	2.2×10^{-2}	2.4×10^{-2}	1.3×10^{-2}
^{106}Rh	2.2×10^{-2}	2.5×10^{-2}	1.4×10^{-2}	^{203}Hg	9.6×10^{-3}	1.6×10^{-2}	3.7×10^{-4}
^{131}Te	2.3×10^{-2}	2.8×10^{-2}	1.0×10^{-2}	^{210}Bi	1.9×10^{-2}	2.3×10^{-2}	7.4×10^{-3}
^{132}Te	7.0×10^{-3}	1.3×10^{-2}	4.7×10^{-5}	^{214}Bi	2.0×10^{-2}	2.3×10^{-2}	9.6×10^{-3}
^{129}I	1.9×10^{-3}	5.7×10^{-3}	0.0	^{235}U	1.1×10^{-3}	3.1×10^{-3}	2.9×10^{-7}
^{131}I	1.5×10^{-2}	2.1×10^{-2}	3.0×10^{-3}	^{237}Np	6.8×10^{-4}	4.3×10^{-3}	0.0
^{132}I	1.9×10^{-2}	2.3×10^{-2}	8.2×10^{-3}	^{238}Np	1.2×10^{-2}	1.8×10^{-2}	3.5×10^{-3}
^{133}I	1.9×10^{-2}	2.3×10^{-2}	7.6×10^{-3}	^{239}Np	2.3×10^{-2}	3.6×10^{-2}	1.2×10^{-3}

Internal radiation dose induced by radioactive gas inhalation

Annual effective doses of internal radiation due to inhalation of contaminated air are calculated using the following formula:

$$\dot{H} = QGVB;$$

where $\dot{H}$ is the annual effective dose, Sv, Q is release, Bq/year, G is average annual meteorological dilution factor, s/m^3, V is inhalation rate, m^3/s. The conversion dose factor B, Sv/Bq, characterises the expected effective dose induced by nuclide inhalation with an activity of 1 Bq.

1.1.2 CAP-88

CAP-88 is a software suite to assess compliance with the Clean Air Act of 1988, which is a set of software programs and databases for assessing doses and risks related to radionuclide ingress in atmospheric air. CAP-88 software suite is described in [14]. The system is intended for assessing doses and risks related to radionuclide ingress in atmospheric air and, moreover, allows calculating the following parameters:

- ✓ concentration of radionuclides in the air;
- ✓ amount of radionuclides deposited on the ground surface;

- ✓ concentrations of radionuclides in food products (concentrations in food products, greengrocery, dairy and meat consumed by humans are calculated using ground food chain models as recommended by IAEA);
- ✓ amount of radionuclides that enter human body with food produced in areas under consideration.

The assessment is performed for a round grid of distances and directions with an 80 km (50 miles) radius around the source.

The software suite is not intended for assessing short-time radionuclide releases or high-rate releases, since the dose and risk assessment only applies to low-rate chronic radiation.

The database includes 825 nuclides and 13 decay chains. Build up factors include all isotopes from the necessary chains. The chain length can be selected independently. Dose factors depend on the radionuclide chemical form. Organ doses are calculated for 23 internal organs. Risk of radiation-induced death is calculated for 15 carcinogenic areas in a human body.

CAP-88 applies modified Gaussian equation to the release plume in order to assess average radionuclide dispersion from multiple sources (up to 6 sources, however all sources are modelled as if they are located at the same point, and the same mechanism for migrating plume formation is used for each source). CAP-88 allows consideration of both point sources (stacks) and area sources (tailing dumps, waste dumps).

Dry deposition is calculated using a source depletion model, while wet deposition is calculated using washout factors. Ground surface and soil concentrations are calculated for the buildup period of 100 years taking into account radionuclide soil depletion rate of 2 % per year. The time of exposure in CAP-88 during dose and risk assessment is 50 years.

The dose and risk are assessed using combined impact of radionuclides incorporated by humans via inhalation, food consumption or external radiation from air or ground radionuclides. Methodology from ICRP Publication No. 60 [11] was used.

Mathematical model

Air dispersion of impurities

Model of dispersion in the air is built based on the modified Gaussian equation:

$$A = \left(\frac{Q}{2\pi\sigma_y\sigma_z\mu}\right)\cdot\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\cdot\{\exp[-0.5\cdot(z-H)/\sigma_z)^2]+\exp[-0.5\cdot(z+H)/\sigma_z)^2]\}, \quad (1.13)$$

$\overline{A}$ is mean air activity at point (x, z), Bq/m^3;

Q is radionuclide air intake rate, Ci/s;

μ is wind speed, m/s;

σ_y, σ_z are horizontal and vertical dispersion factors, m.

Equation (1.13) provides the following expression for radionuclide surface air concentrations along the centre-line of the outward plume (where y and z are set to zero):

$$A_0 = (Q/\pi\sigma_y\sigma_z\mu)\times\exp[-0.5\times(H/\sigma_z)^2].$$

Angle sector-average surface air concentrations (22.5° around the plume centre-line) are calculated using the following equation:

$$A_{avg} = f\cdot A_0, \text{ where}$$

$$f = \int_0^\infty \exp\left[-0.5*\left(y/\sigma_y\right)^2\right]dy/y_s = \sigma_y(\pi/2)^{1/2}/y_s \text{ , and}$$

$$y_s = \tan(11.5°)\cdot x.$$

When the above expression is inserted, sector-average surface air nuclide concentration is as follows:

$$A_0 = (Q/0.15871\pi x\sigma_z\mu)\cdot\exp[-0.5\cdot(H/\sigma_z)^2].$$

This sector-based averaging method compresses the plume within the limits of each of 16 interrelated 22.5° sectors. This method is not accurate for unstable Pasquill classes, in which horizontal dispersion is high enough to go well beyond the sector limits.

As a portion of input data, a mean "upper limit" value is provided for the area under assessment. The "upper limit" is considered not to impact the plume until x (downwind distance) becomes equal to 2x, where 2x is the value x, for which $\sigma_z = 0.47L$ (L is the "upper limit" height). Vertical dispersion is limited for values above 2x, and radionuclide air concentration is considered to remain unchanged from the ground level to the "upper limit".

Mean concentration between the ground and the "upper limit", which is a surface air concentration for values above 2x, may be expressed as follows:

$$A_{cp} = \left(\int_0^{\infty} A dz \right) \Big/ L,$$

where A is taken from equation (1.1). Expression (1.15) integration result is as follows:

$$A_{avg} = (Q/2.5066\sigma_y\mu)\cdot\exp(-y^2/2\sigma_y^2).$$

Sector-average air concentration of radionuclides may be obtained by substituting exponential expression in (1.16) with f (equation (1.14)):

$$A_{avg} = Q/0.397825xL\mu.$$

It should be noted that for downwind distances above 2x, dispersion (1.17) may not be described using Gaussian equation any more. This model is a plain model of uniform distribution over a rectangle with dimension LID and 2x·tan(11.5°).

The frequency of wind directions for each atmospheric stability class is accounted using the following formula:

$$A_i(x,z) = \sum_j f_{i,j} A_{i,j}(x,z) \ ,$$

where $f_{i,j}$ is frequency of wind direction within a specified sector (i) for atmospheric stability class j; x is distance from the source.

Dispersion factors

Horizontal and vertical dispersion factors σ_y and σ_z, which are used to calculate dispersion and the share of radionuclides being depleted, are different functions of downwind distance x for each Pasquill stability class in open space conditions. See Table 1.7.

Table 1.7 — Horizontal and vertical dispersion factors as functions of downwind distance

Pasquill stability class	σ_y	σ_z
A	$0.22x(1+0.0001x)^{-1/2}$	$0.2x$
B	$0.16x(1+0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1+0.0001x)^{-1/2}$	$0.08x(1+0.0002x)^{-1/2}$
D	$0.08x(1+0.0001x)^{-1/2}$	$0.06x(1+0.0015x)^{-1/2}$
E	$0.06x(1+0.0001x)^{-1/2}$	$0.03x(1+0.0003x)^{-1/2}$
F	$0.04x(1+0.0001x)^{-1/2}$	$0.016x(1+0.0003x)^{-1/2}$

Plume depletion

The total content of impurities in the plume during its migration with the average wind is reduced due to dry deposition, rain- and snow wash (wet deposition) onto the ground, radioactive decay and changes die to radioactive conversion within the mother radionuclide chain. The first three processes are described using the so-called depletion factor $F = Q'/Q$, which is a share of the nuclide amount that remains within the plume until it moves away for distance x from the point of radionuclide entry into atmospheric air. The first two processes of atmospheric elimination result in formation of a flow of impurities fallout onto the ground.

Dry deposition

Dry deposition model is such that dry deposition is proportional to the radionuclide surface air concentration: $R_{dry} = V_r \cdot A$, where R_{dry} is radionuclide deposition rate per unit area (pCi/(cm^2·s)); V_r is deposition rate (cm/s); A is radionuclide concentration in the surface air (pCi/cm^3).

V_r proportionality constant is generally above the actual constant value, i. e. the measured radionuclide ground deposition rate. V_r shall include radionuclide deposition due to interception of radioactive precipitation by leaves that later fall on the ground and, therefore, increase the deposition amount. The default values of deposition rates used by CAP-88 equal $3.5 \cdot 10^{-2}$ m/s for iodine, $1.8 \cdot 10^{-3}$ m/s for aerosols and 0 m/s for gases.

Wet deposition

Fraction of radionuclides washed from the plume with rain or snow is modelled using the following equation:

$$R_{wet} = \Phi \cdot A_{avg} \cdot L,$$

where R_{wet} is surface deposition rate (pCi/(cm^2×s)); Φ is washout factor (s^{-1}); A_{avg} is average radionuclide concentration within the plume up to the "upper limit" (pCi/cm^3); L is "upper limit" height (tropospheric mixing level, mixing height).

The washout factor is calculated in CAP-88 by multiplying the annual precipitation share (cm/year) by 1×10^{-7} year/(cm×s).

Depletion factor

Fraction of radionuclides removed from the plume (ratio of the amount of released radionuclides, which is reduced due to the above factors, Q′ to the initial amount of released radionuclides Q) for each value of downwind distance x, in this case, consists of 3 components:

$$F = Q'/Q = (Q'/Q)_{wet} \cdot (Q'/Q)_{dry} \cdot (Q'/Q)_{decay} = F_{wet} \cdot F_{dry} \cdot F_{decay}.$$

Fraction of radionuclide depletion with precipitations for each value of downwind distance x is as follows:

$$F_{wet} = \exp(-\Phi t),$$

where Φ is washout factor (s^{-1}); t is time (s) necessary for the plume to reach downwind distance x.

Fraction of radionuclides removed from the plume due to dry deposition is derived from (1.13) by equating value z to zero (for surface concentrations):

$$F_{cyy} = \exp\left\{-(2/\pi)^{1/2} \cdot (V_{dry}/\mu)\int_0^x \left(\exp\left(-(H - V_z x/\mu)^2 / 2\sigma_z^2\right)/\sigma_z\right)dx\right\}.$$

The values of removed fraction for cases when V_r equals zero are derived from a separate sub-program of CAP-88. The sub-program uses the removed fraction values calculated for a sequence of radionuclide release heights and downwind distances using Simpson's rule, under the following condition: $V_{wet} = 0.01$ m/s and μ = 1 m/s for each Pasquill stability class. The sub-program converses these values using linear interpolation into an appropriate value for the desired wind direction, radionuclide release height and Pasquill stability class, and adjusts it to the actual deposition rate and wind speed.

Radionuclide removal from the plume for downwind distances above 2x (equation (1.4)) is modelled using the following equation: $Q'_x / Q'_{2xL} = \exp\left[-\left(V_{cyx}(x - 2x_L)/L\mu\right)\right]$, to calculate the reduction in released radionuclide fractions at distances x and 2x, respectively.

Fraction of radionuclides depleted from the plume by radioactive decay: $F_{decay} = \exp(-\lambda_r t)$, where λ_r is effective constant of decay within the plume. λ_r is not an valid constant of radioactive decay in all cases considered. For instance, if a radionuclide is a short-lived product of decay, which is in balance with a long-lived mother isotope, then the effective decay constant would be equal to the valid decay constant for the mother isotope.

CAP-88 calculates the reduction in radionuclide fractions eliminated due to radioactive decay and radionuclide losses due to precipitations using an approximate calculation method that establishes 3 wind speed values (1 m/s, average wind speed and 6 m/s) to build a model of actual wind distribution spectrum by speed values for each separate wind direction and Pasquill stability class.

Ground surface concentrations

Ground surface and soil concentrations are calculated for radionuclides that are subject to dry deposition and washout. Buildup time for total deposition is set to 100 years. This value sets a 100-year period of time following the radionuclide release, i. e. it is considered that a significant internal intake of radionuclides or external radiation due to radionuclide deposition of ground surface may occur during this period. Following deposition, radionuclide transport is calculated using separate compartment models for soil and food products.

Gain on the mother radionuclide is calculated using the decay product gain factor, which is a correlation between decay product concentration released from a single fraction of the deposited mother radionuclide and the decay product itself, respectively. These factors are calculated for a 100-year buildup period, taking into account radionuclide soil (surface) depletion rate, which is equal to 2 % per year.

1.1.3 Other parameters used in calculations

See Table 1.8 for radioactive release indices during normal operation, which were used in calculations. These values have been calculated based on the actual data on releases of inert radioactive gases (IRG), radioiodine, and radioactive aerosols (long-lived radionuclides, LLN) from Rivne NPP. Calculations also include NPP releases of radiocarbon, which are not controlled by direct measurements. Isotopic composition of IRG, radioiodine and LLN has been calculated based on the available references [15, 16], if the isotopes were not measured by direct measurements at NPP.

Table 1.8 - Radioactive releases from SS Rivne NPP, which are used in calculations

Radionuclide	Rivne NPP release, Bq/year
Cs-137	6.28E+06
Cs-134	9.66E+05
Co-60	7.27E+06
Co-58	1.09E+06
Mn-54	1.22E+06
Cr-51	4.56E + 06
Sr-90	2.60E+05
Zr-95	5.80E+05
Nb-95	2.23E+06
H-3	1.01E+12
C-14*	1.99E+11
Kr-87**	2.35E+12
Xe-133**	1.69E+13
Xe-135**	4.23E+12
I-131***	9.43E+07
I-133***	5.04E+07
I-135***	1.31E+07

* values calculated based on literature references [15, 16];

** releases of these radionuclides have been calculated based on Table 1.9 [17] and actual IRG releases (Table 1.10–1.11);

*** values calculated based on literature references [16] and actual iodine-131 releases (Table 1.10–1.11).

Table 1.9 – Content IRG and Iodine

Radionuclide	Content ratio in IRG mixture, k_n	Radionuclide	Content ratio in iodine mixture, k_i
^{88}Kr	0.10	^{131}I	0.60
^{133}Xe	0.72	^{133}I	0.32
^{135}Xe	0.18	^{135}I	0.08

Table 1.10 - Annual gas-aerosol radioactive air releases by

SS Rivne NPP facilities

Radiation parameter	Year	VS, units No. 1, 2	VS-1, unit No. 3	VS-2, unit No. 3	VS-1, unit No. 3	VS-2, unit No. 4	Aux. build. VS, units No. 3, 4	RNPP
IRG, GBq/year	2013	2.92E+04	7.96E+03	1.10E+03	4.36E+03	1.07E+02	4.72E+03	4.75E+04
	2014	2.71E+04	8.05E+03	7.97E+02	9.22E+03	3.23E+02	4.24E+03	4.97E+04
	2015	1.78E+04	8.38E+03	7.90E+02	8.77E+03	6.32E+02	4.23E+03	4.06E+04
	2016	2.02E+04	5.71E+03	1.44E+03	4.72E+03	1.70E+02	9.48E+02	3.32E+04
	2017							3.52E+04
LLN, GBq/year	2013	1.20E-01	1.88E-02	9.39E-04	1.11E-02	6.10E-04	4.43E-02	1.96E-01
	2014	1.01E-01	1.64E-02	1.03E-03	1.11E-02	4.85E-04	4.02E-02	1.70E-01
	2015	1.22E-01	1.40E-02	6.13E-04	9.36E-03	5.50E-04	3.63E-02	1.83E-01
	2016	8.44E-02	1.18E-02	4.02E-03	7.28E-03	1.77E-04	2.93E-02	1.37E-01
	2017							9.97E-02
Iodine, GBq/year	2013	6.11E-02	5.12E-03	7.19E-03	2.59E-03	1.83E-04	8.79E-03	8.51E-02
	2014	2.48E-01	2.22E-03	2.55E-04	4.22E-03	2.03E-04	6.90E-03	2.62E-01
	2015	2.21E-01	2.49E-03	2.75E-04	1.55E-02	1.88E-03	8.54E-03	2.50E-01
	2016	7.14E-02	1.30E-03	4.08E-04	1.59E-03	1.01E-04	4.18E-03	7.90E-02
	2017							4.14E-02

Table 1.11 - Gas-aerosol radioactive releases into vent stacks of Rivne NPP

Nuclide	Activity, GBq				
	2013	**2014**	**2015**	**2016**	**2017**
IRG	4.75E+04	4.97E+04	4.06E+04	3.32E+04	3.52E+04
Iodine	8.50E-02	2.62E-01	2.50E-01	7.90E-02	4.14E-02
Cr-51	1.19E-02	4.76E-03	1.49E-02	5.11E-03	1.86E-03
Mn-54	1.68E-03	1.40E-03	3.79E-03	1.17E-03	8.65E-04
Co-58	2.03E-03	1.08E-03	3.39E-03	1.24E-03	6.86E-04
Fe-59	1.02E-03	6.39E-04	9.67E-04	3.40E-04	2.23E-04
Co-60	1.43E-02	1.14E-02	2.06E-02	8.38E-03	5.29E-03
Nb-95	4.78E-03	3.75E-03	6.81E-03	2.11E-03	1.57E-03
Zr-95	4.41E-03	1.30E-03	1.70E-03	6.81E-04	4.13E-04
Ag-110m	1.62E-02	4.24E-03	8.95E-03	8.05E-03	5.04E-03
Cs-134	2.62E-03	7.64E-04	2.48E-03	1.11E-03	1.04E-03
Cs-137	1.30E-02	7.71E-03	1.67E-02	7.59E-03	5.70E-03
Sr-90	4.13E-04	6.03E-04	4.88E-04	3.71E-04	3.77E-04
H-3	1.33E+03	1.15E+03	1.60E+03	1.66E+03	1.63E+03

See Table 1.12 [17] for values of standard food consumption rates used in calculations.

Table 1.12 - Annual food consumption by humans (kg×year^{-1})

Food product	Reference age				
	1 year	5 years	10 years	15 years	Adult
Spring wheat, grain	0.3	0.5	0.7	0.7	0.9
Spring wheat, flour	1.4	3.0	3.7	4.4	5.5
Autumn wheat, grain	2.2	4.7	5.8	6.6	8.4
Autumn wheat, flour	12.8	26.6	33.2	36.5	47.5
Rye, grain	0.8	1.8	2.2	2.5	3.2
Rye, flour	3.4	6.9	8.8	10.2	12.8
Oat	1.1	1.1	1.4	1.6	2.0
Potato	16.4	12.8	21.9	30.3	58.4
Leaf vegetables	10	13	14	15	18
Root vegetables	7.7	8.8	10.6	12.0	12.0
Fruit vegetables	4.4	13.1	15.0	16.8	17.2
Fruits	54.8	26.3	33.2	36.5	43.8
Berries	0	3.7	4.4	5.1	5.1
Milk	204.4	51.1	65.7	76.7	84.0
Condensed milk	0	4.0	5.1	5.8	6.6
Cream	0	3.5	4.7	5.1	5.8
Butter	0	2.2	3.5	4.4	6.6
Hard cheese	0	3.7	5.1	6.9	9.5
Soft cheese	0	2.4	3.2	4.4	6.2
Beef	0.5	6.6	6.9	8.4	9.9
Pork	1.4	26.3	28.5	32.9	39.4
Poultry	0.5	4.0	4.4	5.1	6.2
Eggs	1.8	6.6	9.1	13.1	15.7

CAP-88 calculates food product rates using parameters typical of Volodymyretskyi District of Rivne Region, as follows: agricultural land - 21.13 %, beef breed pastures - 1.22 units/km^2, dairy breed pastures - 2.42 units/km^2.

According to the weather observation data at RNPP in 2013–2017, special CAP-88 meteorological files, which take into account atmospheric stability classification and wind speed, have been developed for calculation purposes. The amount of precipitation based on the observation data in 2006-2017 is 563.79 mm/year, average temperature is 8.94 °C, conservatively assumed average mixing layer height is 560 m.

1.2 Models used during accidents

Modelling of atmospheric propagation of radioactive substances and formation of radiation doses dependent on radionuclide releases during accidents was carried out using software suite PC COSYMA by National Radiological Protection Board (UK). Based on Publication No. 103 of the International Commission on Radiological Protection (ICRP), which overviews certain principles of radiation impact assessment compared with previous publications No. 60 and No. 72, on which the software suite and regulations NRBU-97 and BSRRS are based, this report uses two methods of effective radiation dose assessment. In the future, during comparison of the calculated values with the standards adopted in Ukraine, the method, which produces higher dose values shall be used. This way, conservative approach to assessment is preserved.

PC COSYMA (Code System for MARIA) is a software suite used to model impact of accidental air release of radioactive substances. PC COSYMA was developed by joint efforts of National Radiological Protection Board (UK) and Forschungszentrum Karlsruhe (Germany) within the framework of MARIA (Methods for Accidental Radiation Impact Assessment) project of the European Commission.

PC COSYMA suite and its separate modules are described in [18].

The system allows assessing the following parameters and impacts:

– surface air volumetric activity of radionuclides and activity of radionuclides deposited on the ground surface at certain points within the area;

– expected individual and collective doses within the selected periods;

– number of people covered by countermeasures (shelter, evacuation, dispensing of stable iodine tablets, relocation, deactivation, restricted use of agricultural products), and area on which countermeasures (accidental release measures) are taken;

– amount of agricultural products prohibited for use;

– number of latent and non-latent diseases;

– economic cost of countermeasures and treatment.

The system may be used for deterministic and probabilistic assessment. Deterministic assessment allows calculating the impact for a single user-specified set of weather conditions, while probabilistic assessment takes into account probable variations of weather conditions as may occur during the accident.

Impurities air transport models are built in MUSEMET module. This module utilises a model of segmented Gaussian spot that takes into account hourly wind speed and direction changes, atmospheric stability classes and amounts of precipitation, which impact the released substances. The model assumes that weather conditions in the entire affected area are identical. Hourly changes in weather conditions are only taken into account in probabilistic assessment. Deterministic assessment assumes that weather conditions (wind speed and direction, atmospheric stability class and amount of precipitation) remain unchanged throughout the entire period of time under consideration. MUSEMET utilises the mixing layer height as well as horizontal and vertical dispersion factors, which are functions of atmospheric stability. Dispersion factors have two parameter values for smooth (agricultural areas) and rugged (cities) ground surfaces.

Deterministic assessment method in this report is used for a single worst case weather category (critical approach).

The system may take into account the following pathways of human exposure: external gamma radiation from radionuclides in a release cloud; internal radiation from inhaled radionuclides in a release cloud; external beta radiation from radionuclides deposited on skin and clothes; external gamma radiation from radionuclides deposited on the ground surface; internal radiation from radioactive dust wind-swept from the ground surface; internal radiation from contaminated food products.

The conservative ratio of iodine isotope chemical forms is as follows:

- ✓ 91 % of released iodine remains in its molecular (elemental) form;
- ✓ 5 % is released as aerosol;
- ✓ 4 % is released in organic form.

Weather conditions for accidents have been selected based on calculated population radiation doses, i. e. the worst case weather conditions, which result in maximum dose values (conservative approach). See Appendix A for detailed analysis of various weather conditions.

Weather conditions of stability class F, heavy precipitation (25 mm/hour) and wind speed of 1 m/s are used to calculate the maximum expected population radiation doses in the immediate vicinity of the NPP at the border of the sanitary protection zone (2.5 km).

Weather conditions of stability class F, moderate precipitation (0.3 mm/hour) and wind speed of 0.5 m/s are used to calculate the maximum expected population radiation doses at the border of the observation zone (30 km).

Weather conditions of stability class F, no precipitation and wind speed of 0.5 m/s are used to calculate the maximum expected population radiation doses in a transboundary context.

This report deals with the following accidents with radioactive release according to method [19]:

- ✓ Maximum design basis accident.
- ✓ Steam generator header cover lift-up - Emergency spike.
- ✓ Steam generator header cover lift-up - Pre-emergency spike.
- ✓ Hydraulic lock drop in the spent fuel pool.
- ✓ Fuel assembly drop on the reactor core and FA top nozzles in the spent fuel pool.
- ✓ Spent fuel container drop from height of more than 9 meters.
- ✓ Fuel assembly drop on the reactor core in the rector.
- ✓ Impulse tube rupture beyond the containment.
- ✓ Planned cool down line rupture.
- ✓ Rupture of the process blow off pipeline for cleaning in the process blow off system of the reactor building.

The report also deals with beyond design basis accidents.

2 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES FROM SS RIVNE NPP DURING NORMAL OPERATION

2.1 Soil surface fallout and surface air volumetric activities of radionuclides

Fig. 2.1−2.3 show the results of radionuclide surface air activity calculations as function of distance, and Fig. 2.4−2.6 show the results of calculations for fallout density on the ground surface.

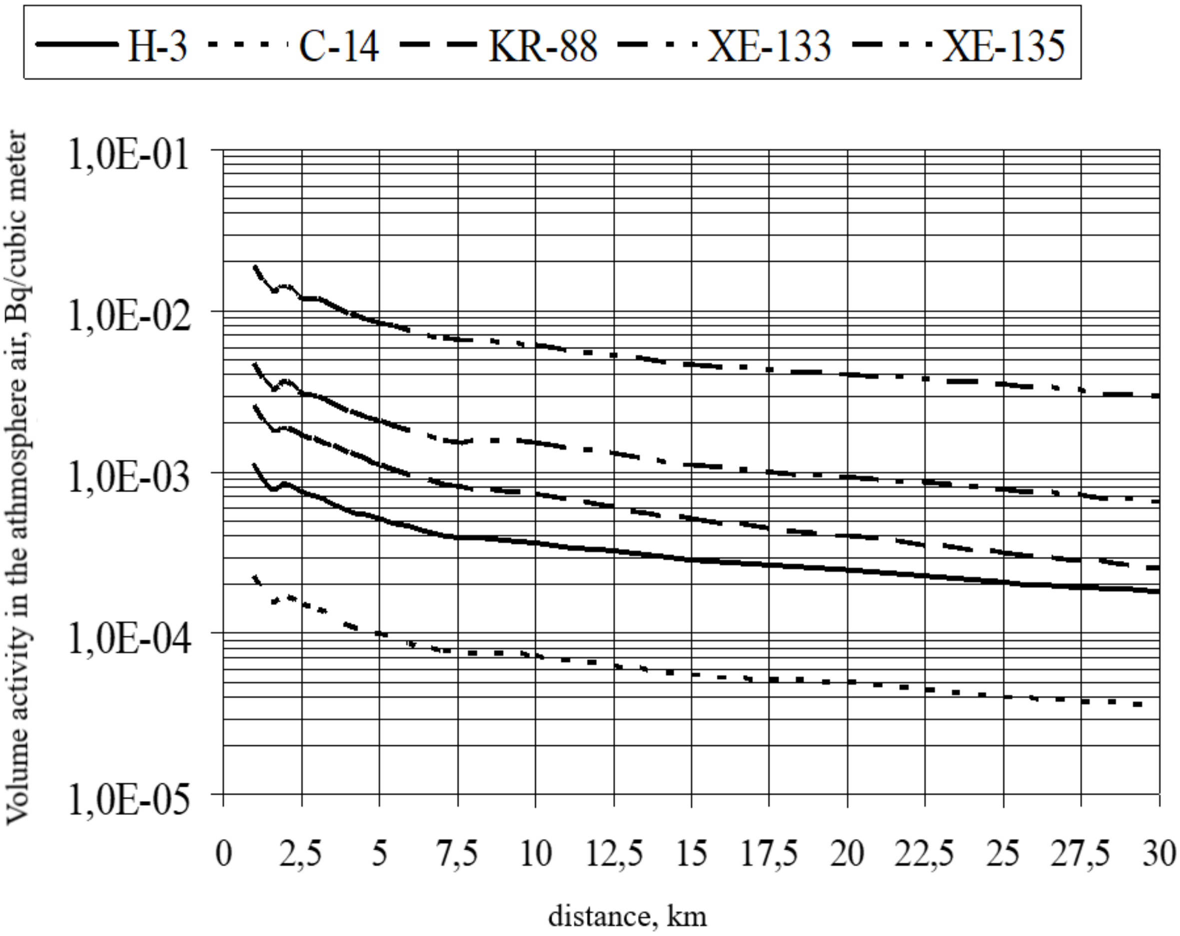
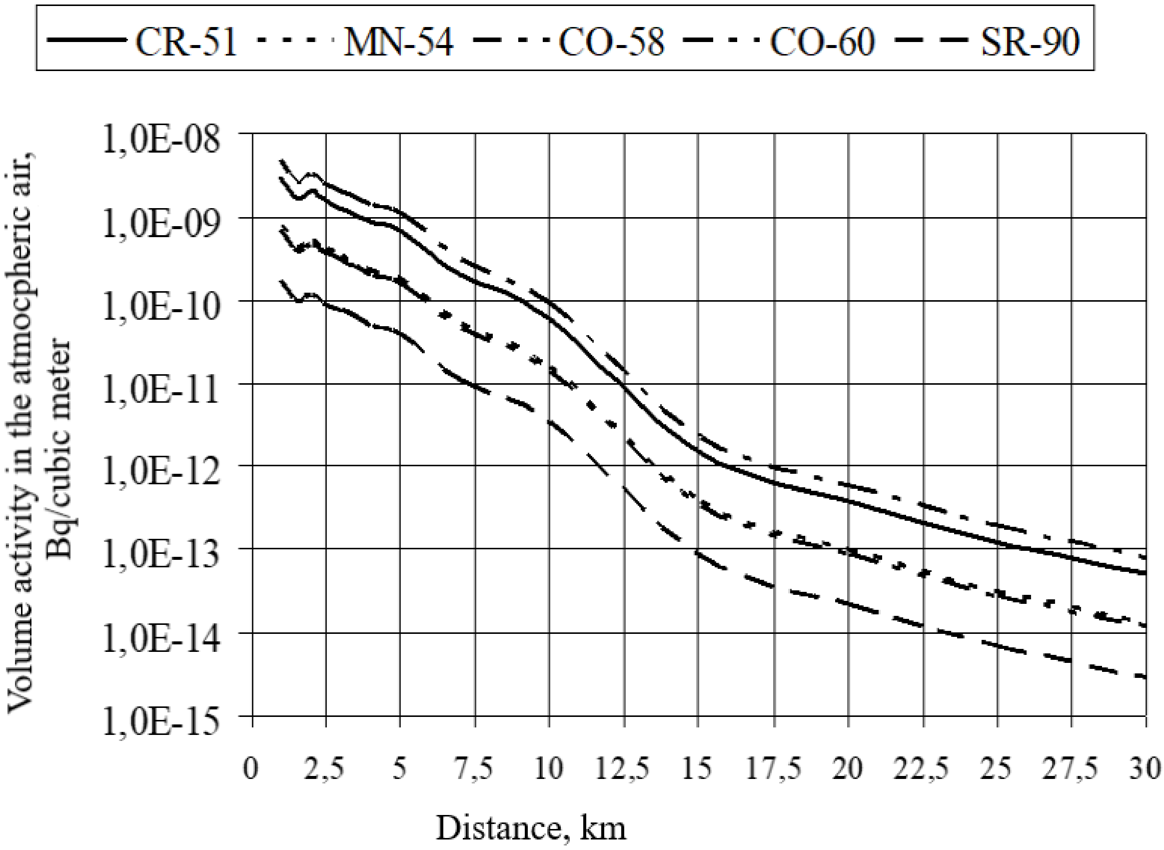


Figure 2.1 - Distance dependence of expected volumetric activity of IRG, hydrogen-3 (H-3) and carbon in surface air



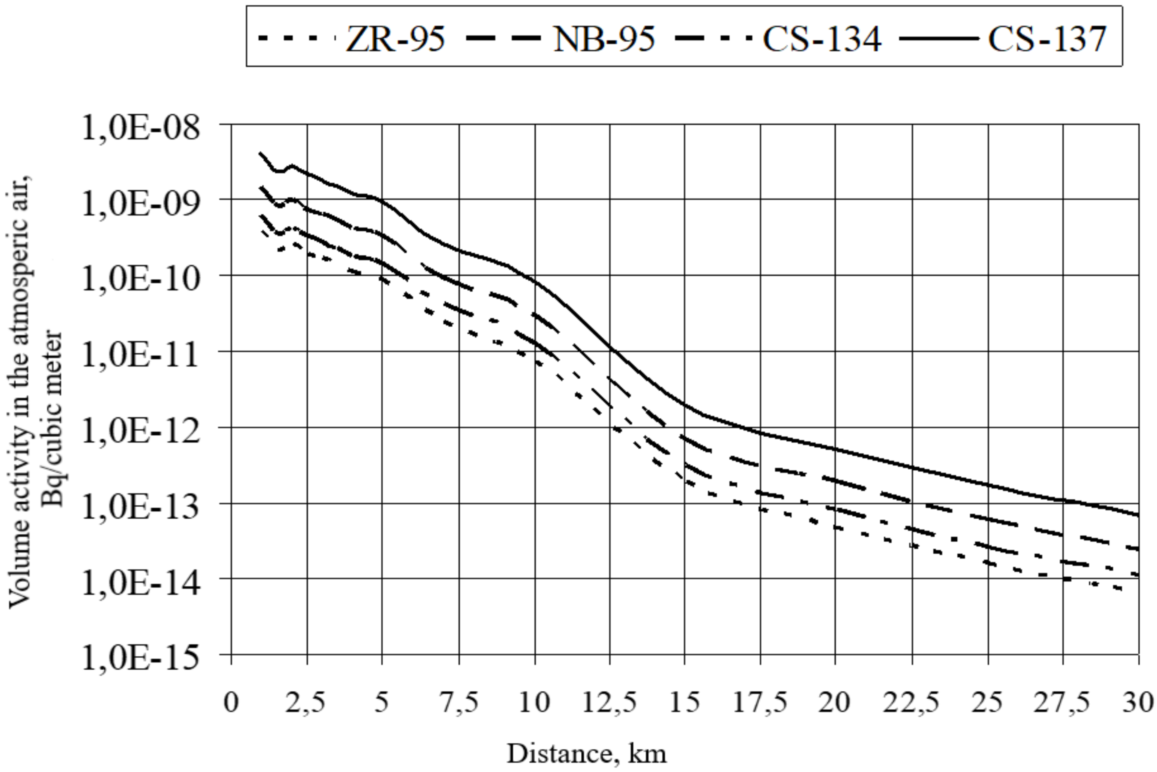


Figure 2.2 - Distance dependence of expected volumetric activity of LLN in surface air

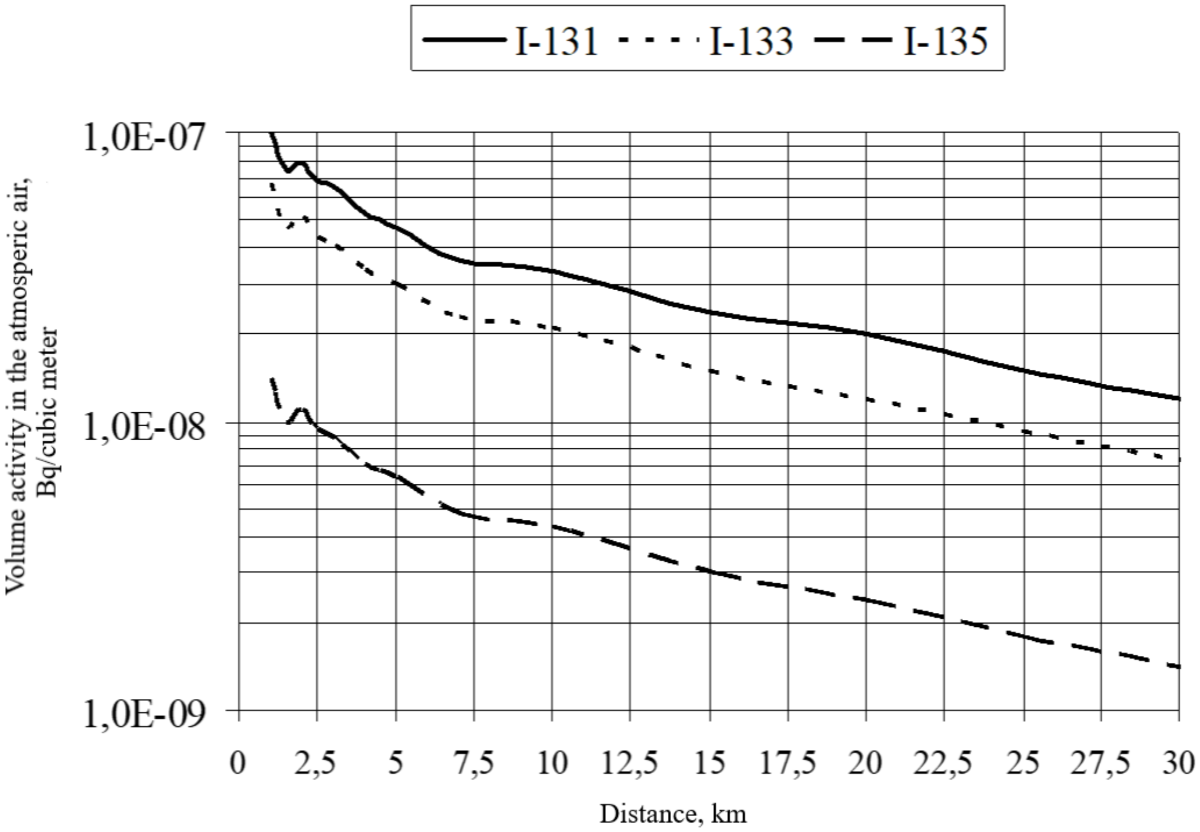


Figure 2.3 - Distance dependence of expected volumetric activity of iodine isotopes in surface air

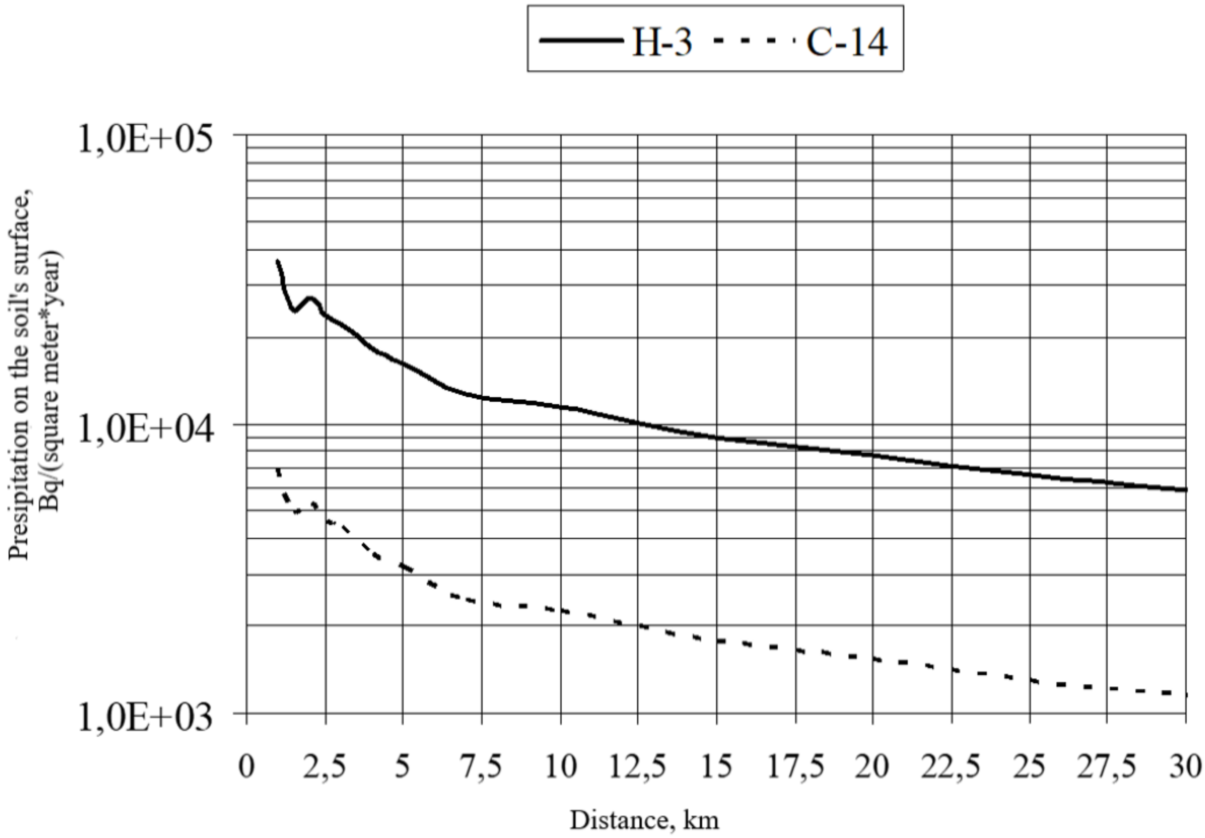
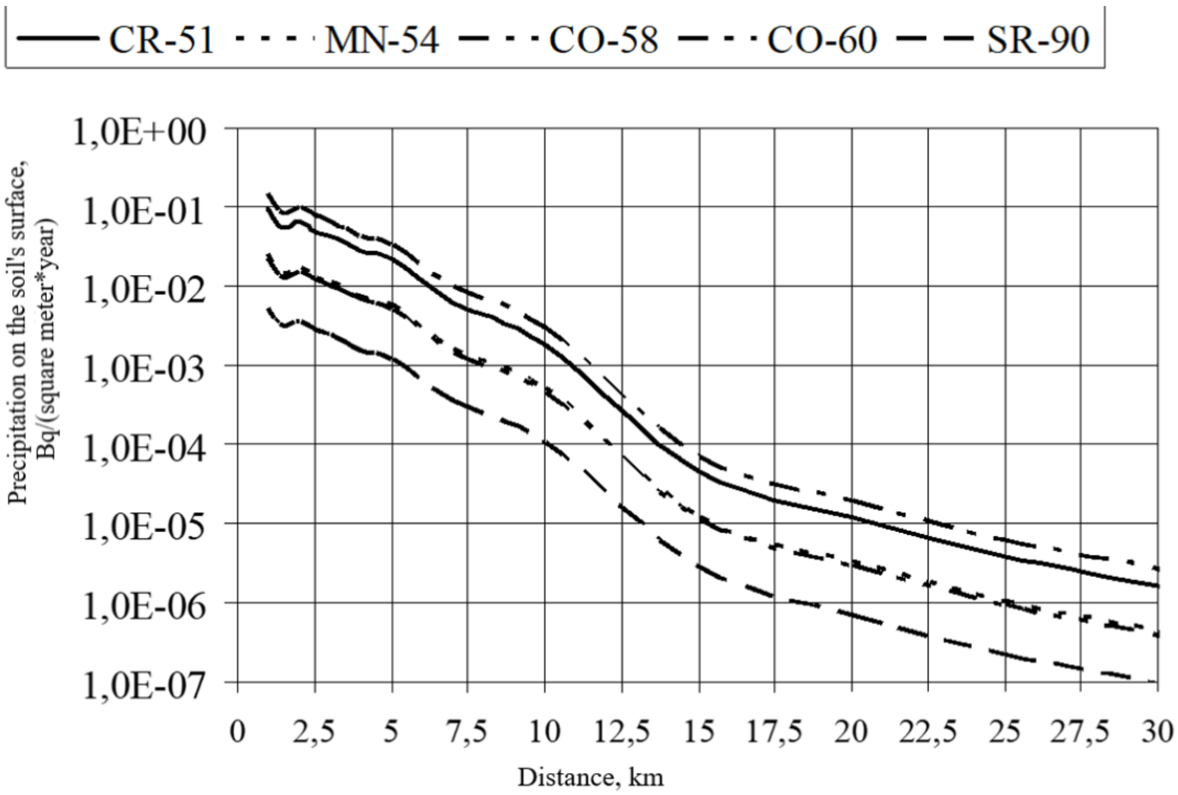


Figure 2.4 - Distance dependence of expected H-3 and carbon soil fallout



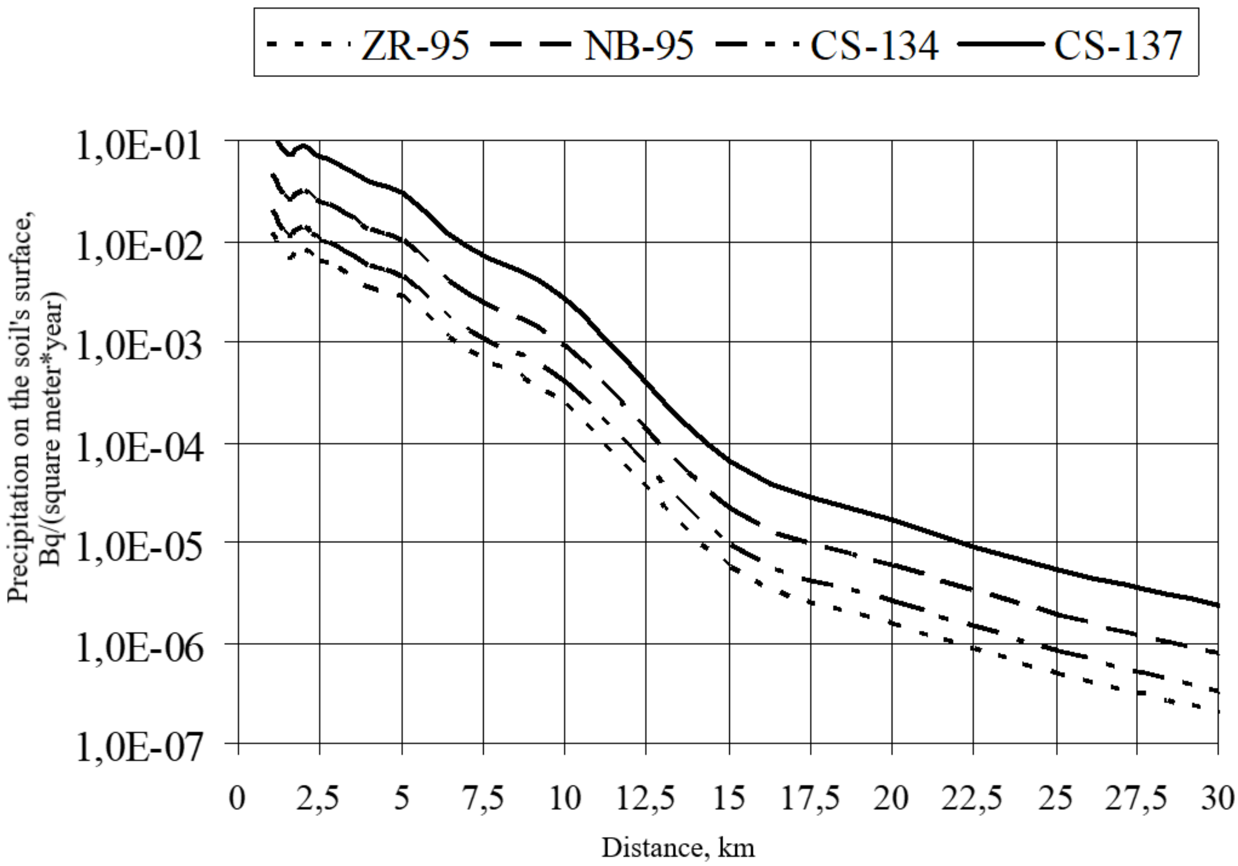


Figure 2.5 - Distance dependence of expected LLN soil fallout

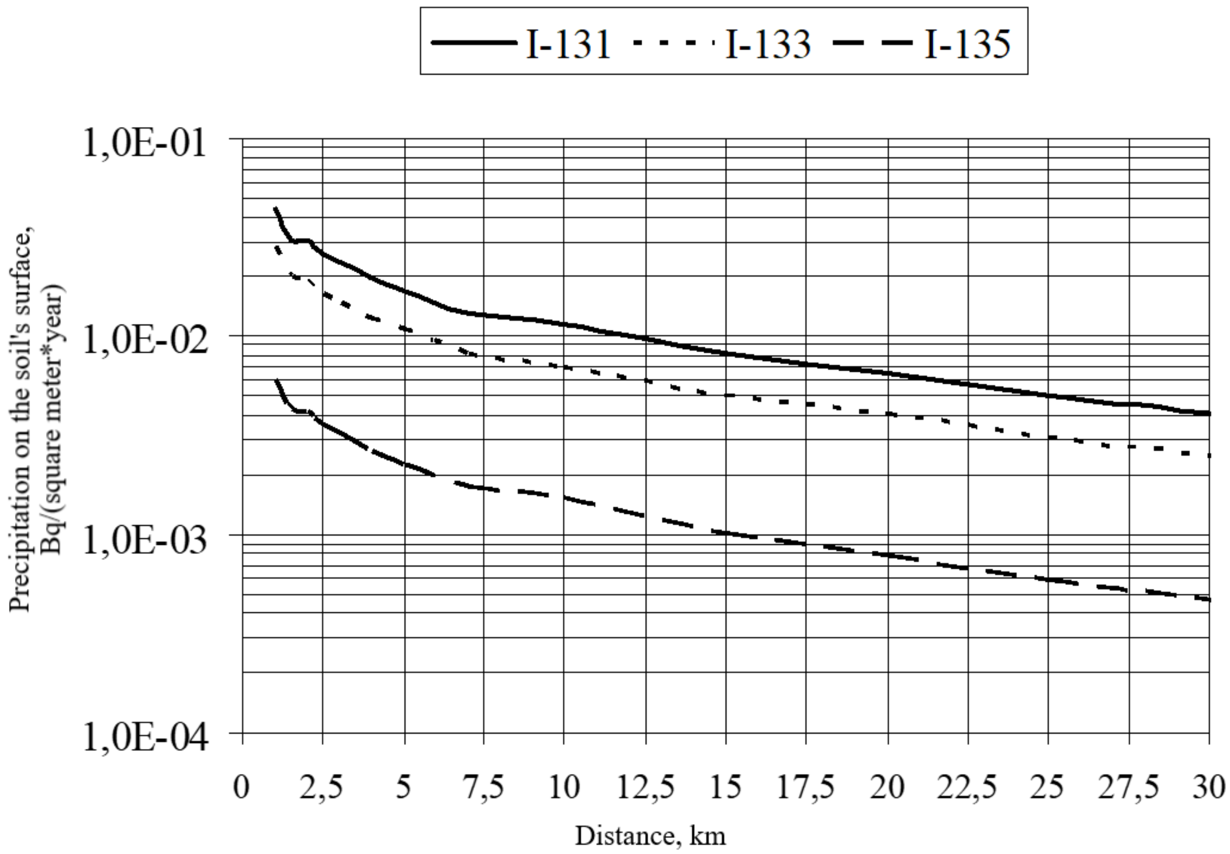


Figure 2.6 - Distance dependence of expected iodine isotopes soil fallout

As can be seen from the above figures, average annual air volumetric activities at the border of the SPZ (2500 m) are expected to make 0.012 Bq/m^3 for ^{133}Xe and 0.0031 Bq/m^3 for ^{135}Xe, while the values at the border of the observation zone (OZ) (30 000 m) are expected to make 0.003 Bq/m^3 for ^{133}Xe and 0.0007 Bq/m^3 for ^{135}Xe. The volumetric activity values of radionuclides released in the air from RNPP at the border with the nearest state, Republic of Belarus (at the distance of 60 km), shall not exceed 0.002 Bq/m^3.

The maximum values of soil fallout at the border of the SPZ (2500 m) are expected to make 23.4 kBq/(m^2×year) for H-3 and 0.08 Bq/(m^2×year) for ^{60}Co, while the values at the border of the OZ (30 000 m) are expected to make 5.86 kBq/(m^2×year) for H-3 and 4.12 mBq/(m^2×year) for ^{131}I. The soil fallout values for radionuclides released from RNPP at the border with the Republic of Belarus shall not exceed 3.91 kBq/(m^2×year) (H-3).

2.2 Population radiation doses

Fig. 2.7 shows the results of the maximum expected population radiation dose calculations as function of distance. The results are given for 3 age groups: infants under 1 YOA, children under 10 YOA and adults.

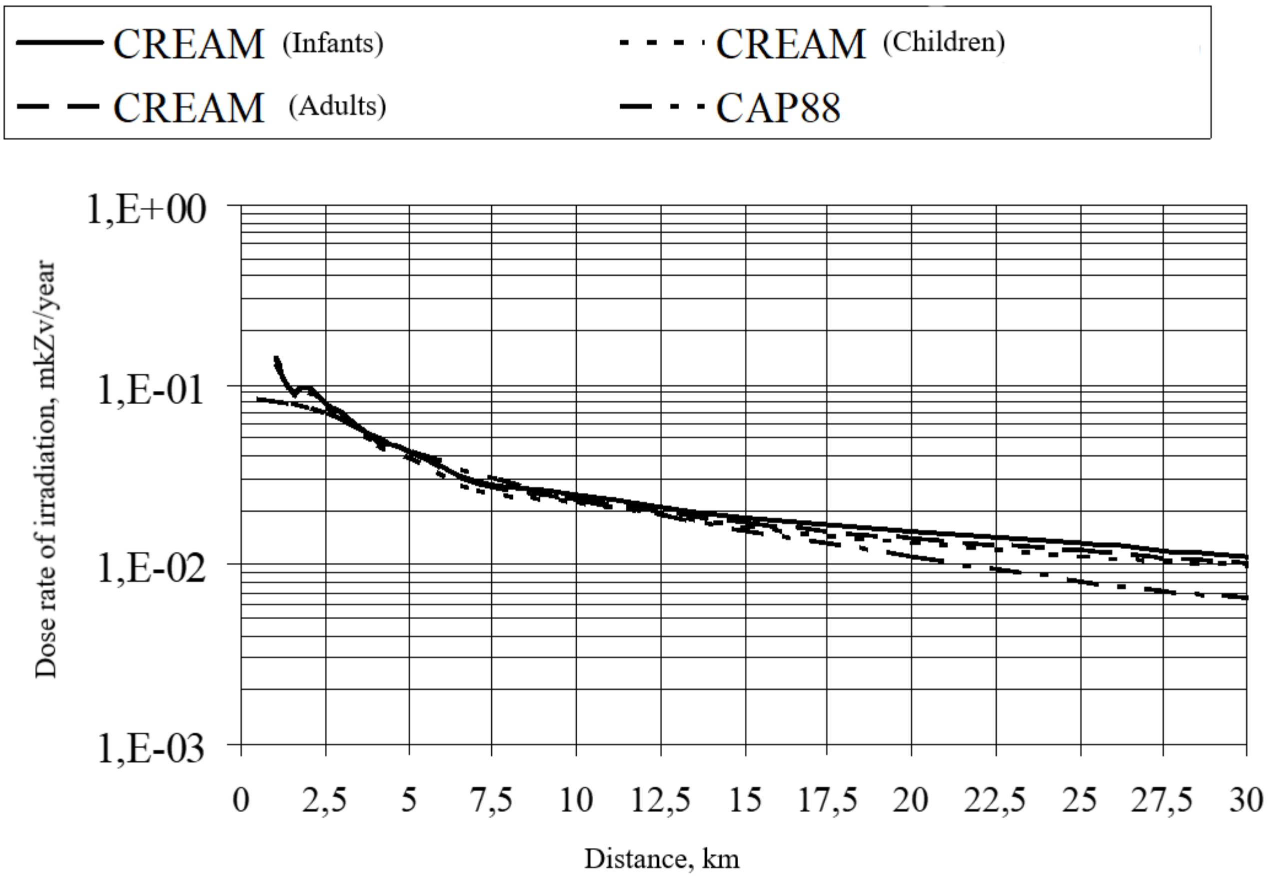


Figure 2.7 - Distance dependence of expected population radiation doses

As can be seen from the figure, the limit dose rate of 40 μSv/year as per NRBU-97 for RNPP releases is not exceeded (irrespective of the critical population group location). Maximum doses at the border of the SPZ do not exceed 0.078 μSv/year, and at the border of the OZ – 0.011 μSv/year. The doses of radiation released from RNPP at the border with the Republic of Belarus (at the distance of 60 km) do not exceed 0.006 μSv/year.

Fig. 2.8 shows relative shares of radiation dose formation pathways. As we can see, the dose is mainly formed due to food consumption (83-93 %). The dose is generally 88-99 % dependent on the internal radiation pathways.

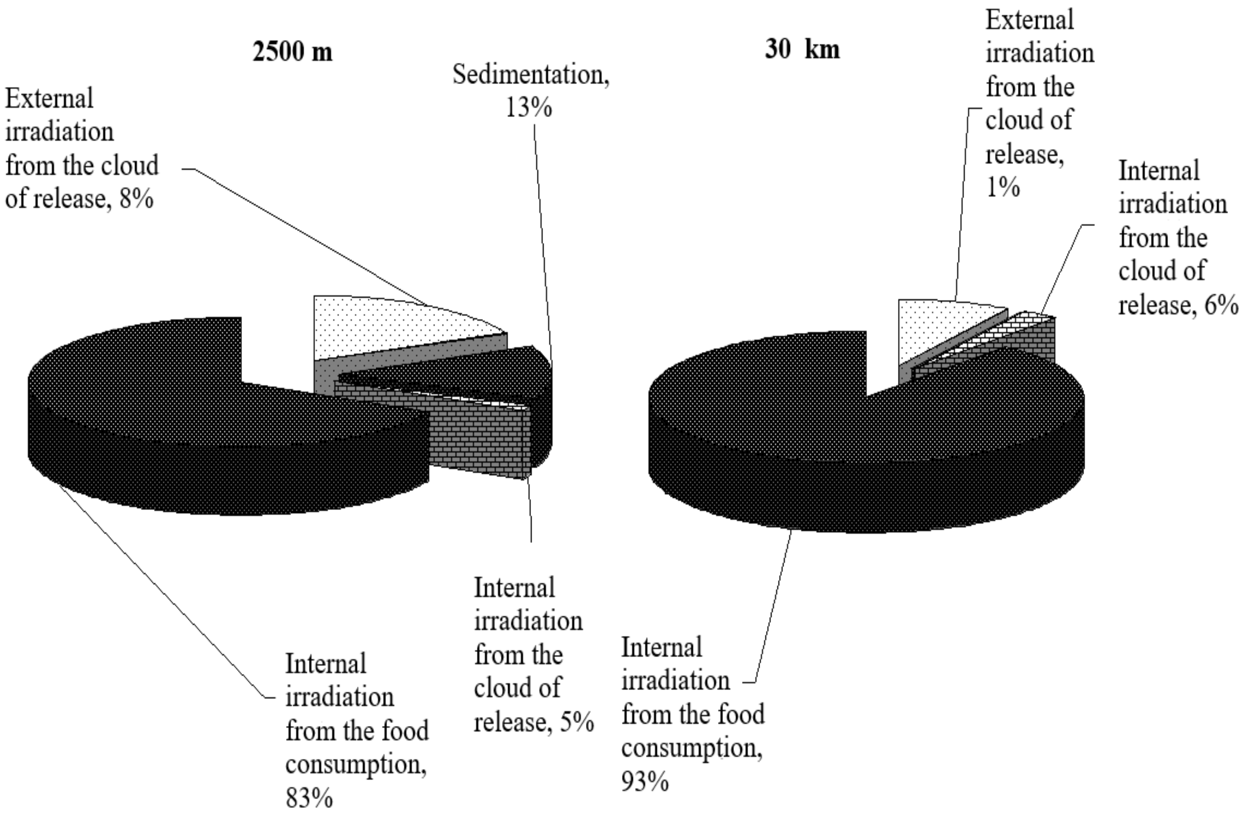
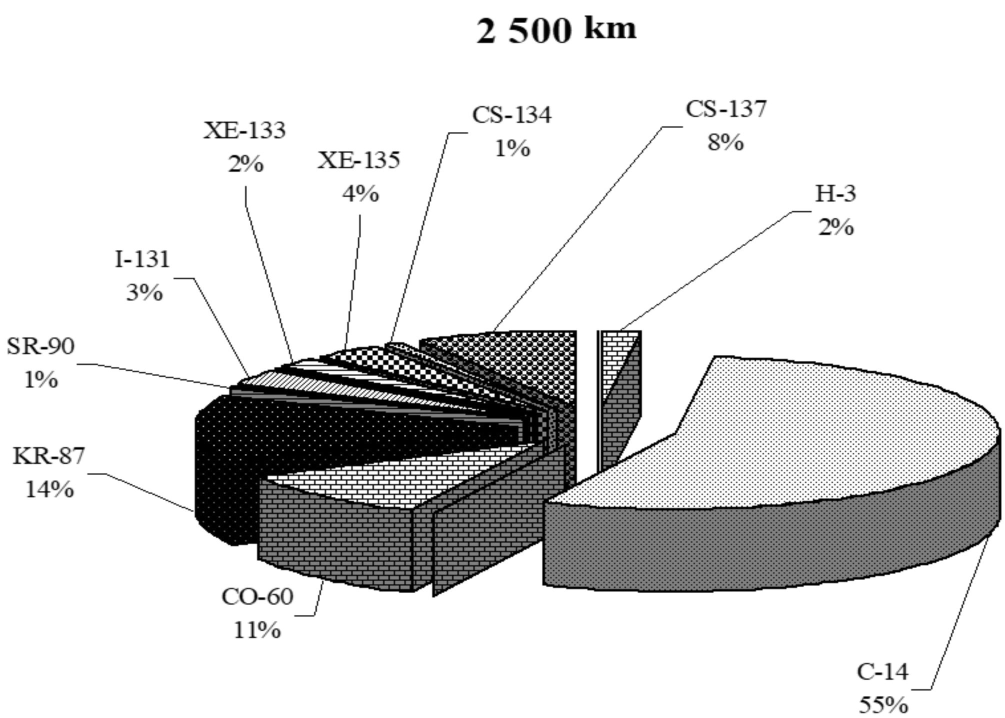


Figure 2.8 - Relative shares of radiation dose formation pathways

Fig. 2.9 shows relative shares of radionuclides in the radiation dose. As we can see, the dose is mainly formed from carbon (55-85 %), with a prominent share of IRG, H-3, cobalt-60, and caesium, iodine-131 and strontium isotopes.



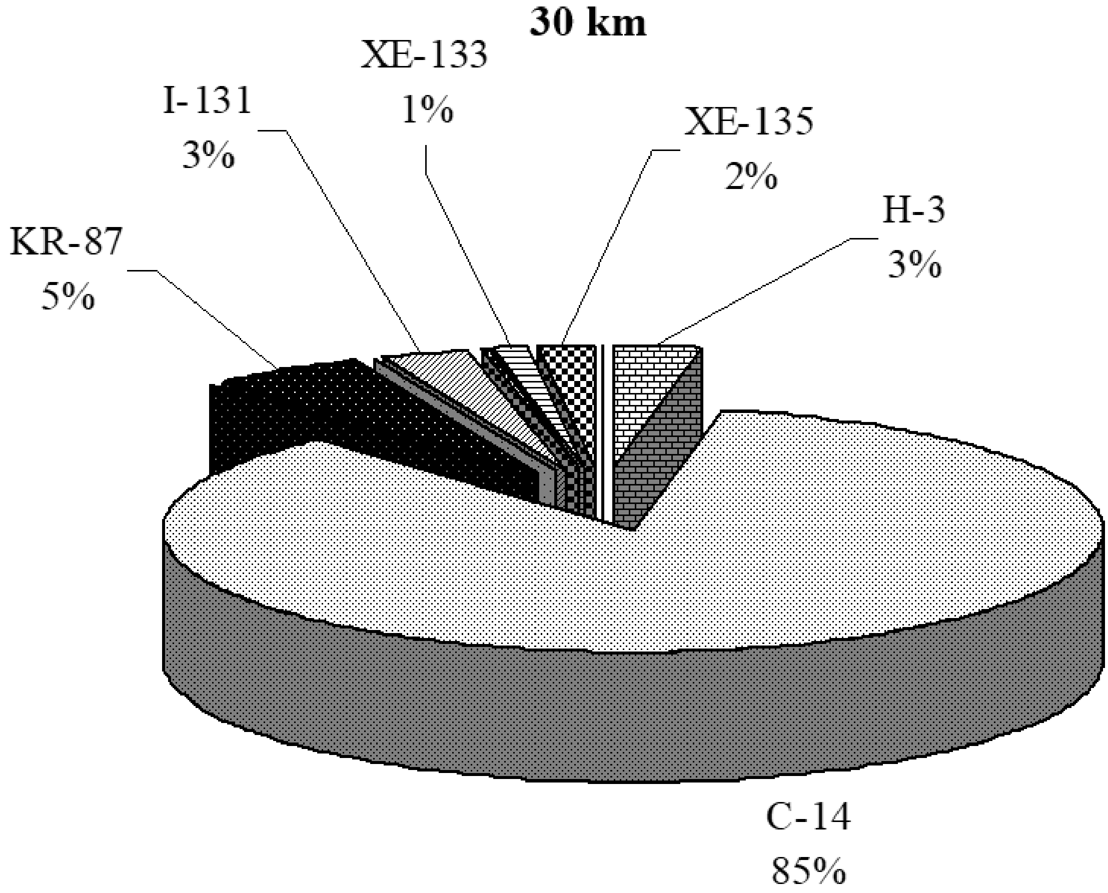


Figure 2.9 - Relative shares of radionuclides in the radiation dose

3 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A MAXIMUM DESIGN BASIS ACCIDENT (MDBA)

3.1 Input data for calculating radiation exposure during the MDBA

Effective values of the total environmental radioactive release are shown in Table 3.1.

Table 3.1 - Radioactive release during the MDBA

Radionuclide	Environmental release, Bq
Kr-88	2.00E+13
Sr-90	3.10E+11
Ru-103	4.50E+12
Ru-106	6.60E+11
I-131	4.98E+12
I-132	2.70E+12
I-133	4.00E+12
I-135	2.30E+12
Cs-134	7.80E+11
Cs-137	5.00E+11
La-140	8.40E+12
Ce-141	1.40E+13
Ce-144	8.60E+12
Total activity	7.17E+13

3.2 Calculation results for the MDBA at the border of the SPZ (2.5 km)

Table 3.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during the MDBA.

Table 3.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during the MDBA

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-88	7.89E+03	0.00E+00
Sr-90	1.95E+02	6.36E+03
Ru-103	2.84E+03	9.23E+04
Ru-106	4.16E+02	1.35E+04
I-131	2.52E+03	1.66E+05
I-132	5.78E+02	3.81E+04
I-133	1.86E+03	1.22E+05
I-135	8.69E+02	5.73E+04
Cs-134	4.92E+02	1.60E+04
Cs-137	3.15E+02	1.03E+04
La-140	5.04E+03	1.64E+05
Ce-141	8.83E+03	2.87E+05
Ce-144	5.42E+03	1.76E+05
Total	**3.73E+04**	**1.15E+06**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 8.8 kBq/m^3 for ^{141}Ce and up to 7.9 kBq/m^3 for ^{88}Kr. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 287 kBq/m^2 for ^{141}Ce, up to 176 kBq/m^2 for ^{144}Ce, up to 166 kBq/m^2 for ^{131}I and up to 164 kBq/m^2 for ^{140}La.

Tables 3.3–3.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 3.1–3.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 1.88 mSv.

Table 3.3 - Human organ and tissue radiation doses at MDBA over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external) , Gy
Kr-88	8,06E-07	8,92E-07	8,50E-07	7,04E-07	6,78E-07	8,06E-07	6,36E-07	7,58E-07	9,35E-07	7,66E-07
Sr-90	1,71E-08	1,35E-08	2,30E-09	2,00E-08	9,61E-08	1,57E-15	2,30E-09	3,97E-06	6,89E-09	0,00E+00
Ru-103	1,48E-06	3,82E-06	1,14E-06	9,90E-07	1,68E-06	1,08E-06	9,41E-07	1,86E-05	1,19E-06	1,45E-06
Ru-106	3,45E-07	1,31E-06	7,26E-08	6,30E-08	1,31E-06	6,73E-08	5,99E-08	1,39E-10	9,44E-08	2,93E-07
I-131	2,62E-06	1,46E-06	2,62E-05	1,35E-06	1,23E-06	1,50E-06	1,27E-06	2,83E-04	3,20E-05	2,34E-06
I-132	1,64E-07	1,51E-07	5,70E-07	1,36E-07	1,24E-07	1,51E-07	1,26E-07	5,00E-06	6,15E-07	1,58E-07
I-133	1,40E-06	7,04E-07	1,52E-05	6,44E-07	5,88E-07	7,08E-07	6,08E-07	1,14E-04	1,98E-05	1,19E-06
I-135	4,97E-07	4,00E-07	2,71E-06	3,68E-07	3,36E-07	4,07E-07	3,47E-07	2,13E-05	3,04E-06	4,67E-07
Cs-134	5,87E-07	5,83E-07	6,45E-07	5,51E-07	5,08E-07	5,89E-07	5,21E-07	4,94E-06	6,45E-07	5,87E-07
Cs-137	1,46E-07	1,45E-07	1,56E-07	1,34E-07	1,27E-07	1,39E-07	1,27E-07	4,22E-06	1,59E-07	1,44E-07
La-140	5,85E-06	9,41E-06	4,92E-06	4,29E-06	8,38E-06	4,62E-06	4,10E-06	5,75E-05	5,12E-06	5,74E-06
Ce-141	2,37E-06	1,34E-05	5,28E-07	4,58E-07	3,71E-06	4,97E-07	4,40E-07	1,16E-04	6,76E-07	2,03E-06
Ce-144	4,10E-06	1,97E-05	1,75E-07	1,54E-07	1,56E-05	1,64E-07	1,46E-07	3,62E-05	3,46E-07	2,09E-06
Total	**2,04E-05**	**5,20E-05**	**5,33E-05**	**9,87E-06**	**3,43E-05**	**1,07E-05**	**9,33E-06**	**6,65E-04**	**6,47E-05**	**1,73E-05**

Table 3.4 - Human organ and tissue radiation doses at MDBA over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	8.06E-07	8.92E-07	8.50E-07	7.04E-07	6.78E-07	8.06E-07	6.36E-07	7.58E-07	9.35E-07	7.66E-07
Sr-90	6.63E-08	3.97E-08	1.49E-08	1.74E-07	3.50E-07	2.95E-14	1.49E-08	3.26E-05	4.48E-08	0.00E+00
Ru-103	7.65E-06	1.90E-05	6.84E-06	5.85E-06	7.34E-06	6.44E-06	5.49E-06	1.04E-04	6.98E-06	7.57E-06
Ru-106	1.57E-06	7.92E-06	4.74E-07	4.08E-07	3.70E-06	4.42E-07	3.83E-07	8.45E-10	5.69E-07	1.41E-06
I-131	1.18E-05	6.13E-06	1.25E-04	5.78E-06	5.23E-06	6.47E-06	5.43E-06	1.13E-03	1.55E-04	1.04E-05
I-132	1.64E-07	1.51E-07	5.70E-07	1.36E-07	1.24E-07	1.51E-07	1.26E-07	5.00E-06	6.15E-07	1.58E-07
I-133	2.26E-06	9.00E-07	2.87E-05	8.32E-07	7.60E-07	9.12E-07	7.84E-07	1.41E-04	3.96E-05	1.83E-06
I-135	5.20E-07	4.07E-07	3.06E-06	3.75E-07	3.43E-07	4.14E-07	3.52E-07	2.14E-05	3.43E-06	4.89E-07
Cs-134	3.70E-06	3.81E-06	4.22E-06	3.61E-06	3.34E-06	3.88E-06	3.44E-06	3.00E-05	4.22E-06	3.70E-06
Cs-137	9.10E-07	9.30E-07	1.03E-06	8.80E-07	8.35E-07	9.20E-07	8.45E-07	2.59E-05	1.03E-06	9.10E-07
La-140	9.91E-06	1.75E-05	8.36E-06	7.31E-06	1.54E-05	7.84E-06	6.92E-06	9.83E-05	8.69E-06	9.71E-06
Ce-141	1.04E-05	6.12E-05	3.12E-06	2.69E-06	1.10E-05	2.95E-06	2.53E-06	6.29E-04	3.68E-06	9.47E-06
Ce-144	1.77E-05	1.13E-04	1.18E-06	1.03E-06	4.22E-05	1.11E-06	9.55E-07	2.18E-04	2.05E-06	1.12E-05
Total	**6.75E-05**	**2.31E-04**	**1.83E-04**	**2.98E-05**	**9.13E-05**	**3.23E-05**	**2.79E-05**	**2.44E-03**	**2.27E-04**	**5.76E-05**

Table 3.5 - Human organ and tissue radiation doses at MDBA over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	8.06E-07	8.92E-07	8.50E-07	7.04E-07	6.78E-07	8.06E-07	6.36E-07	7.58E-07	9.35E-07	7.66E-07
Sr-90	5.18E-07	6.70E-08	4.00E-08	3.32E-06	4.84E-07	9.02E-13	4.00E-08	1.30E-04	1.20E-07	0.00E+00
Ru-103	2.88E-05	5.90E-05	2.85E-05	2.44E-05	2.42E-05	2.70E-05	2.28E-05	2.39E-04	2.91E-05	2.85E-05
Ru-106	1.60E-05	8.65E-05	7.06E-06	6.04E-06	9.57E-06	6.60E-06	5.65E-06	2.85E-09	7.91E-06	1.51E-05
I-131	1.80E-05	8.67E-06	2.05E-04	8.17E-06	7.37E-06	9.11E-06	7.67E-06	1.44E-03	2.63E-04	1.55E-05
I-132	1.64E-07	1.51E-07	5.70E-07	1.36E-07	1.24E-07	1.51E-07	1.26E-07	5.00E-06	6.15E-07	1.58E-07
I-133	2.26E-06	9.12E-07	2.88E-05	8.40E-07	7.68E-07	9.24E-07	7.92E-07	1.41E-04	3.97E-05	1.83E-06
I-135	5.20E-07	4.07E-07	3.06E-06	3.75E-07	3.43E-07	4.14E-07	3.52E-07	2.14E-05	3.43E-06	4.89E-07
Cs-134	6.17E-05	6.43E-05	7.13E-05	6.09E-05	5.57E-05	6.67E-05	5.79E-05	1.05E-04	7.13E-05	6.17E-05
Cs-137	1.70E-05	1.77E-05	1.96E-05	1.68E-05	1.55E-05	1.81E-05	1.59E-05	9.30E-05	1.96E-05	1.70E-05
La-140	9.91E-06	1.78E-05	8.38E-06	7.34E-06	1.54E-05	7.85E-06	6.95E-06	9.91E-05	8.72E-06	9.71E-06
Ce-141	2.77E-05	1.50E-04	1.19E-05	1.02E-05	1.85E-05	1.12E-05	9.51E-06	1.36E-03	1.33E-05	2.61E-05
Ce-144	1.32E-04	9.46E-04	1.96E-05	1.78E-05	6.58E-05	1.86E-05	1.57E-05	7.28E-04	2.59E-05	1.07E-04
Total	**3.16E-04**	**1.35E-03**	**4.05E-04**	**1.57E-04**	**2.14E-04**	**1.67E-04**	**1.44E-04**	**4.36E-03**	**4.83E-04**	**2.84E-04**

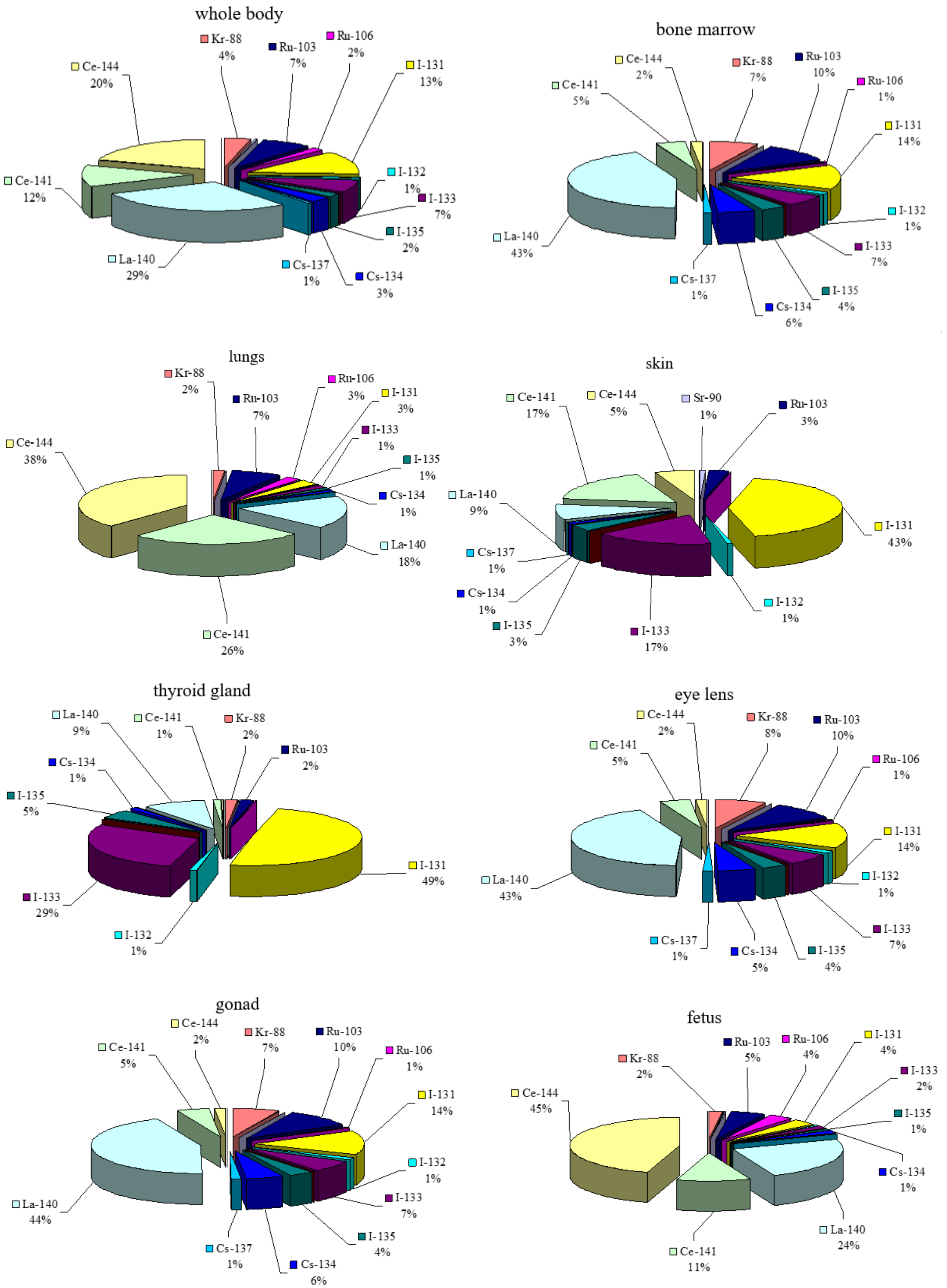


Figure 3.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

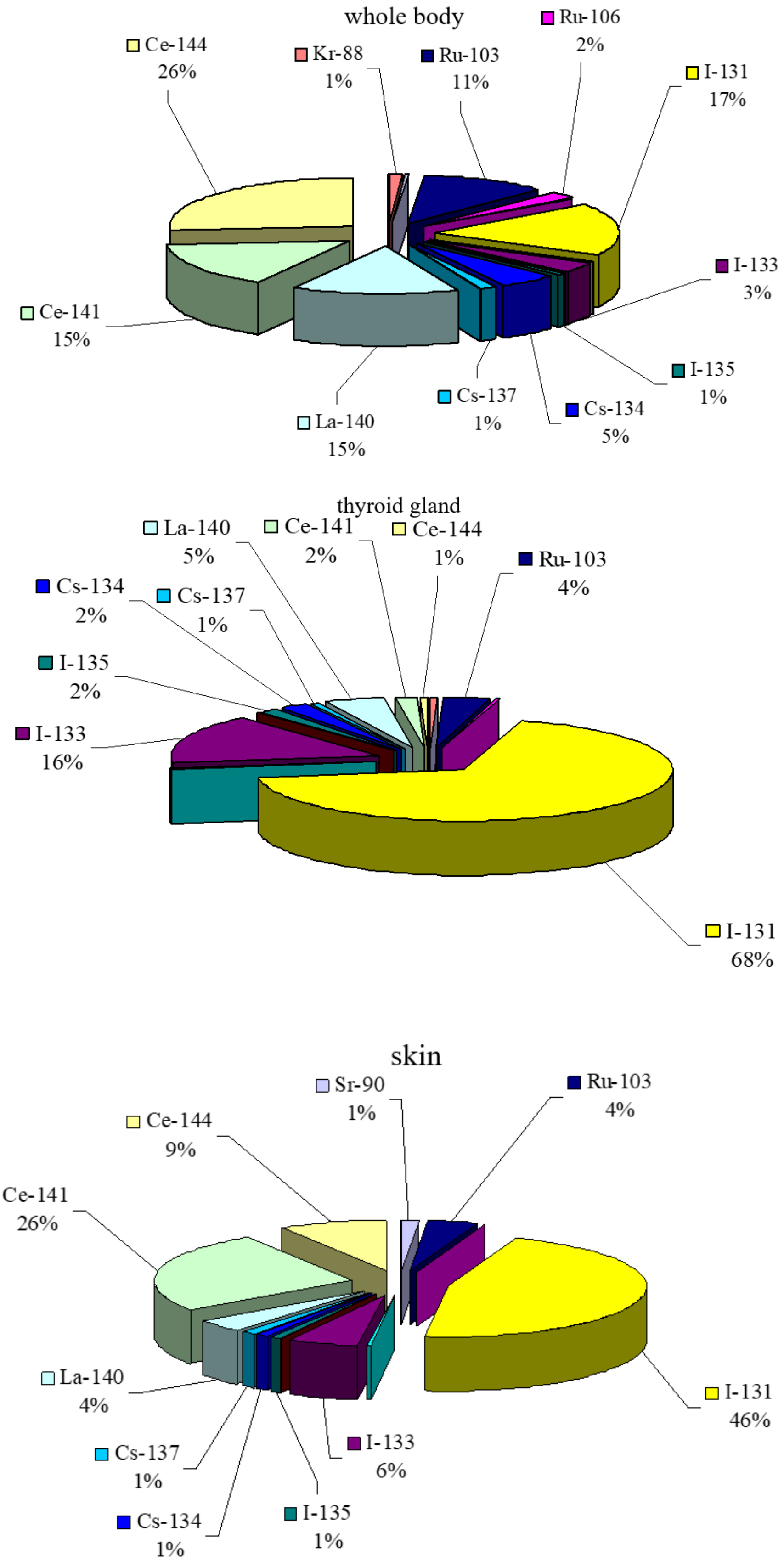


Figure 3.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

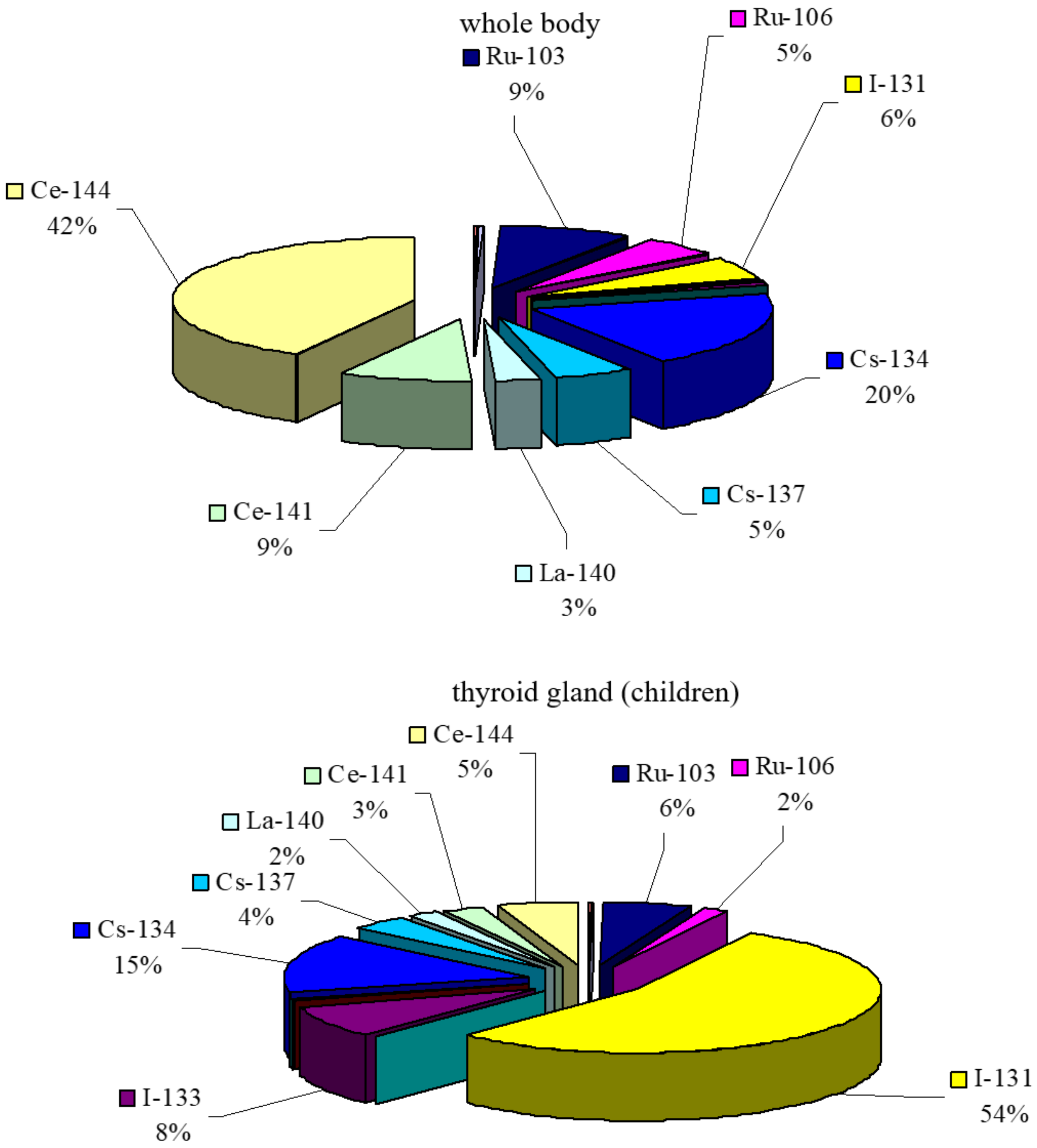


Figure 3.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

3.2.1 Radiation impact estimates for MDBA as per NRBU97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 3.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 3.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	MDBA estimates, Gy
Entire body (bone marrow)[1]	1	1.73E-05 (9.87E-06)
Lungs	6	5.20E-05
Skin	3	6.65E-04
Thyroid gland	5	5.33E-05
Eye lens	2	1.07E-05
Gonad	2	9.33E-06
Fetus	0.1	3.43E-05

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 3.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 3.7, while calculation results for standardized values for the MDBA are given in Table 3.8.

Table 3.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 3.8 - Dose estimates over the first 2 weeks following the MDBA

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.068	0.18	2.44

Based on the calculation results given in Table 3.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the MDBA upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

3.2.2 Radiation impact estimates for the MDBA as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during the MDBA shall be 0.00048 Sv/year, and for the entire body due to external radiation - 0.00038 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

3.3 Calculation results for the MDBA at the border of the OZ (30 km)

Table 3.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during the MDBA.

Table 3.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during the MDBA

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-88	4.94E+03	0.00E+00
Sr-90	3.50E+00	3.50E+03
Ru-103	5.08E+01	5.09E+04
Ru-106	7.46E+00	7.46E+03
I-131	3.28E+02	1.42E+05
I-132	9.98E+01	4.32E+04
I-133	2.49E+02	1.08E+05
I-135	1.25E+02	5.38E+04
Cs-134	8.82E+00	8.81E+03
Cs-137	5.65E+00	5.65E+03
La-140	9.17E+01	9.16E+04
Ce-141	1.58E+02	1.58E+05
Ce-144	9.72E+01	9.72E+04
Total	**6.17E+03**	**7.70E+05**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 4.9 kBq/m^3 for ^{88}Kr. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 0.16 MBq/m^2 for ^{141}Ce, up to 0.14 MBq/m^2 for ^{131}I and up to 0.11 MBq/m^2 for ^{133}I.

Tables 3.10–3.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 3.4–3.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.73 mSv.

Table 3.10 - Human organ and tissue radiation doses during the MDBA over a 2-day period

Nuclide	Bone marrow, Gy	Lungs, Gy	Skin, Gy	Thyroid gland (adults), Gy	Thyroid gland (children), Gy	Eye lens, Gy	Gonad, Gy	Fetus, Gy	Entire body (external), Gy	Effective dose, Sv
Kr-88	5.10E-07	5.82E-07	1.80E-07	6.08E-07	6.69E-07	5.84E-07	4.66E-07	4.82E-07	5.19E-07	5.46E-07
Sr-90	3.60E-10	1.90E-10	7.04E-08	4.12E-11	1.24E-10	7.41E-16	4.12E-11	1.67E-09	0.00E+00	2.94E-10
Ru-103	5.04E-07	5.85E-07	3.33E-07	5.94E-07	6.18E-07	5.67E-07	4.77E-07	4.73E-07	5.07E-07	5.18E-07
Ru-106	3.15E-08	5.56E-08	2.49E-12	3.71E-08	4.82E-08	3.54E-08	2.98E-08	5.11E-08	3.15E-08	3.70E-08
I-131	1.13E-06	1.20E-06	3.69E-05	4.54E-06	5.53E-06	1.26E-06	1.06E-06	1.02E-06	1.16E-06	1.30E-06
I-132	1.12E-07	1.19E-07	8.59E-07	2.02E-07	2.18E-07	1.25E-07	1.05E-07	1.01E-07	1.13E-07	1.18E-07
I-133	5.32E-07	5.64E-07	1.53E-05	2.56E-06	3.33E-06	5.92E-07	5.00E-07	4.80E-07	5.41E-07	6.36E-07
I-135	3.06E-07	3.24E-07	3.06E-06	6.85E-07	7.68E-07	3.40E-07	2.88E-07	2.76E-07	3.07E-07	3.27E-07
Cs-134	2.75E-07	2.91E-07	8.81E-08	3.24E-07	3.24E-07	3.09E-07	2.60E-07	2.50E-07	2.79E-07	2.79E-07
Cs-137	6.50E-08	6.90E-08	7.55E-08	7.65E-08	7.80E-08	7.30E-08	6.15E-08	5.90E-08	6.53E-08	6.60E-08
La-140	2.08E-06	2.29E-06	1.05E-06	2.44E-06	2.54E-06	2.34E-06	1.97E-06	1.97E-06	2.09E-06	2.13E-06
Ce-141	2.34E-07	4.79E-07	2.07E-06	2.74E-07	3.51E-07	2.62E-07	2.21E-07	2.72E-07	2.32E-07	2.70E-07
Ce-144	7.87E-08	4.33E-07	6.48E-07	9.20E-08	1.82E-07	8.86E-08	7.43E-08	3.48E-07	7.68E-08	1.51E-07
Total	**5.86E-06**	**6.99E-06**	**6.06E-05**	**1.24E-05**	**1.47E-05**	**6.57E-06**	**5.51E-06**	**5.79E-06**	**5.92E-06**	**6.39E-06**

Table 3.11 - Human organ and tissue radiation doses during the MDBA over a 2-week period

Nuclide	Bone marrow, Gy	Lungs, Gy	Skin, Gy	Thyroid gland (adults), Gy	Thyroid gland (children), Gy	Eye lens, Gy	Gonad, Gy	Fetus, Gy	Entire body (external), Gy	Effective dose, Sv
Kr-88	5.10E-07	5.82E-07	1.80E-07	6.08E-07	6.69E-07	5.84E-07	4.66E-07	4.82E-07	5.19E-07	5.46E-07
Sr-90	3.16E-09	5.86E-10	5.83E-07	2.72E-10	8.15E-10	1.61E-14	2.72E-10	6.23E-09	0.00E+00	1.18E-09
Ru-103	3.14E-06	3.55E-06	1.85E-06	3.69E-06	3.76E-06	3.52E-06	2.97E-06	2.88E-06	3.18E-06	3.21E-06
Ru-106	2.15E-07	3.63E-07	1.50E-11	2.53E-07	3.03E-07	2.42E-07	2.03E-07	2.55E-07	2.15E-07	2.39E-07
I-131	4.91E-06	5.18E-06	1.47E-04	2.12E-05	2.63E-05	5.53E-06	4.64E-06	4.45E-06	5.04E-06	5.73E-06
I-132	1.12E-07	1.19E-07	8.59E-07	2.02E-07	2.18E-07	1.25E-07	1.05E-07	1.01E-07	1.13E-07	1.18E-07
I-133	6.92E-07	7.36E-07	1.89E-05	4.52E-06	6.24E-06	7.76E-07	6.56E-07	6.28E-07	7.23E-07	8.92E-07
I-135	3.11E-07	3.29E-07	3.06E-06	7.41E-07	8.29E-07	3.47E-07	2.92E-07	2.81E-07	3.13E-07	3.34E-07
Cs-134	1.89E-06	2.00E-06	5.37E-07	2.22E-06	2.22E-06	2.11E-06	1.79E-06	1.71E-06	1.91E-06	1.91E-06
Cs-137	4.49E-07	4.74E-07	4.62E-07	5.25E-07	5.25E-07	5.00E-07	4.24E-07	4.07E-07	4.54E-07	4.54E-07
La-140	3.69E-06	4.07E-06	1.79E-06	4.33E-06	4.50E-06	4.13E-06	3.48E-06	3.50E-06	3.70E-06	3.77E-06
Ce-141	1.44E-06	2.58E-06	1.13E-05	1.69E-06	2.00E-06	1.61E-06	1.36E-06	1.46E-06	1.45E-06	1.60E-06
Ce-144	5.44E-07	2.61E-06	3.91E-06	6.38E-07	1.11E-06	6.09E-07	5.13E-07	1.25E-06	5.37E-07	8.53E-07
Total	**1.79E-05**	**2.26E-05**	**1.91E-04**	**4.06E-05**	**4.87E-05**	**2.01E-05**	**1.69E-05**	**1.74E-05**	**1.81E-05**	**1.97E-05**

Table 3.12 - Human organ and tissue radiation doses during the MDBA over one year period

Nuclide	Bone marrow, Gy	Lungs, Gy	Skin, Gy	Thyroid gland (adults), Gy	Thyroid gland (children), Gy	Eye lens, Gy	Gonad, Gy	Fetus, Gy	Entire body (external), Gy	Effective dose, Sv
Kr-88	5.10E-07	5.82E-07	1.80E-07	6.08E-07	6.69E-07	5.84E-07	4.66E-07	4.82E-07	5.19E-07	5.46E-07
Sr-90	7.32E-08	1.23E-09	2.33E-06	8.77E-10	2.63E-09	4.96E-13	8.77E-10	1.05E-08	0.00E+00	1.14E-08
Ru-103	1.32E-05	1.46E-05	4.27E-06	1.55E-05	1.58E-05	1.48E-05	1.25E-05	1.20E-05	1.33E-05	1.34E-05
Ru-106	3.24E-06	5.12E-06	5.10E-11	3.81E-06	4.27E-06	3.64E-06	3.06E-06	3.03E-06	3.28E-06	3.49E-06
I-131	6.92E-06	7.32E-06	1.88E-04	3.37E-05	4.32E-05	7.77E-06	6.52E-06	6.27E-06	7.11E-06	8.27E-06
I-132	1.12E-07	1.19E-07	8.59E-07	2.02E-07	2.18E-07	1.25E-07	1.05E-07	1.01E-07	1.13E-07	1.18E-07
I-133	7.00E-07	7.44E-07	1.89E-05	4.56E-06	6.29E-06	7.84E-07	6.64E-07	6.36E-07	7.29E-07	9.00E-07
I-135	3.11E-07	3.29E-07	3.06E-06	7.41E-07	8.29E-07	3.47E-07	2.92E-07	2.81E-07	3.13E-07	3.34E-07
Cs-134	3.27E-05	3.45E-05	1.88E-06	3.84E-05	3.84E-05	3.66E-05	3.08E-05	2.96E-05	3.31E-05	3.31E-05
Cs-137	8.85E-06	9.35E-06	1.67E-06	1.04E-05	1.04E-05	9.90E-06	8.35E-06	8.05E-06	8.95E-06	8.95E-06
La-140	3.70E-06	4.09E-06	1.80E-06	4.33E-06	4.51E-06	4.14E-06	3.49E-06	3.51E-06	3.71E-06	3.79E-06
Ce-141	5.50E-06	8.43E-06	2.44E-05	6.45E-06	7.23E-06	6.17E-06	5.19E-06	5.15E-06	5.54E-06	5.89E-06
Ce-144	9.12E-06	2.90E-05	1.30E-05	1.07E-05	1.41E-05	1.01E-05	8.57E-06	9.29E-06	9.40E-06	1.16E-05
Total	**8.49E-05**	**1.14E-04**	**2.60E-04**	**1.29E-04**	**1.46E-04**	**9.50E-05**	**8.00E-05**	**7.85E-05**	**8.60E-05**	**9.04E-05**

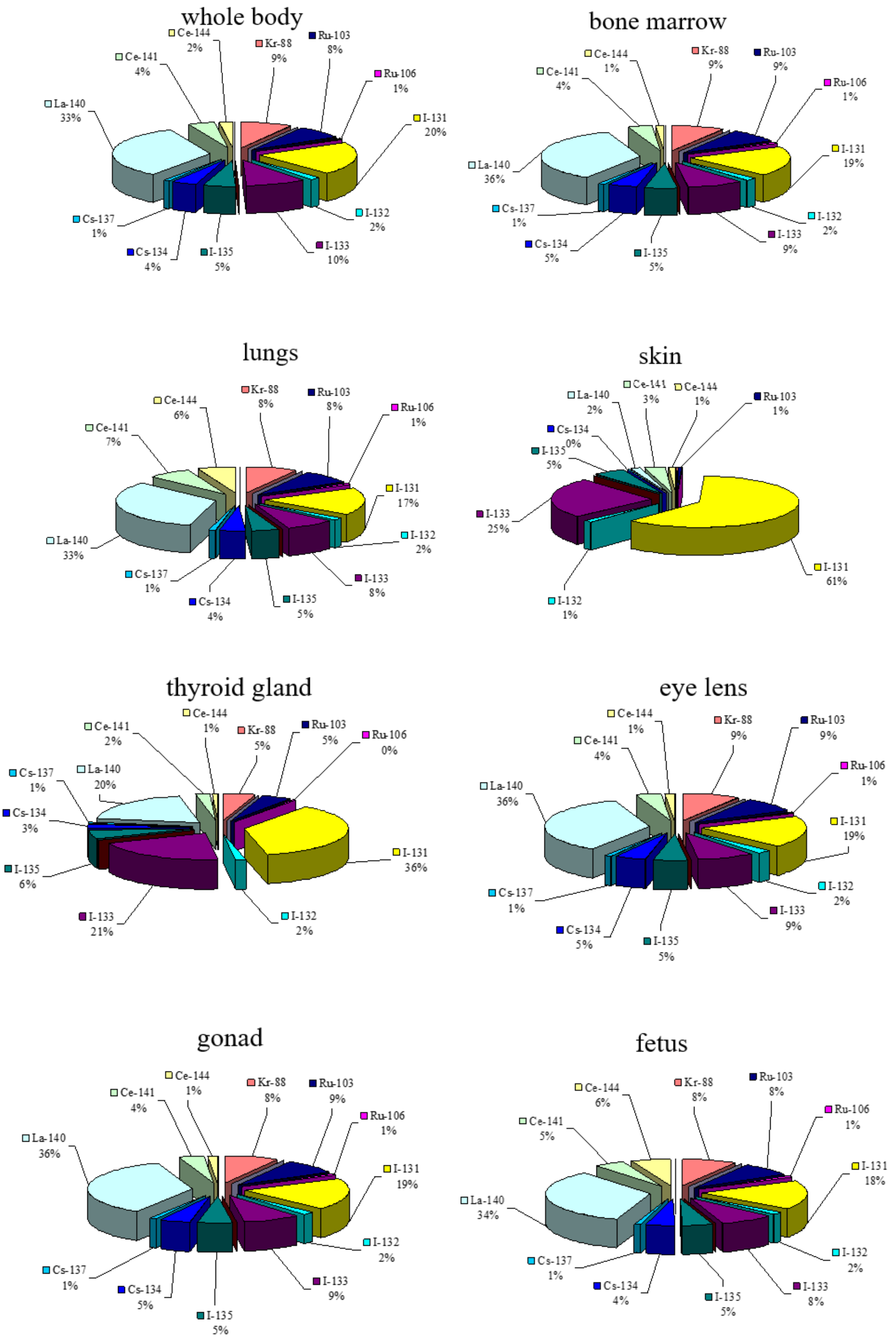


Figure 3.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

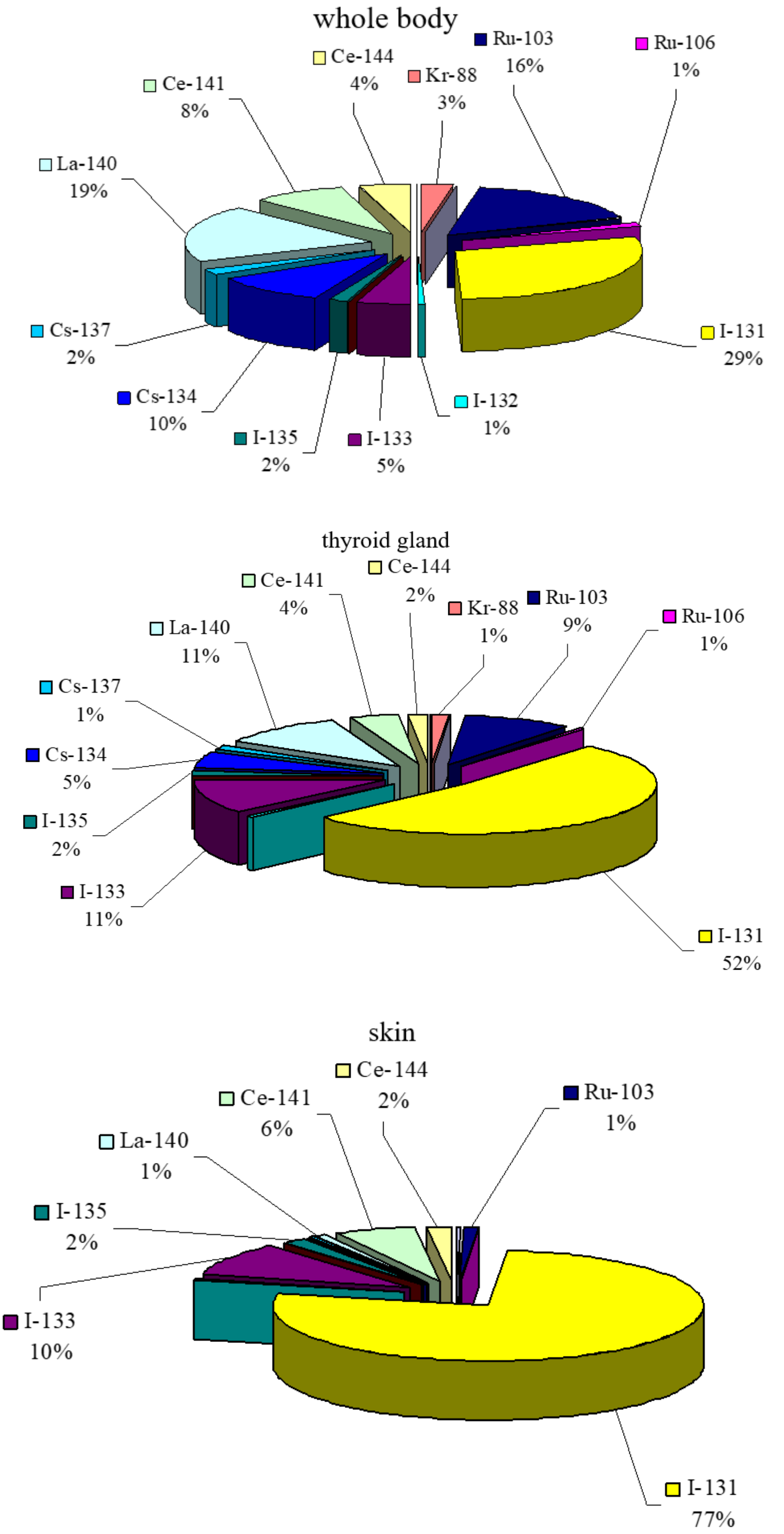


Figure 3.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

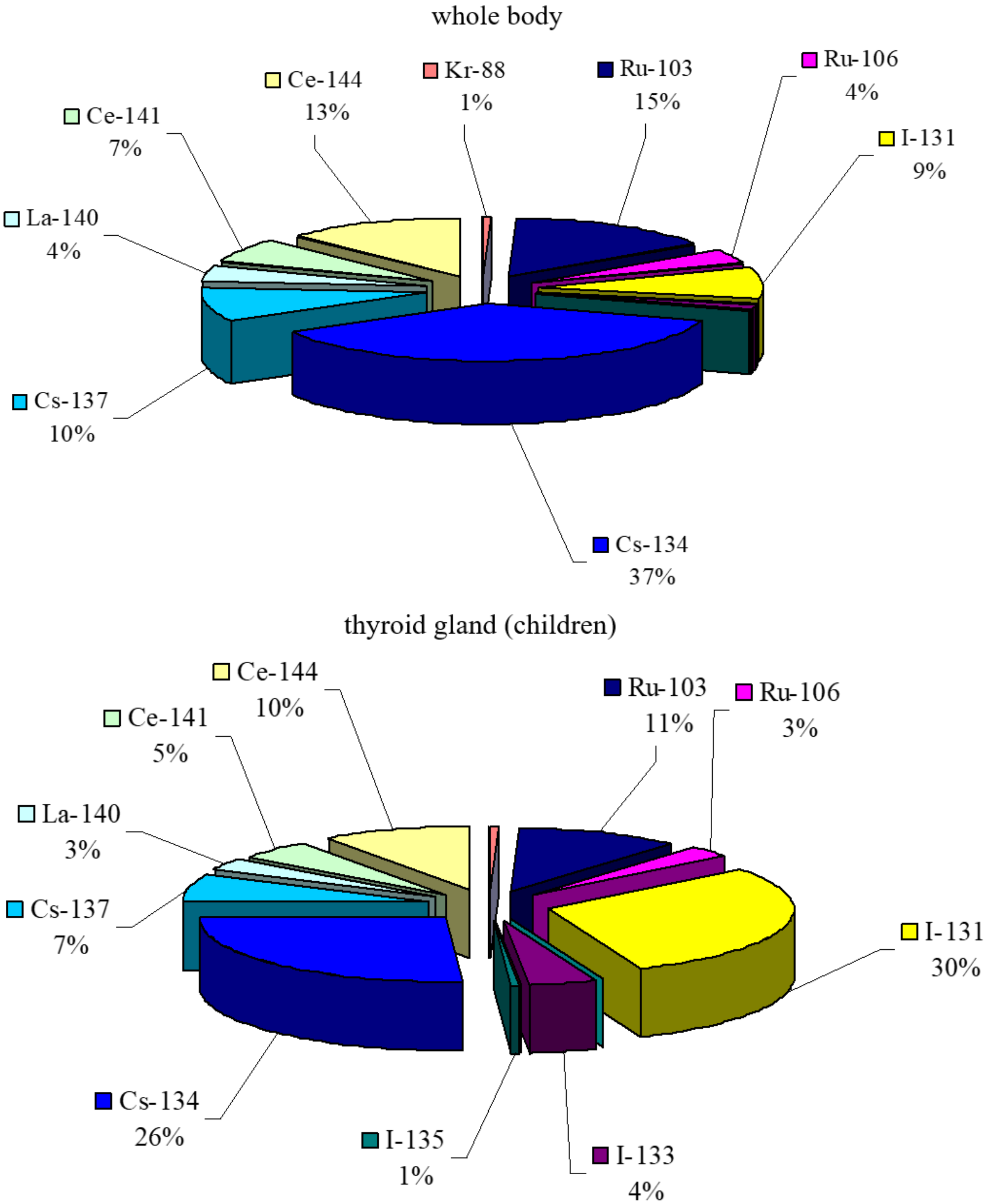


Figure 3.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

3.3.1 Radiation impact estimates for the MDBA as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 3.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 3.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	MDBA estimates, Gy
Entire body (bone marrow)[1]	1	5.92E-06 (5.86E-06)
Lungs	6	6.99E-06
Skin	3	6.06E-05
Thyroid gland	5	1.24E-05
Eye lens	2	6.57E-06
Gonad	2	5.51E-06
Fetus	0.1	5.79E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 3.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 3.14, while calculation results for standardized values for the MDBA are given in Table 3.15.

Table 3.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 3.15 - Dose estimates over the first 2 weeks following the MDBA

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.02	0.041	0.19

Based on the calculation results given in Table 3.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the MDBA upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

3.3.2Radiation impact estimates for the MDBA as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
  - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
  - 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during the MDBA shall be 0.00015 Sv/year, and for the entire body due to external radiation - 0.000086 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

4 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT "STEAM GENERATOR HEADER COVER LIFT-UP — EMERGENCY SPIKE" (ES)

4.1 Input data for calculating radiation exposure during ES

Effective values of the total environmental radioactive release are shown in Table 4.1.

Table 4.1 - Radioactive release during ES

Radionuclide	Environmental release, Bq
Kr-87	6.50E+13
Kr-88	2.00E+14
I-131	2.53E+13
I-132	9.20E+13
I-133	8.44E+13
I-134	1.00E+14
I-135	7.90E+13
Cs-134	2.10E+11
Cs-137	5.30E+11
La-140	2.60E+12
Xe-133	2.00E+15
Xe-135	1.70E+15
Total activity	4.35E+15

4.2 Calculation results for ES at the border of the SPZ (2.5 km)

Table 4.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during ES.

Table 4.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during ES

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-87	1.07E+04	0.00E+00
Kr-88	7.89E+04	0.00E+00

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
I-131	1.28E+04	8.42E+05
I-132	1.97E+04	1.30E+06
I-133	3.92E+04	2.58E+06
I-134	5.25E+03	3.46E+05
I-135	2.98E+04	1.97E+06
Cs-134	1.32E+02	4.31E+03
Cs-137	3.34E+02	1.09E+04
La-140	1.56E+03	5.07E+04
Xe-133	1.56E+06	0.00E+00
Xe-135	1.08E+06	0.00E+00
Total	**2.84E+06**	**7.10E+06**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 1.1-1.56 MBq/m^3 for xenon isotopes. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 2.6 MBq/m^2 for ^{133}I, up to 2.0 MBq/m^2 for ^{135}I and up to 1.3 MBq/m^2 for ^{132}I.

Tables 4.3–4.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 4.1–4.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 1.67 mSv.

Table 4.3 — Human organ and tissue radiation doses during ES over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	2.94E-07	2.98E-07	3.45E-07	2.76E-07	2.52E-07	3.21E-07	2.52E-07	0.00E+00	3.45E-07	2.94E-07
Kr-88	8.06E-06	8.92E-06	8.50E-06	7.04E-06	6.78E-06	8.06E-06	6.36E-06	7.58E-06	9.35E-06	7.66E-06
I-131	1.33E-05	7.41E-06	1.33E-04	6.88E-06	6.25E-06	7.64E-06	6.48E-06	1.44E-03	1.63E-04	1.19E-05
I-132	5.59E-06	5.16E-06	1.94E-05	4.64E-06	4.22E-06	5.15E-06	4.28E-06	1.70E-04	2.10E-05	5.37E-06
I-133	2.95E-05	1.49E-05	3.22E-04	1.36E-05	1.24E-05	1.49E-05	1.28E-05	2.41E-03	4.18E-04	2.51E-05
I-134	9.41E-07	9.22E-07	1.67E-06	8.01E-07	7.46E-07	9.20E-07	7.26E-07	2.59E-05	1.80E-06	9.03E-07
I-135	1.71E-05	1.37E-05	9.32E-05	1.26E-05	1.15E-05	1.40E-05	1.19E-05	7.31E-04	1.04E-04	1.60E-05
Cs-134	1.58E-07	1.57E-07	1.74E-07	1.48E-07	1.37E-07	1.59E-07	1.40E-07	1.33E-06	1.74E-07	1.58E-07
Cs-137	1.54E-07	1.53E-07	1.65E-07	1.42E-07	1.34E-07	1.47E-07	1.35E-07	4.47E-06	1.68E-07	1.53E-07
La-140	1.81E-06	2.91E-06	1.52E-06	1.33E-06	2.59E-06	1.43E-06	1.27E-06	1.78E-05	1.58E-06	1.78E-06
Xe-133	1.44E-06	1.40E-06	1.67E-06	1.03E-06	1.03E-06	1.94E-06	9.02E-07	0.00E+00	1.67E-06	1.44E-06
Xe-135	8.26E-06	8.33E-06	9.50E-06	7.65E-06	6.95E-06	9.50E-06	6.48E-06	0.00E+00	9.50E-06	8.26E-06
Total	**8.67E-05**	**6.43E-05**	**5.91E-04**	**5.62E-05**	**5.30E-05**	**6.42E-05**	**5.18E-05**	**4.80E-03**	**7.31E-04**	**7.90E-05**

Table 4.4 - Human organ and tissue radiation doses during ES over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	2.94E-07	2.98E-07	3.45E-07	2.76E-07	2.52E-07	3.21E-07	2.52E-07	0.00E+00	3.45E-07	2.94E-07
Kr-88	8.06E-06	8.92E-06	8.50E-06	7.04E-06	6.78E-06	8.06E-06	6.36E-06	7.58E-06	9.35E-06	7.66E-06
I-131	6.00E-05	3.11E-05	6.35E-04	2.93E-05	2.66E-05	3.29E-05	2.76E-05	5.74E-03	7.87E-04	5.28E-05
I-132	5.59E-06	5.16E-06	1.94E-05	4.64E-06	4.22E-06	5.15E-06	4.28E-06	1.70E-04	2.10E-05	5.37E-06
I-133	4.76E-05	1.90E-05	6.06E-04	1.76E-05	1.60E-05	1.92E-05	1.65E-05	2.98E-03	8.36E-04	3.86E-05
I-134	9.41E-07	9.22E-07	1.67E-06	8.01E-07	7.46E-07	9.20E-07	7.26E-07	2.59E-05	1.80E-06	9.03E-07
I-135	1.79E-05	1.40E-05	1.05E-04	1.29E-05	1.18E-05	1.42E-05	1.21E-05	7.35E-04	1.18E-04	1.68E-05
Cs-134	9.95E-07	1.02E-06	1.14E-06	9.72E-07	8.99E-07	1.04E-06	9.26E-07	8.09E-06	1.14E-06	9.95E-07
Cs-137	9.65E-07	9.86E-07	1.09E-06	9.33E-07	8.85E-07	9.75E-07	8.96E-07	2.74E-05	1.09E-06	9.65E-07
La-140	3.07E-06	5.41E-06	2.59E-06	2.26E-06	4.76E-06	2.43E-06	2.14E-06	3.04E-05	2.69E-06	3.01E-06
Xe-133	1.44E-06	1.40E-06	1.67E-06	1.03E-06	1.03E-06	1.94E-06	9.02E-07	0.00E+00	1.67E-06	1.44E-06
Xe-135	8.26E-06	8.33E-06	9.50E-06	7.65E-06	6.95E-06	9.50E-06	6.48E-06	0.00E+00	9.50E-06	8.26E-06
Total	**1.55E-04**	**9.65E-05**	**1.39E-03**	**8.54E-05**	**8.09E-05**	**9.67E-05**	**7.92E-05**	**9.73E-03**	**1.79E-03**	**1.37E-04**

Table 4.5 - Human organ and tissue radiation doses during ES over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	2.94E-07	2.98E-07	3.45E-07	2.76E-07	2.52E-07	3.21E-07	2.52E-07	0.00E+00	3.45E-07	2.94E-07
Kr-88	8.06E-06	8.92E-06	8.50E-06	7.04E-06	6.78E-06	8.06E-06	6.36E-06	7.58E-06	9.35E-06	7.66E-06
I-131	9.16E-05	4.40E-05	1.04E-03	4.15E-05	3.74E-05	4.63E-05	3.90E-05	7.31E-03	1.33E-03	7.88E-05
I-132	5.59E-06	5.16E-06	1.94E-05	4.64E-06	4.22E-06	5.15E-06	4.28E-06	1.70E-04	2.10E-05	5.37E-06
I-133	4.78E-05	1.92E-05	6.08E-04	1.77E-05	1.62E-05	1.95E-05	1.67E-05	2.98E-03	8.39E-04	3.87E-05
I-134	9.41E-07	9.22E-07	1.67E-06	8.01E-07	7.46E-07	9.20E-07	7.26E-07	2.59E-05	1.80E-06	9.03E-07
I-135	1.79E-05	1.40E-05	1.05E-04	1.29E-05	1.18E-05	1.42E-05	1.21E-05	7.35E-04	1.18E-04	1.68E-05
Cs-134	1.66E-05	1.73E-05	1.92E-05	1.64E-05	1.50E-05	1.80E-05	1.56E-05	2.84E-05	1.92E-05	1.66E-05
Cs-137	1.80E-05	1.87E-05	2.07E-05	1.78E-05	1.64E-05	1.91E-05	1.69E-05	9.86E-05	2.07E-05	1.80E-05
La-140	3.07E-06	5.51E-06	2.59E-06	2.27E-06	4.76E-06	2.43E-06	2.15E-06	3.07E-05	2.70E-06	3.01E-06
Xe-133	1.44E-06	1.40E-06	1.67E-06	1.03E-06	1.03E-06	1.94E-06	9.02E-07	0.00E+00	1.67E-06	1.44E-06
Xe-135	8.26E-06	8.33E-06	9.50E-06	7.65E-06	6.95E-06	9.50E-06	6.48E-06	0.00E+00	9.50E-06	8.26E-06
Total	**2.19E-04**	**1.44E-04**	**1.84E-03**	**1.30E-04**	**1.22E-04**	**1.45E-04**	**1.21E-04**	**1.14E-02**	**2.38E-03**	**1.96E-04**

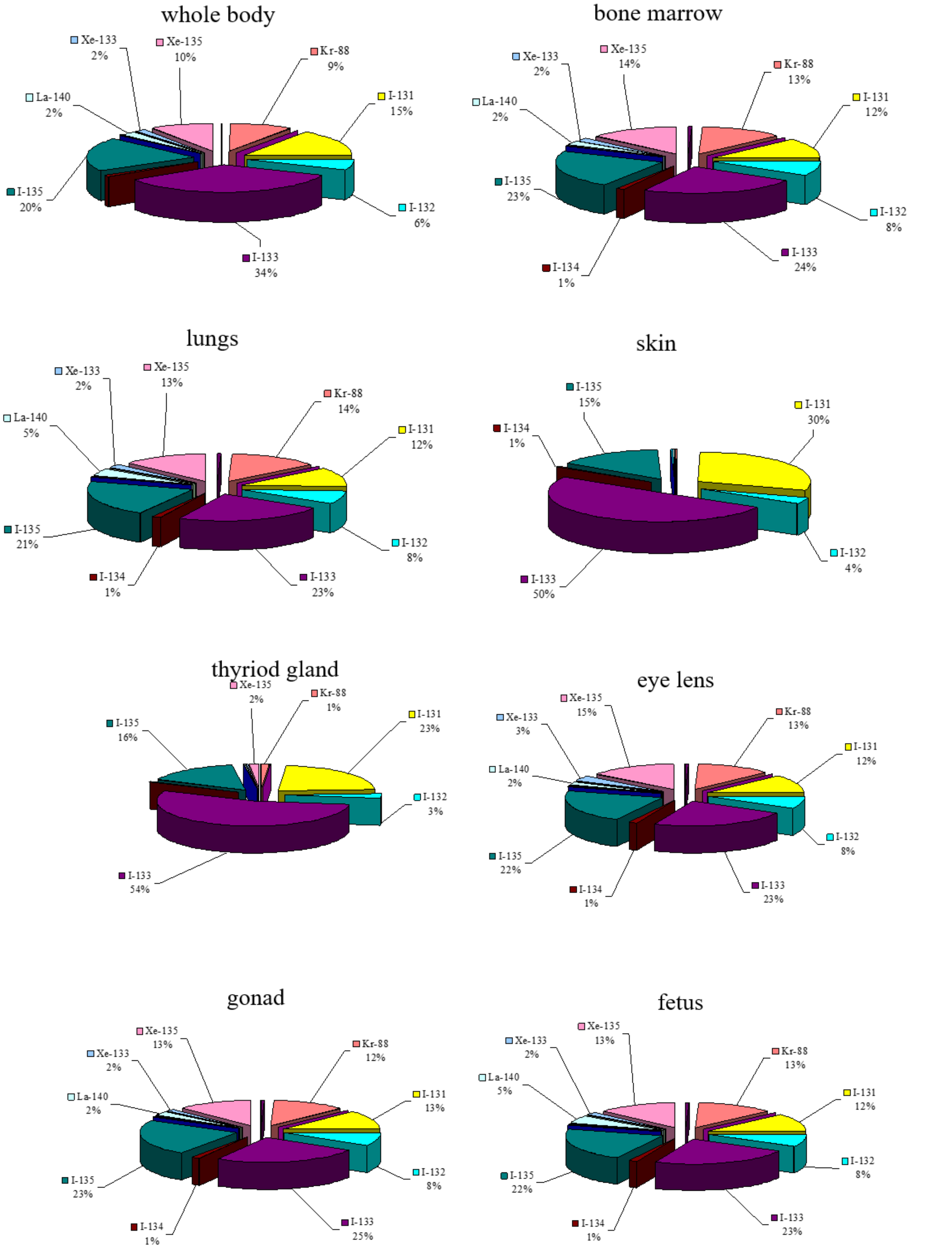
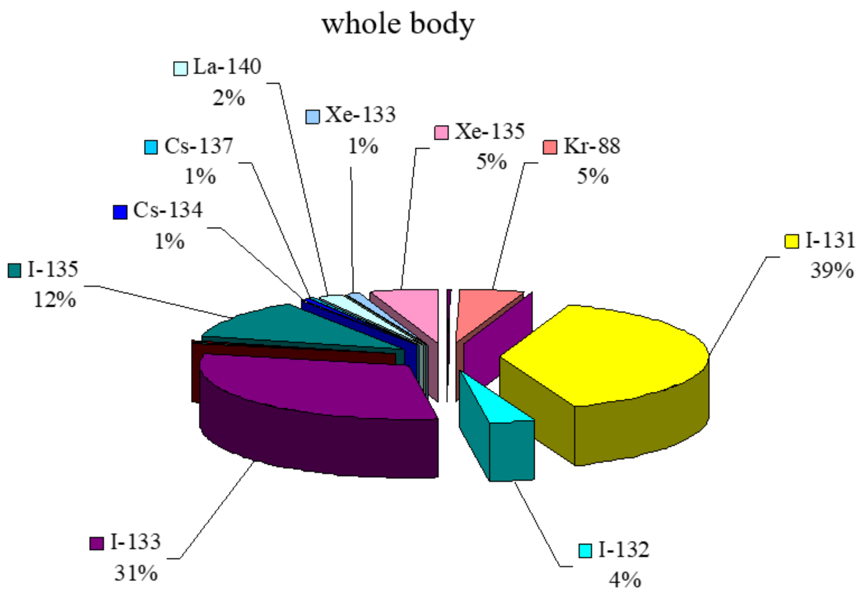
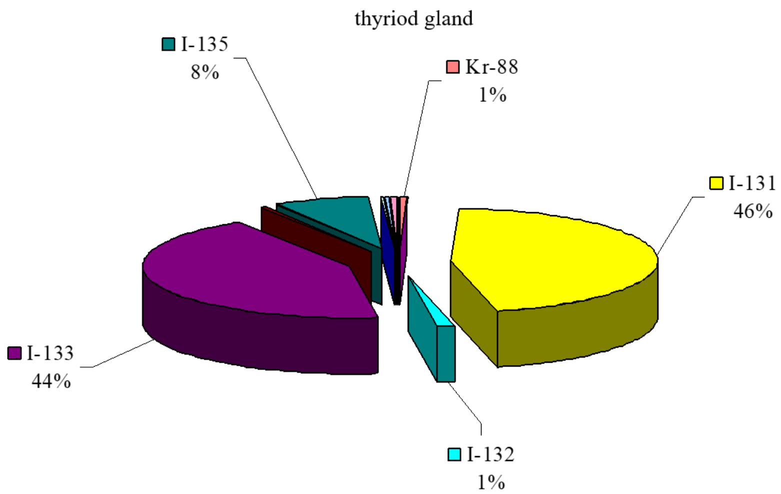


Figure 4.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period





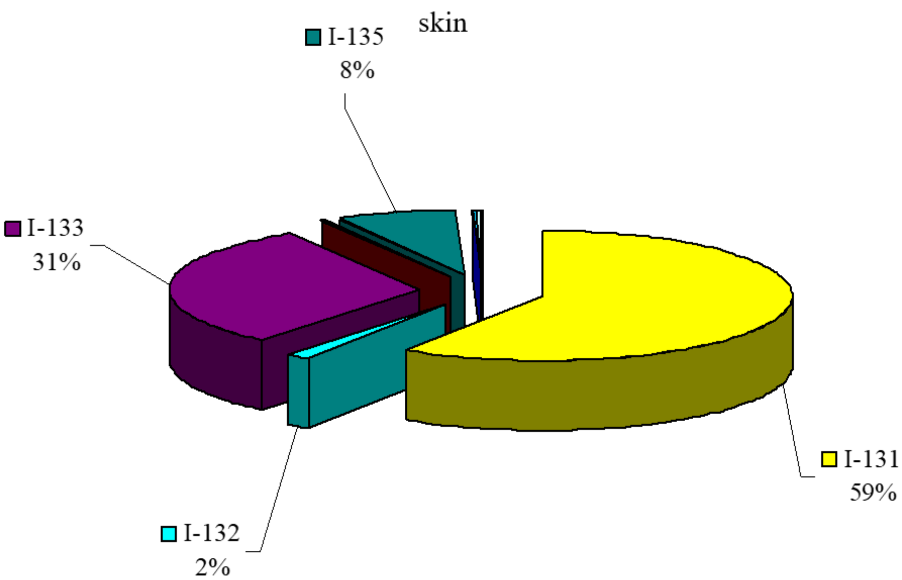
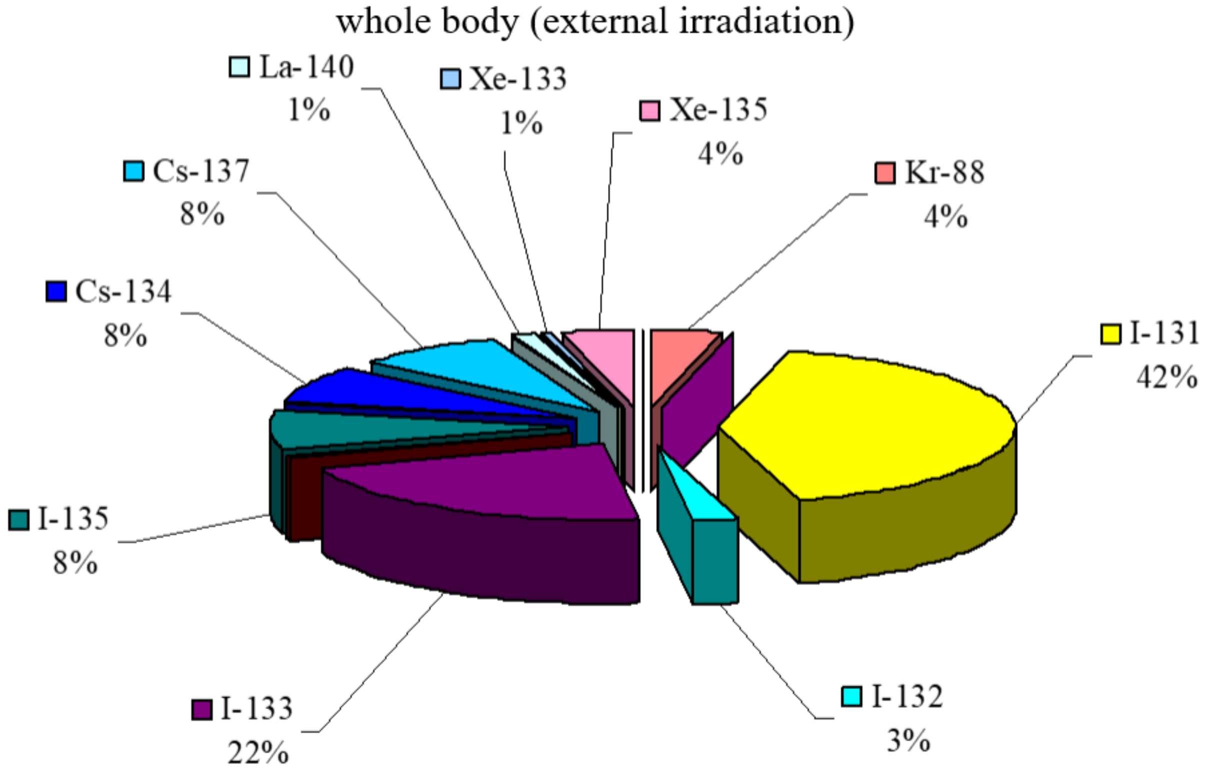


Figure 4.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



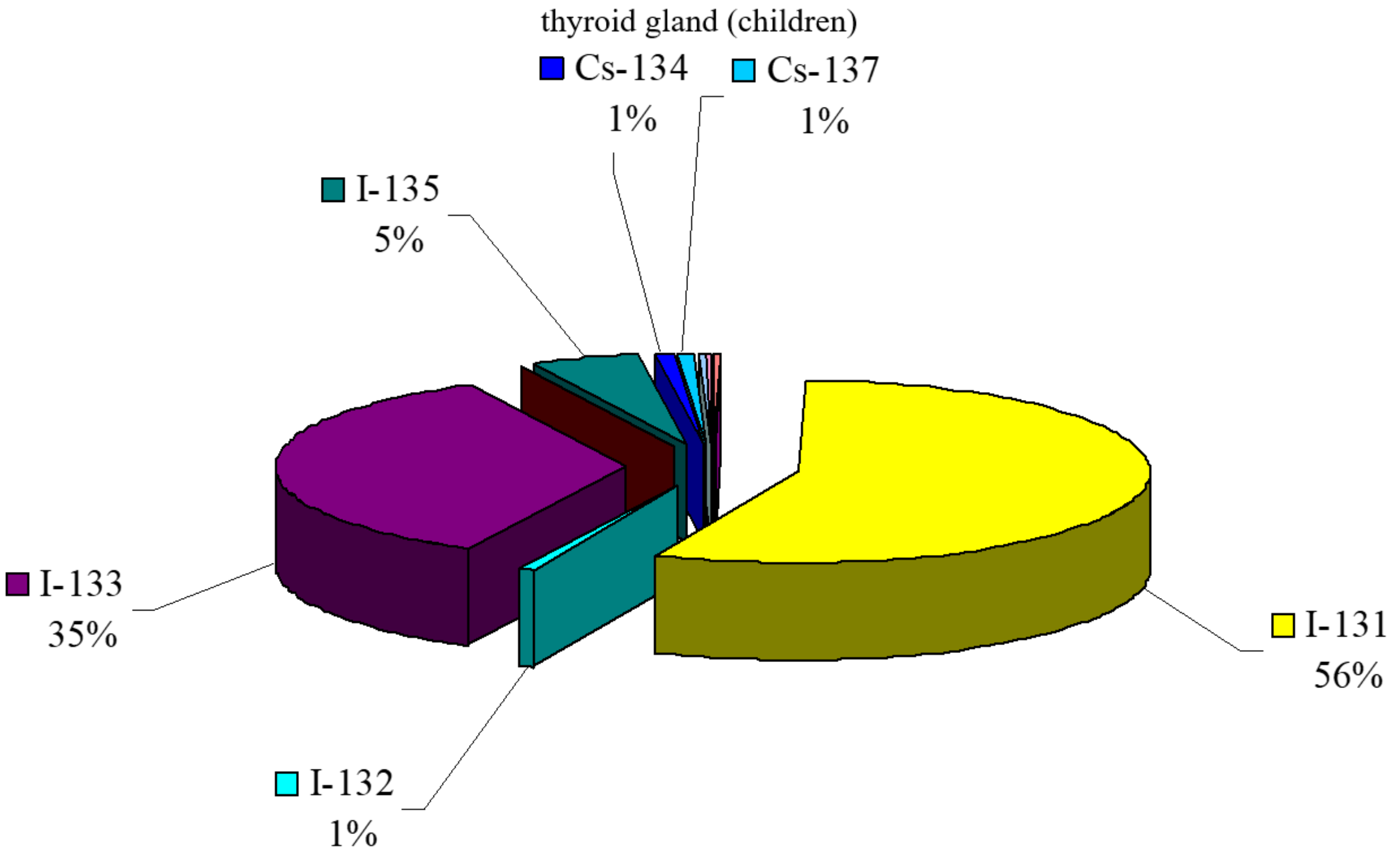


Figure 4.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

4.2.1 Radiation impact estimates for ES as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 4.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens , gonad and fetus.

Table 4.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	ES estimates, Gy
Entire body (bone marrow)[1]	1	7.90E-05 (5.62E-05)
Lungs	6	6.43E-05
Skin	3	4.80E-03
Thyroid gland	5	5.91E-04
Eye lens	2	6.42E-05
Gonad	2	5.18E-05
Fetus	0.1	5.30E-05

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 4.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 4.7, while calculation results for standardized values for ES are given in Table 4.8.

Table 4.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 4.8 - Dose estimates over the first 2 weeks following the ES

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.16	1.39	9.73

Based on the calculation results given in Table 4.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the ES upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

4.2.2Radiation impact estimates for ES as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during ES shall be 0.0024 Sv/year, and for the entire body due to external radiation - 0.00020 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

4.3 Calculation results for ES at the border of the OZ (30 km)

Table 4.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during ES.

Table 4.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during ES

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-87	8.96E+03	0.00E+00
Kr-88	4.94E+04	0.00E+00
I-131	1.67E+03	7.21E+05
I-132	3.40E+03	1.47E+06
I-133	5.25E+03	2.27E+06
I-134	1.43E+03	6.20E+05
I-135	4.28E+03	1.85E+06
Cs-134	2.37E+00	2.37E+03
Cs-137	5.99E+00	5.99E+03

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
La-140	2.84E+01	2.83E+04
Xe-133	7.83E+05	0.00E+00
Xe-135	5.81E+05	0.00E+00
Total	**1.44E+06**	**6.97E+06**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 78.3 kBq/m^3 for xenon isotopes. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 2.27 MBq/m^2 for ^{133}I, up to 1.85 MBq/m^2 for ^{135}I and up to 1.47 MBq/m^2 for ^{132}I.

Tables 4.10–4.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 4.4–4.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 1.27 mSv.

Table 4.10 - Human organ and tissue radiation doses during ES over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	2.45E-07	2.49E-07	2.87E-07	2.29E-07	2.11E-07	2.68E-07	2.11E-07	0.00E+00	2.87E-07	2.45E-07
Kr-88	5.46E-06	5.82E-06	6.08E-06	5.10E-06	4.82E-06	5.84E-06	4.66E-06	1.80E-06	6.69E-06	5.19E-06
I-131	6.63E-06	6.07E-06	2.30E-05	5.72E-06	5.19E-06	6.40E-06	5.39E-06	1.87E-04	2.81E-05	5.90E-06
I-132	4.01E-06	4.07E-06	6.88E-06	3.81E-06	3.45E-06	4.26E-06	3.58E-06	2.93E-05	7.43E-06	3.85E-06
I-133	1.34E-05	1.19E-05	5.41E-05	1.12E-05	1.01E-05	1.25E-05	1.06E-05	3.22E-04	7.03E-05	1.14E-05
I-134	8.11E-07	8.31E-07	1.10E-06	7.66E-07	7.00E-07	8.66E-07	7.16E-07	7.08E-06	1.19E-06	7.79E-07
I-135	1.12E-05	1.11E-05	2.35E-05	1.05E-05	9.48E-06	1.17E-05	9.88E-06	1.05E-04	2.64E-05	1.05E-05
Cs-134	7.52E-08	7.83E-08	8.72E-08	7.41E-08	6.72E-08	8.32E-08	6.99E-08	2.37E-08	8.72E-08	7.52E-08
Cs-137	7.00E-08	7.31E-08	8.11E-08	6.89E-08	6.25E-08	7.74E-08	6.52E-08	8.00E-08	8.27E-08	6.93E-08
La-140	6.60E-07	7.10E-07	7.57E-07	6.45E-07	6.11E-07	7.23E-07	6.08E-07	3.25E-07	7.87E-07	6.47E-07
Xe-133	7.24E-07	7.04E-07	8.38E-07	5.20E-07	5.20E-07	9.72E-07	4.52E-07	0.00E+00	8.38E-07	7.24E-07
Xe-135	4.44E-06	4.47E-06	5.10E-06	4.10E-06	3.72E-06	5.10E-06	3.49E-06	0.00E+00	5.10E-06	4.44E-06
Total	**4.78E-05**	**4.61E-05**	**1.22E-04**	**4.28E-05**	**3.90E-05**	**4.88E-05**	**3.97E-05**	**6.54E-04**	**1.47E-04**	**4.39E-05**

Table 4.11 - Human organ and tissue radiation doses during ES over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	2.45E-07	2.49E-07	2.87E-07	2.29E-07	2.11E-07	2.68E-07	2.11E-07	0.00E+00	2.87E-07	2.45E-07
Kr-88	5.46E-06	5.82E-06	6.08E-06	5.10E-06	4.82E-06	5.84E-06	4.66E-06	1.80E-06	6.69E-06	5.19E-06
I-131	2.91E-05	2.63E-05	1.08E-04	2.49E-05	2.26E-05	2.81E-05	2.36E-05	7.49E-04	1.34E-04	2.56E-05
I-132	4.01E-06	4.07E-06	6.88E-06	3.81E-06	3.45E-06	4.26E-06	3.58E-06	2.93E-05	7.43E-06	3.85E-06
I-133	1.88E-05	1.55E-05	9.54E-05	1.46E-05	1.33E-05	1.64E-05	1.38E-05	3.99E-04	1.32E-04	1.52E-05
I-134	8.11E-07	8.31E-07	1.10E-06	7.66E-07	7.00E-07	8.66E-07	7.16E-07	7.08E-06	1.19E-06	7.79E-07
I-135	1.15E-05	1.13E-05	2.54E-05	1.07E-05	9.64E-06	1.19E-05	1.00E-05	1.05E-04	2.85E-05	1.08E-05
Cs-134	5.15E-07	5.38E-07	5.96E-07	5.08E-07	4.60E-07	5.69E-07	4.81E-07	1.45E-07	5.96E-07	5.15E-07
Cs-137	4.81E-07	5.02E-07	5.57E-07	4.75E-07	4.31E-07	5.30E-07	4.49E-07	4.90E-07	5.57E-07	4.81E-07
La-140	1.17E-06	1.26E-06	1.34E-06	1.14E-06	1.08E-06	1.28E-06	1.08E-06	5.54E-07	1.39E-06	1.14E-06
Xe-133	7.24E-07	7.04E-07	8.38E-07	5.20E-07	5.20E-07	9.72E-07	4.52E-07	0.00E+00	8.38E-07	7.24E-07
Xe-135	4.44E-06	4.47E-06	5.10E-06	4.10E-06	3.72E-06	5.10E-06	3.49E-06	0.00E+00	5.10E-06	4.44E-06
Total	**7.72E-05**	**7.16E-05**	**2.51E-04**	**6.69E-05**	**6.09E-05**	**7.61E-05**	**6.25E-05**	**1.29E-03**	**3.18E-04**	**6.90E-05**

Table 4.12 - Human organ and tissue radiation doses during ES over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	2.45E-07	2.49E-07	2.87E-07	2.29E-07	2.11E-07	2.68E-07	2.11E-07	0.00E+00	2.87E-07	2.45E-07
Kr-88	5.46E-06	5.82E-06	6.08E-06	5.10E-06	4.82E-06	5.84E-06	4.66E-06	1.80E-06	6.69E-06	5.19E-06
I-131	4.20E-05	3.72E-05	1.71E-04	3.52E-05	3.19E-05	3.95E-05	3.31E-05	9.54E-04	2.19E-04	3.61E-05
I-132	4.01E-06	4.07E-06	6.88E-06	3.81E-06	3.45E-06	4.26E-06	3.58E-06	2.93E-05	7.43E-06	3.85E-06
I-133	1.90E-05	1.57E-05	9.62E-05	1.48E-05	1.34E-05	1.65E-05	1.40E-05	3.99E-04	1.33E-04	1.54E-05
I-134	8.11E-07	8.31E-07	1.10E-06	7.66E-07	7.00E-07	8.66E-07	7.16E-07	7.08E-06	1.19E-06	7.79E-07
I-135	1.15E-05	1.13E-05	2.54E-05	1.07E-05	9.64E-06	1.19E-05	1.00E-05	1.05E-04	2.85E-05	1.08E-05
Cs-134	8.90E-06	9.28E-06	1.03E-05	8.80E-06	7.98E-06	9.85E-06	8.30E-06	5.06E-07	1.03E-05	8.90E-06
Cs-137	9.49E-06	9.91E-06	1.10E-05	9.38E-06	8.53E-06	1.05E-05	8.85E-06	1.77E-06	1.10E-05	9.49E-06
La-140	1.17E-06	1.27E-06	1.34E-06	1.14E-06	1.09E-06	1.28E-06	1.08E-06	5.56E-07	1.40E-06	1.15E-06
Xe-133	7.24E-07	7.04E-07	8.38E-07	5.20E-07	5.20E-07	9.72E-07	4.52E-07	0.00E+00	8.38E-07	7.24E-07
Xe-135	4.44E-06	4.47E-06	5.10E-06	4.10E-06	3.72E-06	5.10E-06	3.49E-06	0.00E+00	5.10E-06	4.44E-06
Total	**1.08E-04**	**1.01E-04**	**3.36E-04**	**9.44E-05**	**8.60E-05**	**1.07E-04**	**8.85E-05**	**1.50E-03**	**4.25E-04**	**9.70E-05**

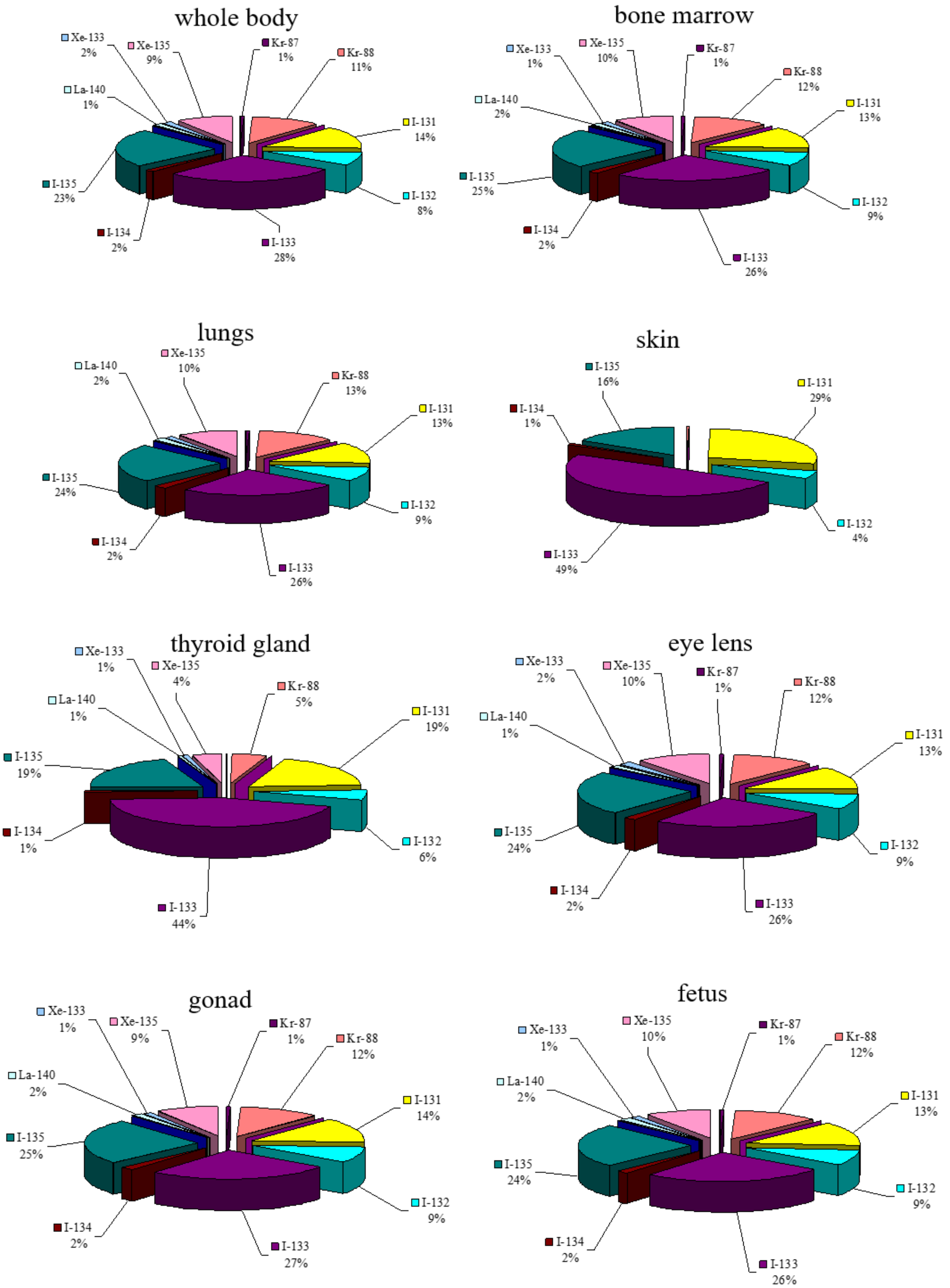


Figure 4.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

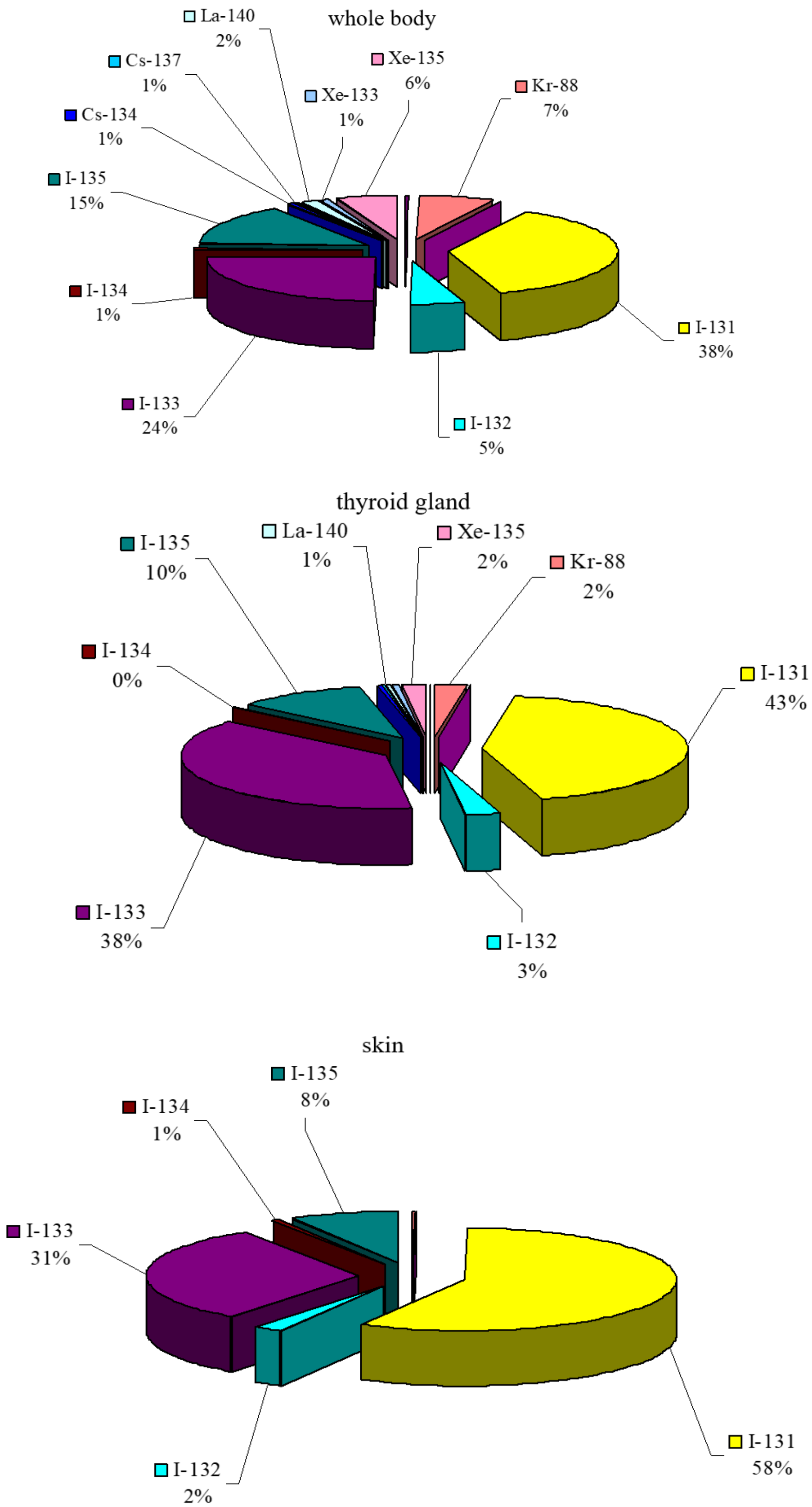
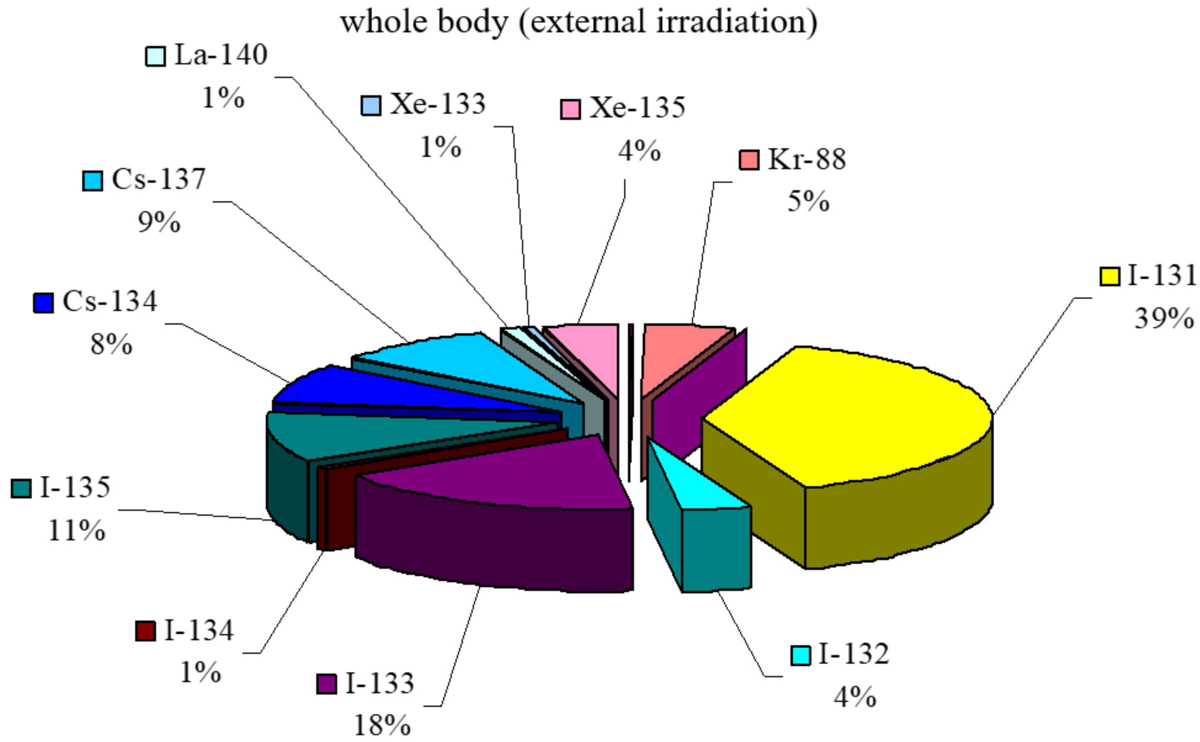


Figure 4.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



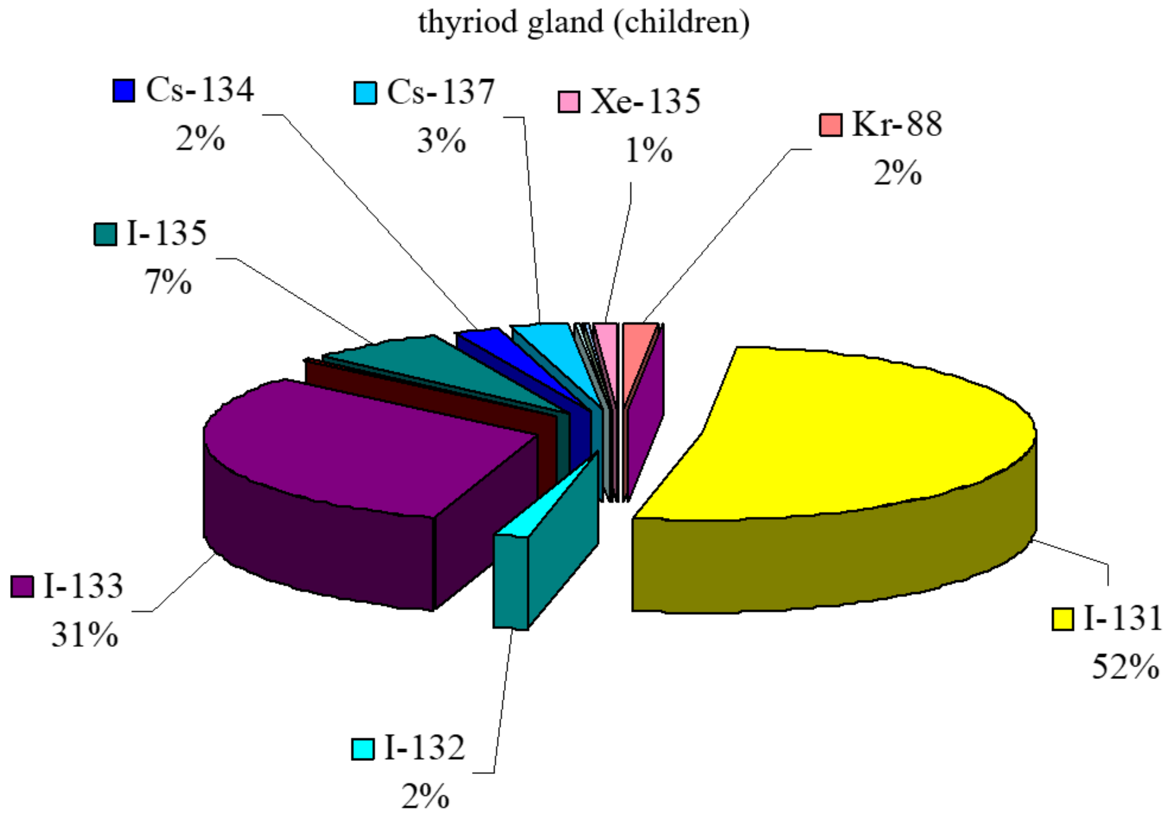


Figure 4.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

4.3.1 Radiation impact estimates for ES as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 4.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 4.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	ES estimates, Gy
Entire body (bone marrow)[1]	1	4.39E-05 (4.28E-05)
Lungs	6	4.61E-05
Skin	3	6.54E-04
Thyroid gland	5	1.22E-04
Eye lens	2	4.88E-05
Gonad	2	3.97E-05
Fetus	0.1	3.90E-05

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 4.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 4.14, while calculation results for standardized values for ES are given in Table 4.15.

Table 4.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 4.15 - Dose estimates over the first 2 weeks following the ES

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.069	0.25	1.29

Based on the calculation results given in Table 4.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the ES upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

4.3.2 Radiation impact estimates for ES as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
  - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
  - 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during ES shall be 0.00043 Sv/year, and for the entire body due to external radiation - 0.000097 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

5 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT “STEAM GENERATOR HEADER COVER LIFT-UP - PRE-EMERGENCY SPIKE” (PES)

5.1 Input data for calculating radiation exposure during PES

Effective values of the total environmental radioactive release are shown in Table 5.1.

Table 5.1 - Radioactive release during PES

Radionuclide	Environmental release, Bq
Kr-88	2.00E+13
I-131	4.50E+12
I-132	1.60E+13
I-133	1.54E+13
I-134	1.70E+13
I-135	1.30E+13
Cs-134	2.10E+11
Cs-137	5.30E+11
La-140	2.60E+12
Xe-135	1.70E+14
Total activity	2.59E+14

5.2 Calculation results for PES at the border of the SPZ (2.5 km)

Table 5.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during PES.

Table 5.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during PES

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-88	7.89E+03	0.00E+00
I-131	2.28E+03	1.50E+05
I-132	3.42E+03	2.26E+05
I-133	7.12E+03	4.70E+05
I-134	8.93E+02	5.88E+04
I-135	4.91E+03	3.24E+05
Cs-134	1.32E+02	4.31E+03
Cs-137	3.34E+02	1.09E+04
La-140	1.56E+03	5.07E+04
Xe-135	1.08E+05	0.00E+00
Total	**1.37E+05**	**1.29E+06**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 108 kBq/m^3 for xenon-135 isotopes. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 470 kBq/m^2 for ^{133}I, up to 324 kBq/m^2 for ^{135}I and up to 226 kBq/m^2 for ^{132}I.

Tables 5.3–5.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 5.1–5.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.55 mSv.

Table 5.3 - Human organ and tissue radiation doses during PES over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	8.06E-07	8.92E-07	8.50E-07	7.04E-07	6.78E-07	8.06E-07	6.36E-07	7.58E-07	9.35E-07	7.66E-07
I-131	2.37E-06	1.32E-06	2.37E-05	1.22E-06	1.11E-06	1.36E-06	1.15E-06	2.56E-04	2.89E-05	2.11E-06
I-132	9.73E-07	8.98E-07	3.38E-06	8.06E-07	7.34E-07	8.96E-07	7.44E-07	2.96E-05	3.65E-06	9.34E-07
I-133	5.37E-06	2.70E-06	5.85E-05	2.47E-06	2.26E-06	2.72E-06	2.33E-06	4.37E-04	7.60E-05	4.57E-06
I-134	1.60E-07	1.57E-07	2.84E-07	1.36E-07	1.27E-07	1.56E-07	1.23E-07	4.40E-06	3.07E-07	1.54E-07
I-135	2.81E-06	2.26E-06	1.53E-05	2.08E-06	1.90E-06	2.30E-06	1.96E-06	1.20E-04	1.72E-05	2.64E-06
Cs-134	1.58E-07	1.57E-07	1.74E-07	1.48E-07	1.37E-07	1.59E-07	1.40E-07	1.33E-06	1.74E-07	1.58E-07
Cs-137	1.54E-07	1.53E-07	1.65E-07	1.42E-07	1.34E-07	1.47E-07	1.35E-07	4.47E-06	1.68E-07	1.53E-07
La-140	1.81E-06	2.91E-06	1.52E-06	1.33E-06	2.59E-06	1.43E-06	1.27E-06	1.78E-05	1.58E-06	1.78E-06
Xe-135	8.26E-07	8.33E-07	9.50E-07	7.65E-07	6.95E-07	9.50E-07	6.48E-07	0.00E+00	9.50E-07	8.26E-07
Total	**1.54E-05**	**1.23E-05**	**1.05E-04**	**9.81E-06**	**1.04E-05**	**1.09E-05**	**9.14E-06**	**8.72E-04**	**1.30E-04**	**1.41E-05**

Table 5.4 - Human organ and tissue radiation doses during PES over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	8.06E-07	8.92E-07	8.50E-07	7.04E-07	6.78E-07	8.06E-07	6.36E-07	7.58E-07	9.35E-07	7.66E-07
I-131	1.07E-05	5.54E-06	1.13E-04	5.22E-06	4.73E-06	5.85E-06	4.91E-06	1.02E-03	1.40E-04	9.39E-06
I-132	9.73E-07	8.98E-07	3.38E-06	8.06E-07	7.34E-07	8.96E-07	7.44E-07	2.96E-05	3.65E-06	9.34E-07
I-133	8.66E-06	3.45E-06	1.10E-04	3.19E-06	2.92E-06	3.50E-06	3.01E-06	5.42E-04	1.52E-04	7.01E-06
I-134	1.60E-07	1.57E-07	2.84E-07	1.36E-07	1.27E-07	1.56E-07	1.23E-07	4.40E-06	3.07E-07	1.54E-07
I-135	2.94E-06	2.30E-06	1.73E-05	2.12E-06	1.94E-06	2.34E-06	1.99E-06	1.21E-04	1.94E-05	2.76E-06
Cs-134	9.95E-07	1.02E-06	1.14E-06	9.72E-07	8.99E-07	1.04E-06	9.26E-07	8.09E-06	1.14E-06	9.95E-07
Cs-137	9.65E-07	9.86E-07	1.09E-06	9.33E-07	8.85E-07	9.75E-07	8.96E-07	2.74E-05	1.09E-06	9.65E-07
La-140	3.07E-06	5.41E-06	2.59E-06	2.26E-06	4.76E-06	2.43E-06	2.14E-06	3.04E-05	2.69E-06	3.01E-06
Xe-135	8.26E-07	8.33E-07	9.50E-07	7.65E-07	6.95E-07	9.50E-07	6.48E-07	0.00E+00	9.50E-07	8.26E-07
Total	**3.01E-05**	**2.15E-05**	**2.51E-04**	**1.71E-05**	**1.84E-05**	**1.89E-05**	**1.60E-05**	**1.79E-03**	**3.22E-04**	**2.68E-05**

Table 5.5 - Human organ and tissue radiation doses during PES over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	8.06E-07	8.92E-07	8.50E-07	7.04E-07	6.78E-07	8.06E-07	6.36E-07	7.58E-07	9.35E-07	7.66E-07
I-131	1.63E-05	7.83E-06	1.85E-04	7.38E-06	6.66E-06	8.24E-06	6.93E-06	1.30E-03	2.37E-04	1.40E-05
I-132	9.73E-07	8.98E-07	3.38E-06	8.06E-07	7.34E-07	8.96E-07	7.44E-07	2.96E-05	3.65E-06	9.34E-07
I-133	8.69E-06	3.50E-06	1.11E-04	3.22E-06	2.95E-06	3.55E-06	3.04E-06	5.42E-04	1.53E-04	7.04E-06
I-134	1.60E-07	1.57E-07	2.84E-07	1.36E-07	1.27E-07	1.56E-07	1.23E-07	4.40E-06	3.07E-07	1.54E-07
I-135	2.94E-06	2.30E-06	1.73E-05	2.12E-06	1.94E-06	2.34E-06	1.99E-06	1.21E-04	1.94E-05	2.76E-06
Cs-134	1.66E-05	1.73E-05	1.92E-05	1.64E-05	1.50E-05	1.80E-05	1.56E-05	2.84E-05	1.92E-05	1.66E-05
Cs-137	1.80E-05	1.87E-05	2.07E-05	1.78E-05	1.64E-05	1.91E-05	1.69E-05	9.86E-05	2.07E-05	1.80E-05
La-140	3.07E-06	5.51E-06	2.59E-06	2.27E-06	4.76E-06	2.43E-06	2.15E-06	3.07E-05	2.70E-06	3.01E-06
Xe-135	8.26E-07	8.33E-07	9.50E-07	7.65E-07	6.95E-07	9.50E-07	6.48E-07	0.00E+00	9.50E-07	8.26E-07
Total	**6.84E-05**	**5.79E-05**	**3.61E-04**	**5.16E-05**	**4.99E-05**	**5.64E-05**	**4.87E-05**	**2.16E-03**	**4.58E-04**	**6.41E-05**

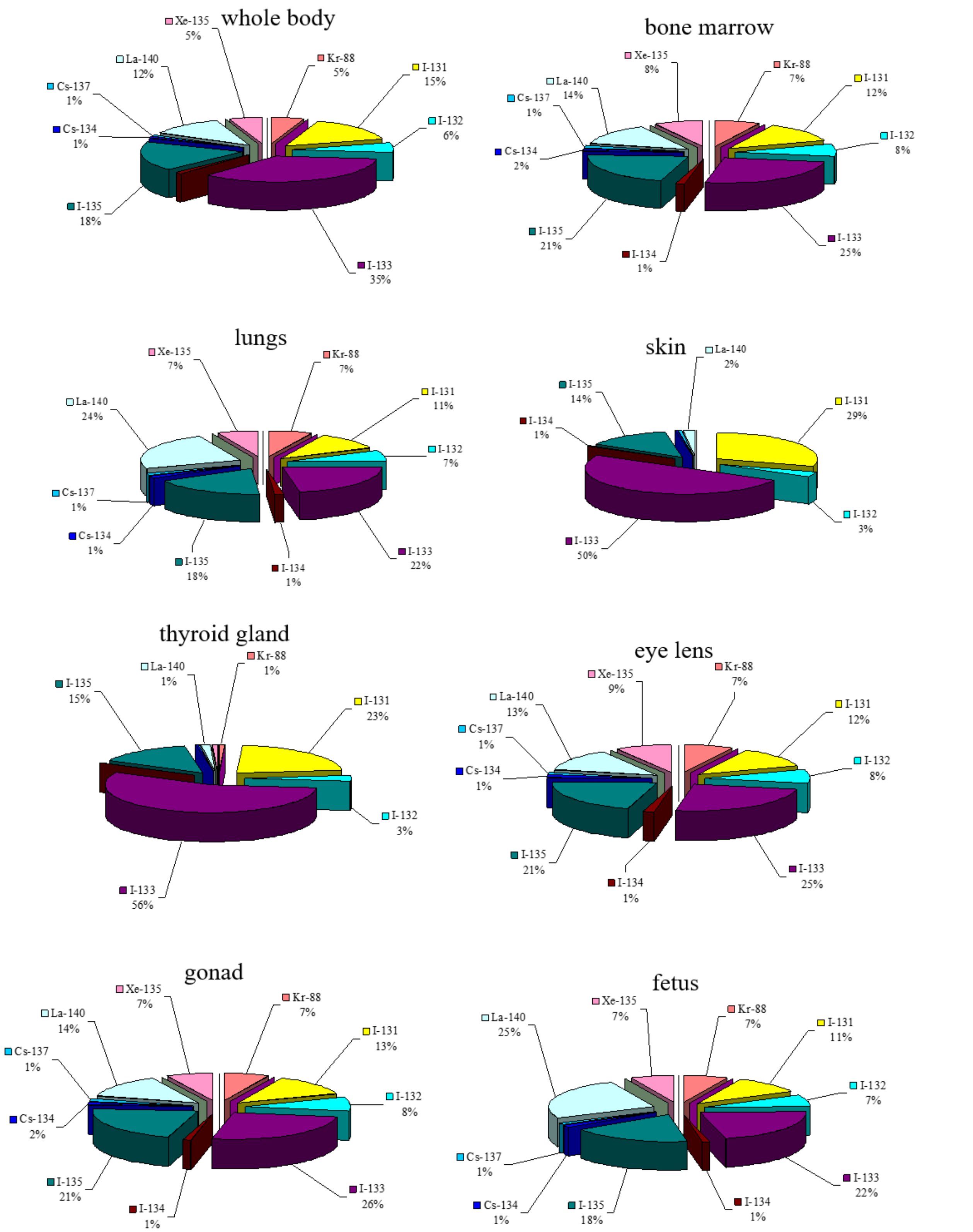


Figure 5.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

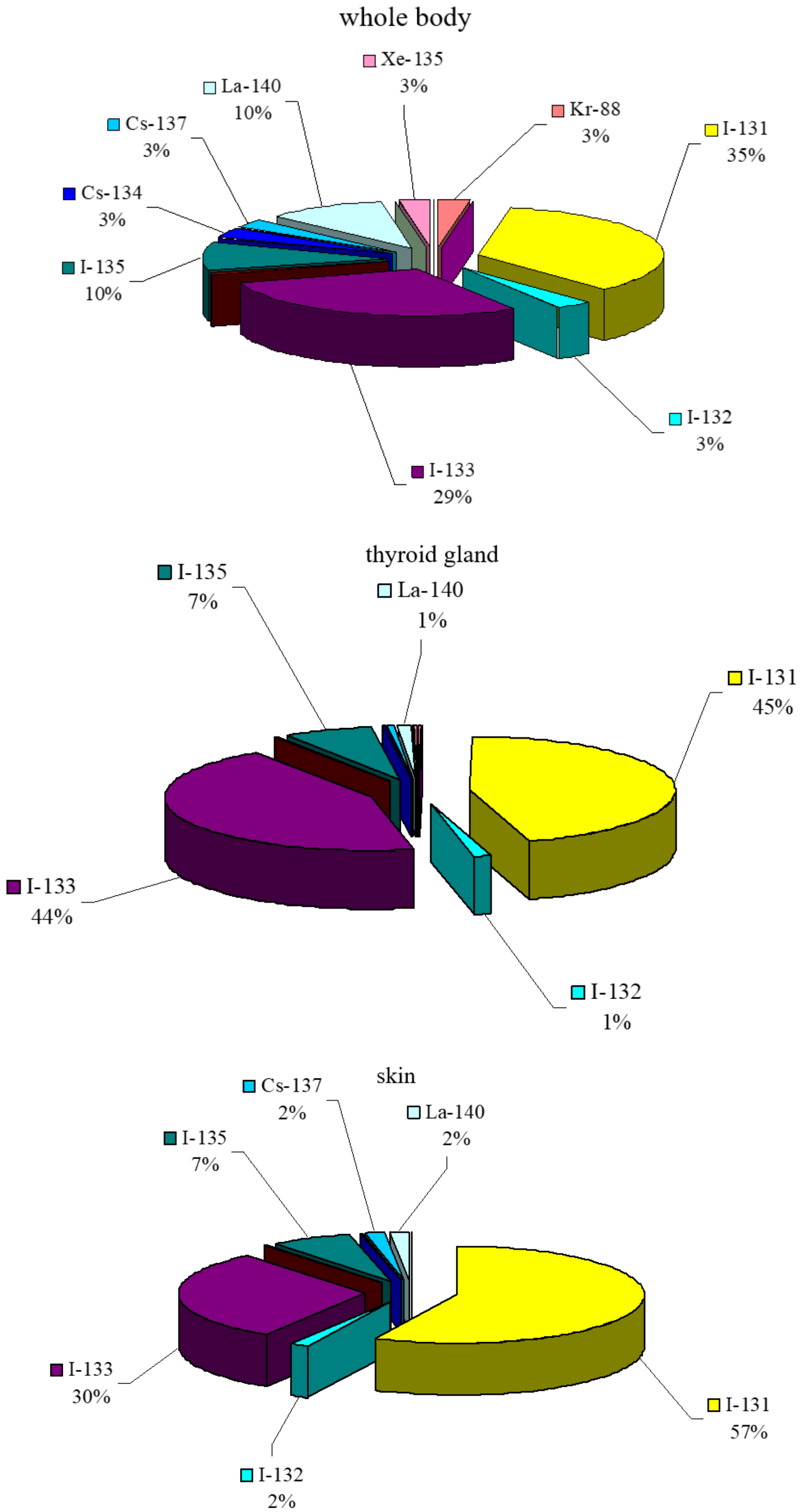


Figure 5.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

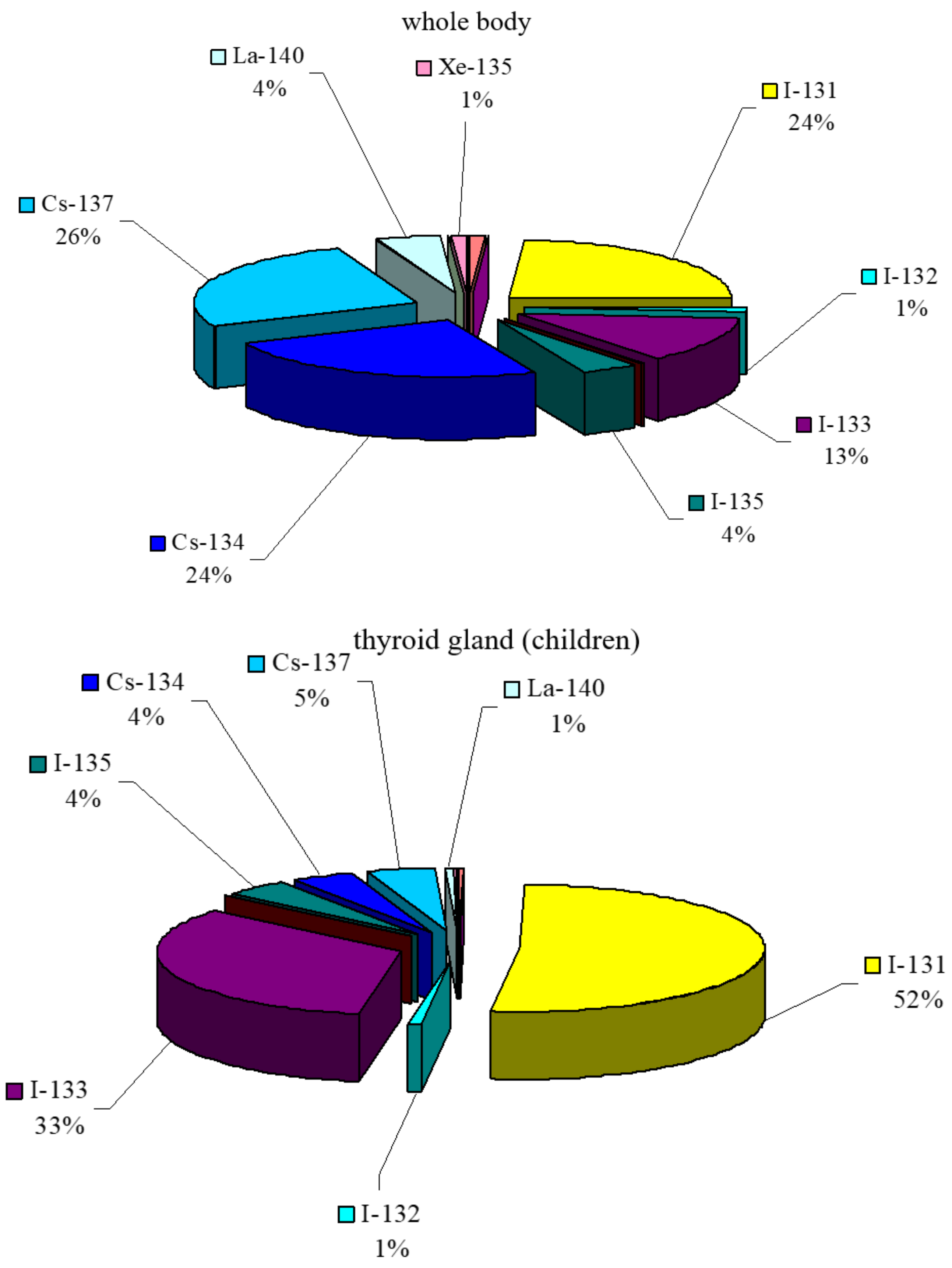


Figure 5.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

5.2.1Radiation impact estimates for PES as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 5.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 5.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	PES estimates, Gy
Entire body (bone marrow)[1]	1	1.41E-05 (9.81E-06)
Lungs	6	1.23E-05
Skin	3	8.72E-04
Thyroid gland	5	1.05E-04
Eye lens	2	1.09E-05
Gonad	2	9.14E-06
Fetus	0.1	1.04E-05

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 5.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 5.7, while calculation results for standardized values for PES are given in Table 5.8.

Table 5.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 5.8 - Dose estimates over the first 2 weeks following the PES

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.030	0.25	1.79

Based on the calculation results given in Table 5.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the PES upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

5.2.2Radiation impact estimates for PES as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during PES shall be 0.00046 Sv/year, and for the entire body due to external radiation - 0.000064 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

5.3 Calculation results for PES at the border of the OZ (30 km)

Table 5.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during PES.

Table 5.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during PES

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-88	4.94E+03	0.00E+00
I-131	2.96E+02	1.28E+05
I-132	5.91E+02	2.56E+05
I-133	9.55E+02	4.13E+05
I-134	2.43E+02	1.05E+05
I-135	7.04E+02	3.04E+05
Cs-134	2.37E+00	2.37E+03
Cs-137	5.99E+00	5.99E+03

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
La-140	2.84E+01	2.83E+04
Xe-135	5.81E+04	0.00E+00
Total	**6.59E+04**	**1.24E+06**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 58.1 kBq/m^3 for xenon-135 isotopes. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 413 kBq/m^2 for ^{133}I, up to 304 kBq/m^2 for ^{135}I and up to 256 kBq/m^2 for ^{132}I.

Tables 5.10–5.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 5.4–5.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.37 mSv.

Table 5.10 - Human organ and tissue radiation doses during PES over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	5.46E-07	5.82E-07	6.08E-07	5.10E-07	4.82E-07	5.84E-07	4.66E-07	1.80E-07	6.69E-07	5.19E-07
I-131	1.18E-06	1.08E-06	4.10E-06	1.02E-06	9.23E-07	1.14E-06	9.59E-07	3.33E-05	5.00E-06	1.05E-06
I-132	6.98E-07	7.07E-07	1.20E-06	6.62E-07	6.00E-07	7.41E-07	6.22E-07	5.09E-06	1.29E-06	6.70E-07
I-133	2.44E-06	2.16E-06	9.84E-06	2.04E-06	1.84E-06	2.27E-06	1.92E-06	5.86E-05	1.28E-05	2.07E-06
I-134	1.38E-07	1.41E-07	1.87E-07	1.30E-07	1.19E-07	1.47E-07	1.22E-07	1.20E-06	2.02E-07	1.32E-07
I-135	1.85E-06	1.83E-06	3.87E-06	1.73E-06	1.56E-06	1.92E-06	1.63E-06	1.73E-05	4.34E-06	1.74E-06
Cs-134	7.52E-08	7.83E-08	8.72E-08	7.41E-08	6.72E-08	8.32E-08	6.99E-08	2.37E-08	8.72E-08	7.52E-08
Cs-137	7.00E-08	7.31E-08	8.11E-08	6.89E-08	6.25E-08	7.74E-08	6.52E-08	8.00E-08	8.27E-08	6.93E-08
La-140	6.60E-07	7.10E-07	7.57E-07	6.45E-07	6.11E-07	7.23E-07	6.08E-07	3.25E-07	7.87E-07	6.47E-07
Xe-135	4.44E-07	4.47E-07	5.10E-07	4.10E-07	3.72E-07	5.10E-07	3.49E-07	0.00E+00	5.10E-07	4.44E-07
Total	**8.10E-06**	**7.82E-06**	**2.12E-05**	**7.29E-06**	**6.64E-06**	**8.20E-06**	**6.80E-06**	**1.16E-04**	**2.58E-05**	**7.42E-06**

Table 5.11 - Human organ and tissue radiation doses during PES over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	5.46E-07	5.82E-07	6.08E-07	5.10E-07	4.82E-07	5.84E-07	4.66E-07	1.80E-07	6.69E-07	5.19E-07
I-131	5.18E-06	4.68E-06	1.92E-05	4.44E-06	4.02E-06	5.00E-06	4.19E-06	1.33E-04	2.38E-05	4.55E-06
I-132	6.98E-07	7.07E-07	1.20E-06	6.62E-07	6.00E-07	7.41E-07	6.22E-07	5.09E-06	1.29E-06	6.70E-07
I-133	3.42E-06	2.82E-06	1.73E-05	2.66E-06	2.41E-06	2.98E-06	2.52E-06	7.26E-05	2.39E-05	2.77E-06
I-134	1.38E-07	1.41E-07	1.87E-07	1.30E-07	1.19E-07	1.47E-07	1.22E-07	1.20E-06	2.02E-07	1.32E-07
I-135	1.89E-06	1.86E-06	4.19E-06	1.76E-06	1.59E-06	1.96E-06	1.65E-06	1.73E-05	4.69E-06	1.77E-06
Cs-134	5.15E-07	5.38E-07	5.96E-07	5.08E-07	4.60E-07	5.69E-07	4.81E-07	1.45E-07	5.96E-07	5.15E-07
Cs-137	4.81E-07	5.02E-07	5.57E-07	4.75E-07	4.31E-07	5.30E-07	4.49E-07	4.90E-07	5.57E-07	4.81E-07
La-140	1.17E-06	1.26E-06	1.34E-06	1.14E-06	1.08E-06	1.28E-06	1.08E-06	5.54E-07	1.39E-06	1.14E-06
Xe-135	4.44E-07	4.47E-07	5.10E-07	4.10E-07	3.72E-07	5.10E-07	3.49E-07	0.00E+00	5.10E-07	4.44E-07
Total	**1.45E-05**	**1.35E-05**	**4.57E-05**	**1.27E-05**	**1.16E-05**	**1.43E-05**	**1.19E-05**	**2.31E-04**	**5.76E-05**	**1.30E-05**

Table 5.12 - Human organ and tissue radiation doses during PES over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	5.46E-07	5.82E-07	6.08E-07	5.10E-07	4.82E-07	5.84E-07	4.66E-07	1.80E-07	6.69E-07	5.19E-07
I-131	7.47E-06	6.62E-06	3.05E-05	6.26E-06	5.67E-06	7.02E-06	5.90E-06	1.70E-04	3.90E-05	6.42E-06
I-132	6.98E-07	7.07E-07	1.20E-06	6.62E-07	6.00E-07	7.41E-07	6.22E-07	5.09E-06	1.29E-06	6.70E-07
I-133	3.45E-06	2.86E-06	1.75E-05	2.69E-06	2.44E-06	3.01E-06	2.55E-06	7.26E-05	2.41E-05	2.80E-06
I-134	1.38E-07	1.41E-07	1.87E-07	1.30E-07	1.19E-07	1.47E-07	1.22E-07	1.20E-06	2.02E-07	1.32E-07
I-135	1.89E-06	1.86E-06	4.19E-06	1.76E-06	1.59E-06	1.96E-06	1.65E-06	1.73E-05	4.69E-06	1.77E-06
Cs-134	8.90E-06	9.28E-06	1.03E-05	8.80E-06	7.98E-06	9.85E-06	8.30E-06	5.06E-07	1.03E-05	8.90E-06
Cs-137	9.49E-06	9.91E-06	1.10E-05	9.38E-06	8.53E-06	1.05E-05	8.85E-06	1.77E-06	1.10E-05	9.49E-06
La-140	1.17E-06	1.27E-06	1.34E-06	1.14E-06	1.09E-06	1.28E-06	1.08E-06	5.56E-07	1.40E-06	1.15E-06
Xe-135	4.44E-07	4.47E-07	5.10E-07	4.10E-07	3.72E-07	5.10E-07	3.49E-07	0.00E+00	5.10E-07	4.44E-07
Total	**3.42E-05**	**3.37E-05**	**7.73E-05**	**3.17E-05**	**2.89E-05**	**3.56E-05**	**2.99E-05**	**2.69E-04**	**9.33E-05**	**3.23E-05**

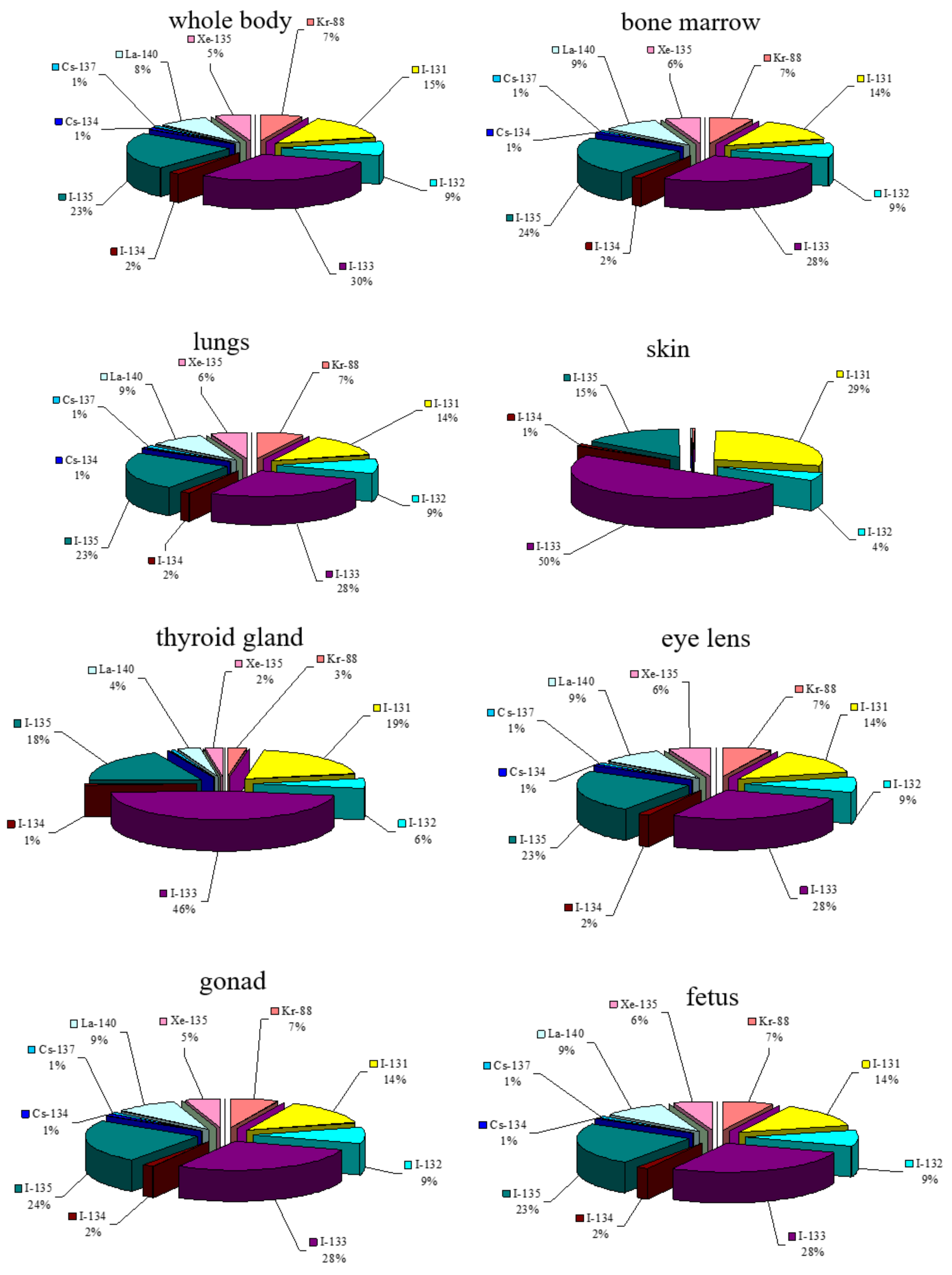


Figure 5.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

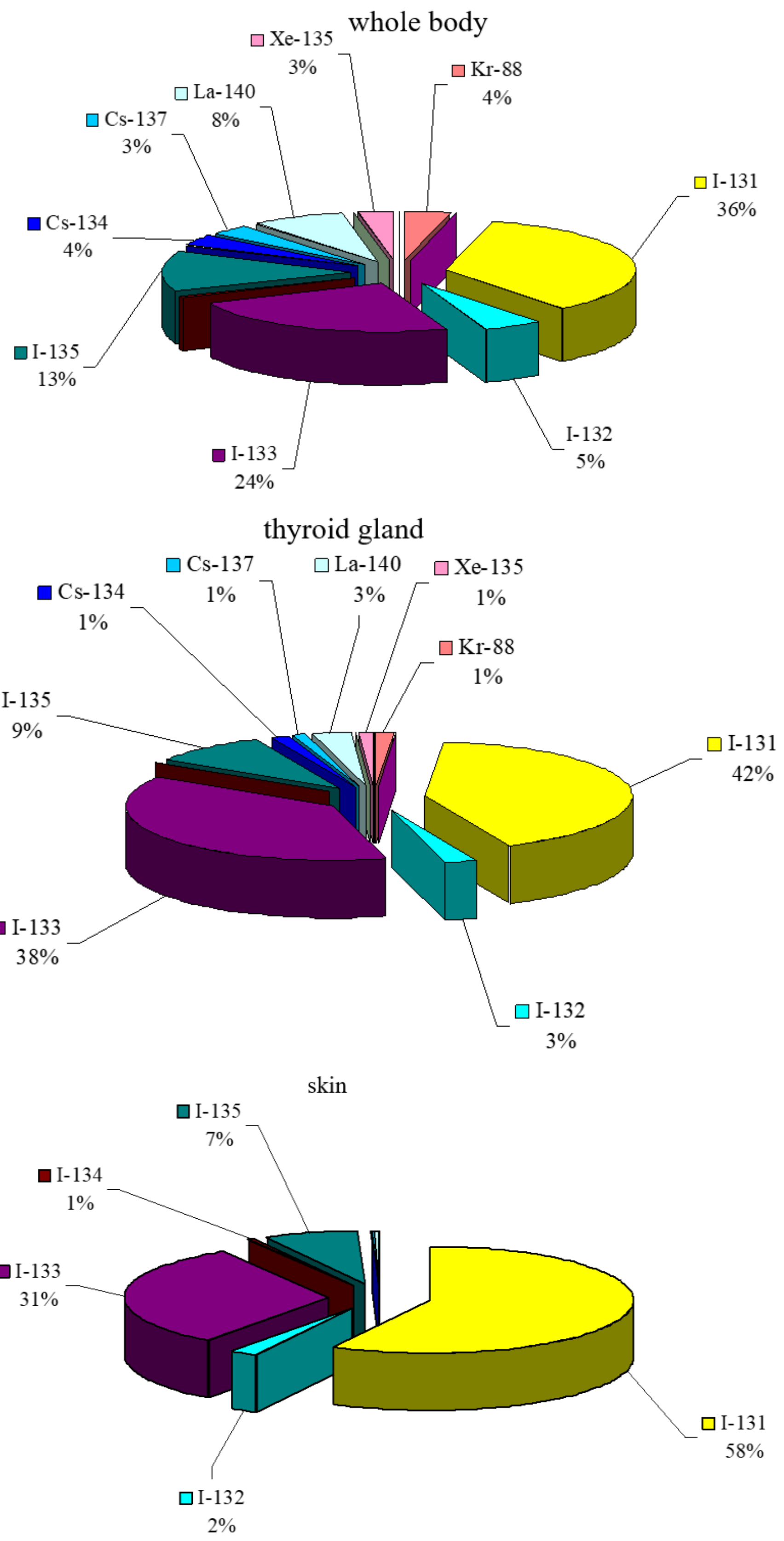
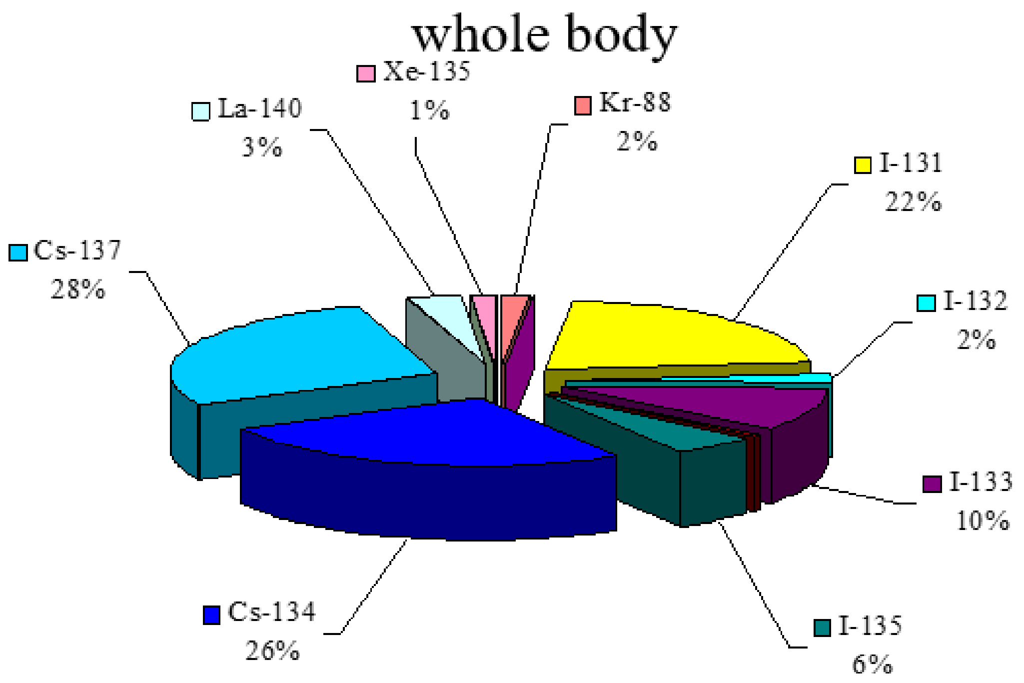


Figure 5.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



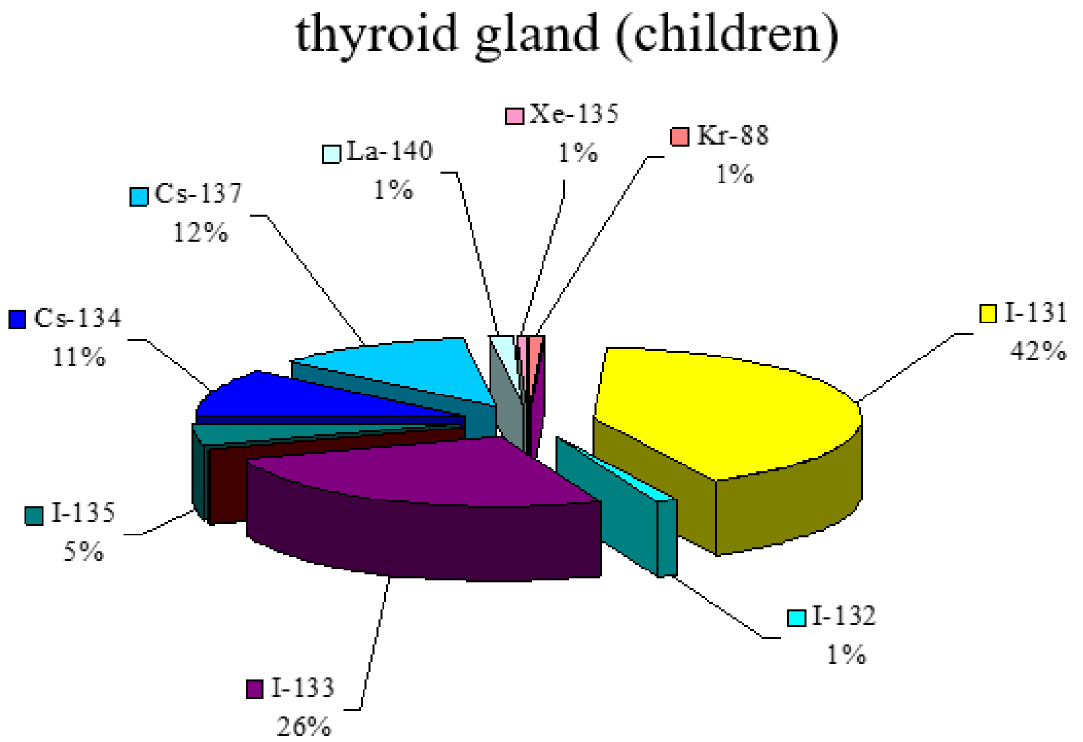


Figure 5.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

5.3.1 Radiation impact estimates for PES as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 5.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens , gonad and fetus.

Table 5.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	PES estimates, Gy
Entire body (bone marrow)[1]	1	7.42E-06 (7.29E-06)
Lungs	6	7.82E-06
Skin	3	1.16E-04
Thyroid gland	5	2.12E-05
Eye lens	2	8.20E-06
Gonad	2	6.80E-06
Fetus	0.1	6.64E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 5.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 5.14, while calculation results for standardized values for PES are given in Table 5.15.

Table 5.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 5.15 - Dose estimates over the first 2 weeks following the PES

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.013	0.046	0.23

Based on the calculation results given in Table 5.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the PES upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

5.2.3 Radiation impact estimates for PES as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
  - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
  - 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during PES shall be 0.000093 Sv/year, and for the entire body due to external radiation - 0.000032 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

6 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT "HYDRAULIC LOCK DROP IN THE SPENT FUEL POOL" (HLD-SFP)

6.1 Input data for calculating radiation exposure during HLD-SFP

Effective values of the total environmental radioactive release are shown in Table 6.1.

Table 6.1 - Radioactive release during HLD-SFP

Radionuclide	Environmental release, Bq
Sr-90	4.70E+11
Ru-103	3.60E+12
Ru-106	4.10E+11
I-131	1.65E+13
I-133	1.50E+12
Cs-134	9.30E+11
Cs-137	5.80E+11
La-140	1.90E+12
Ce-141	6.60E+12
Ce-144	1.40E+12
Xe-133	5.00E+14
Total activity	5.34E+14

6.2 Calculation results for HLD-SFP at the border of the SPZ (2.5 km)

Table 5.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during HLD-SFP.

Table 6.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during HLD-SFP

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Sr-90	2.96E+02	9.64E+03
Ru-103	2.27E+03	7.38E+04
Ru-106	2.59E+02	8.41E+03
I-131	8.35E+03	5.50E+05
I-133	6.96E+02	4.59E+04
Cs-134	5.86E+02	1.91E+04
Cs-137	3.66E+02	1.19E+04
La-140	1.14E+03	3.71E+04
Ce-141	4.16E+03	1.35E+05
Ce-144	8.83E+02	2.87E+04
Xe-133	3.90E+05	0.00E+00
Total	**4.09E+05**	**9.20E+05**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 390 kBq/m^3 for xenon-133 isotopes. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 550 kBq/m^2 for ^{131}I and up to 135 kBq/m^2 for ^{141}Ce.

Tables 6.3–6.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 6.1–6.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.23 mSv.

Table 6.3 - Human organ and tissue radiation doses during HLD-SFP over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	2.59E-08	2.04E-08	3.48E-09	3.03E-08	1.46E-07	2.38E-15	3.48E-09	6.02E-06	1.04E-08	0.00E+00
Ru-103	1.18E-06	3.05E-06	9.14E-07	7.92E-07	1.35E-06	8.60E-07	7.52E-07	1.49E-05	9.51E-07	1.16E-06
Ru-106	2.14E-07	8.12E-07	4.51E-08	3.92E-08	8.12E-07	4.18E-08	3.72E-08	8.65E-11	5.86E-08	1.82E-07
I-131	8.70E-06	4.84E-06	8.70E-05	4.49E-06	4.08E-06	4.99E-06	4.23E-06	9.39E-04	1.06E-04	7.74E-06
I-133	5.25E-07	2.64E-07	5.72E-06	2.42E-07	2.21E-07	2.66E-07	2.28E-07	4.28E-05	7.43E-06	4.46E-07
Cs-134	6.99E-07	6.96E-07	7.69E-07	6.57E-07	6.05E-07	7.02E-07	6.21E-07	5.89E-06	7.69E-07	6.99E-07
Cs-137	1.69E-07	1.68E-07	1.80E-07	1.55E-07	1.47E-07	1.61E-07	1.47E-07	4.90E-06	1.84E-07	1.67E-07
La-140	1.32E-06	2.13E-06	1.11E-06	9.71E-07	1.90E-06	1.05E-06	9.27E-07	1.30E-05	1.16E-06	1.30E-06
Ce-141	1.12E-06	6.32E-06	2.49E-07	2.16E-07	1.75E-06	2.34E-07	2.07E-07	5.45E-05	3.18E-07	9.59E-07
Ce-144	6.68E-07	3.21E-06	2.84E-08	2.51E-08	2.53E-06	2.67E-08	2.38E-08	5.89E-06	5.63E-08	3.41E-07
Xe-133	3.60E-07	3.51E-07	4.17E-07	2.59E-07	2.59E-07	4.84E-07	2.26E-07	0.00E+00	4.17E-07	3.60E-07
Total	**1.50E-05**	**2.19E-05**	**9.64E-05**	**7.88E-06**	**1.38E-05**	**8.81E-06**	**7.40E-06**	**1.09E-03**	**1.18E-04**	**1.34E-05**

Table 6.4 - Human organ and tissue radiation doses during HLD-SFP over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	1.01E-07	6.02E-08	2.27E-08	2.63E-07	5.31E-07	4.47E-14	2.27E-08	4.94E-05	6.80E-08	0.00E+00
Ru-103	6.12E-06	1.52E-05	5.47E-06	4.68E-06	5.87E-06	5.15E-06	4.39E-06	8.28E-05	5.58E-06	6.06E-06
Ru-106	9.76E-07	4.92E-06	2.94E-07	2.53E-07	2.30E-06	2.75E-07	2.38E-07	5.25E-10	3.53E-07	8.78E-07
I-131	3.91E-05	2.03E-05	4.14E-04	1.92E-05	1.73E-05	2.15E-05	1.80E-05	3.75E-03	5.14E-04	3.44E-05
I-133	8.46E-07	3.38E-07	1.08E-05	3.12E-07	2.85E-07	3.42E-07	2.94E-07	5.30E-05	1.49E-05	6.85E-07
Cs-134	4.41E-06	4.54E-06	5.03E-06	4.31E-06	3.98E-06	4.62E-06	4.10E-06	3.58E-05	5.03E-06	4.41E-06
Cs-137	1.06E-06	1.08E-06	1.19E-06	1.02E-06	9.69E-07	1.07E-06	9.80E-07	3.00E-05	1.19E-06	1.06E-06
La-140	2.24E-06	3.95E-06	1.89E-06	1.65E-06	3.48E-06	1.77E-06	1.57E-06	2.22E-05	1.97E-06	2.20E-06
Ce-141	4.90E-06	2.88E-05	1.47E-06	1.27E-06	5.21E-06	1.39E-06	1.19E-06	2.96E-04	1.74E-06	4.46E-06
Ce-144	2.88E-06	1.83E-05	1.92E-07	1.68E-07	6.87E-06	1.81E-07	1.55E-07	3.56E-05	3.34E-07	1.82E-06
Xe-133	3.60E-07	3.51E-07	4.17E-07	2.59E-07	2.59E-07	4.84E-07	2.26E-07	0.00E+00	4.17E-07	3.60E-07
Total	**6.30E-05**	**9.79E-05**	**4.41E-04**	**3.33E-05**	**4.71E-05**	**3.67E-05**	**3.12E-05**	**4.35E-03**	**5.45E-04**	**5.64E-05**

Table 6.5 - Human organ and tissue radiation doses during HLD-SFP over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	7.85E-07	1.02E-07	6.06E-08	5.03E-06	7.33E-07	1.37E-12	6.06E-08	1.97E-04	1.82E-07	0.00E+00
Ru-103	2.30E-05	4.72E-05	2.28E-05	1.95E-05	1.93E-05	2.16E-05	1.83E-05	1.91E-04	2.32E-05	2.28E-05
Ru-106	9.96E-06	5.37E-05	4.39E-06	3.75E-06	5.95E-06	4.10E-06	3.51E-06	1.77E-09	4.91E-06	9.37E-06
I-131	5.98E-05	2.87E-05	6.80E-04	2.71E-05	2.44E-05	3.02E-05	2.54E-05	4.77E-03	8.71E-04	5.14E-05
I-133	8.49E-07	3.42E-07	1.08E-05	3.15E-07	2.88E-07	3.47E-07	2.97E-07	5.30E-05	1.49E-05	6.88E-07
Cs-134	7.36E-05	7.66E-05	8.50E-05	7.26E-05	6.64E-05	7.95E-05	6.90E-05	1.26E-04	8.50E-05	7.36E-05
Cs-137	1.97E-05	2.05E-05	2.27E-05	1.94E-05	1.79E-05	2.09E-05	1.84E-05	1.08E-04	2.27E-05	1.97E-05
La-140	2.24E-06	4.03E-06	1.90E-06	1.66E-06	3.48E-06	1.78E-06	1.57E-06	2.24E-05	1.97E-06	2.20E-06
Ce-141	1.31E-05	7.06E-05	5.59E-06	4.80E-06	8.71E-06	5.30E-06	4.48E-06	6.40E-04	6.26E-06	1.23E-05
Ce-144	2.16E-05	1.54E-04	3.19E-06	2.90E-06	1.07E-05	3.02E-06	2.56E-06	1.18E-04	4.21E-06	1.75E-05
Xe-133	3.60E-07	3.51E-07	4.17E-07	2.59E-07	2.59E-07	4.84E-07	2.26E-07	0.00E+00	4.17E-07	3.60E-07
Total	**2.25E-04**	**4.56E-04**	**8.37E-04**	**1.57E-04**	**1.58E-04**	**1.67E-04**	**1.44E-04**	**6.23E-03**	**1.03E-03**	**2.10E-04**

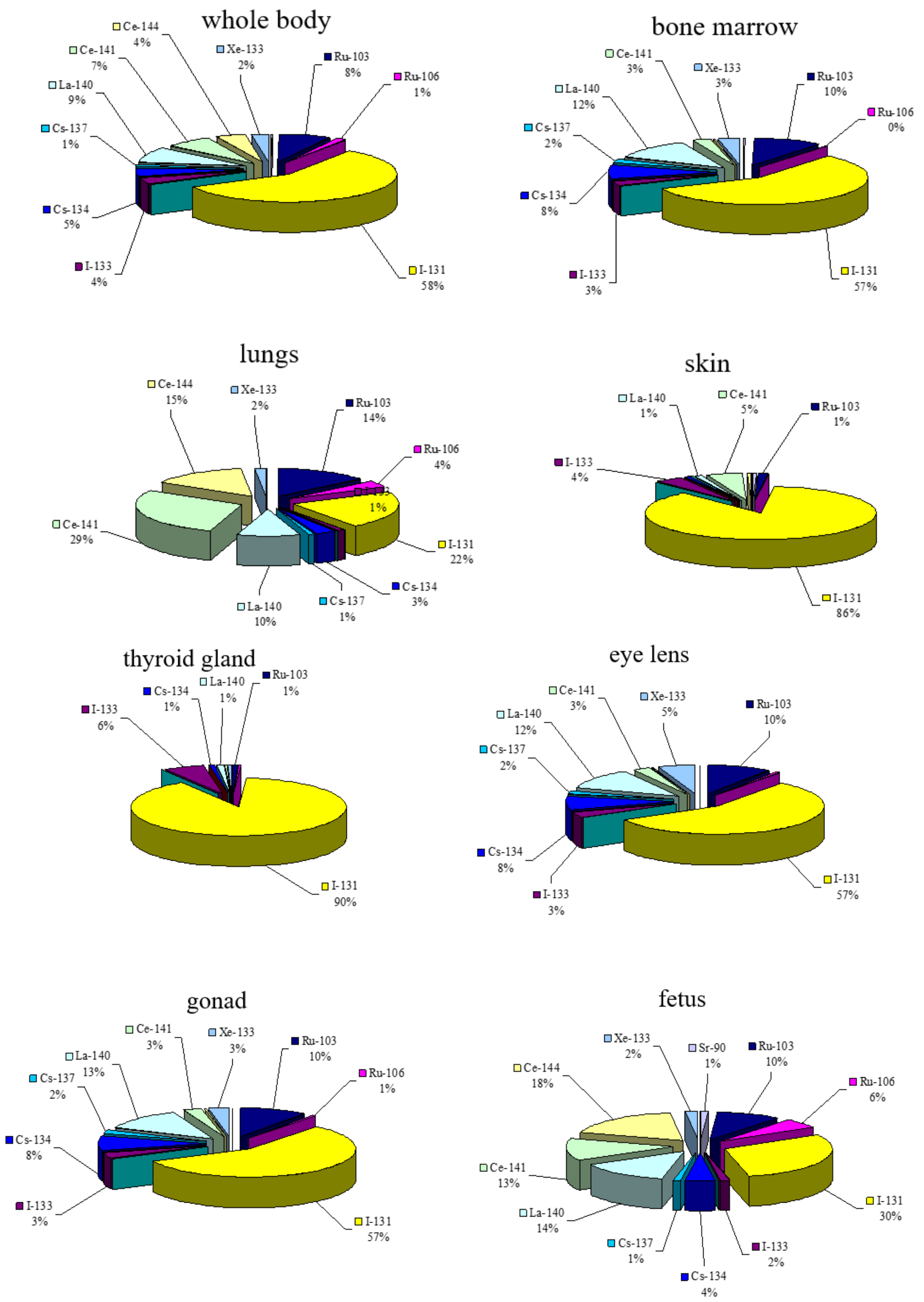
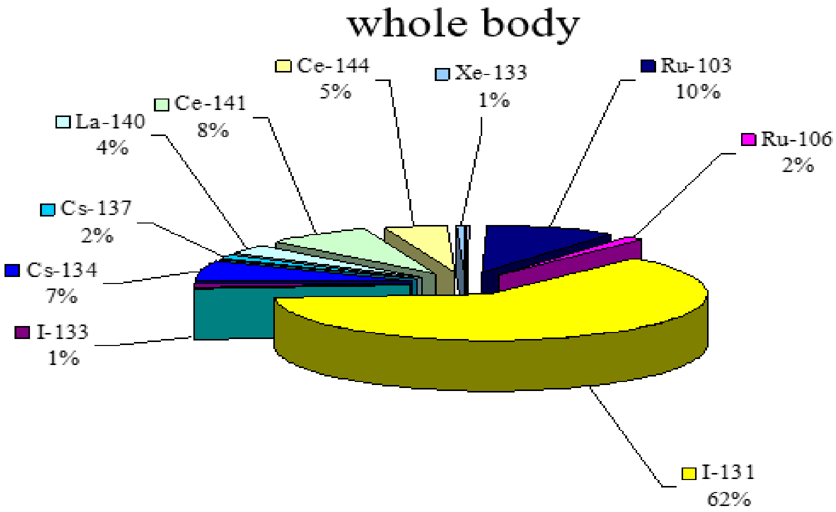
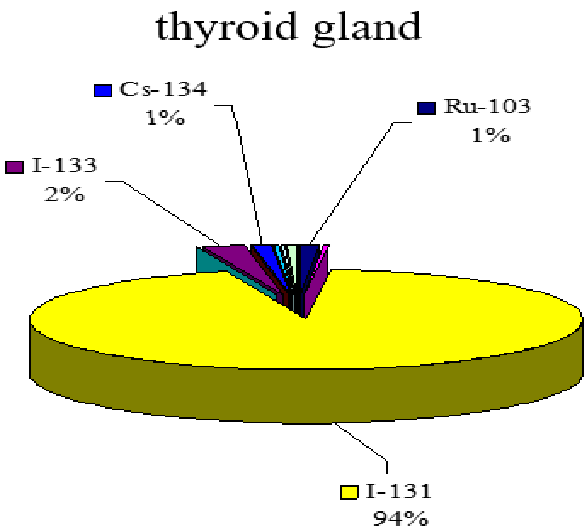


Figure 6.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period





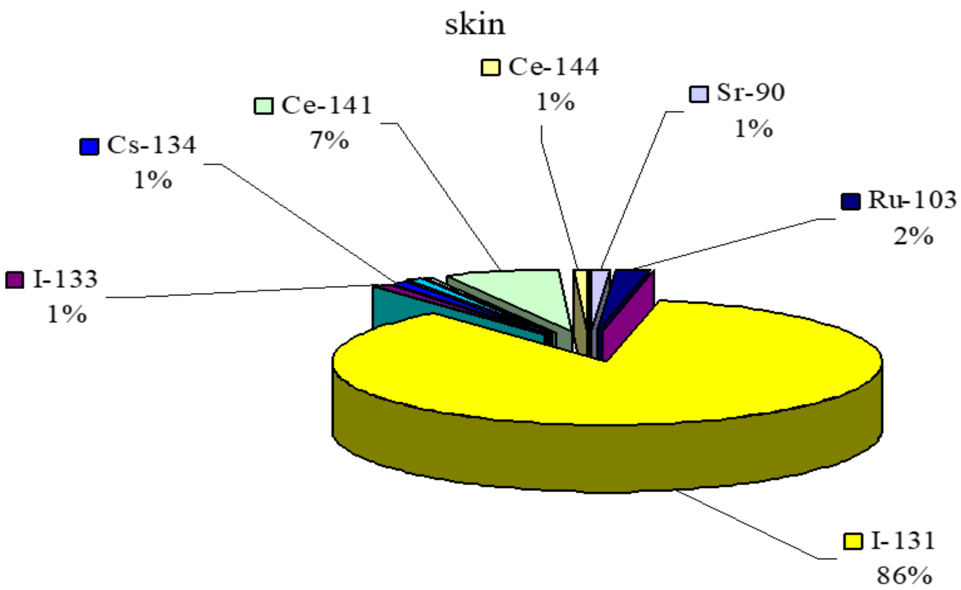


Figure 6.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

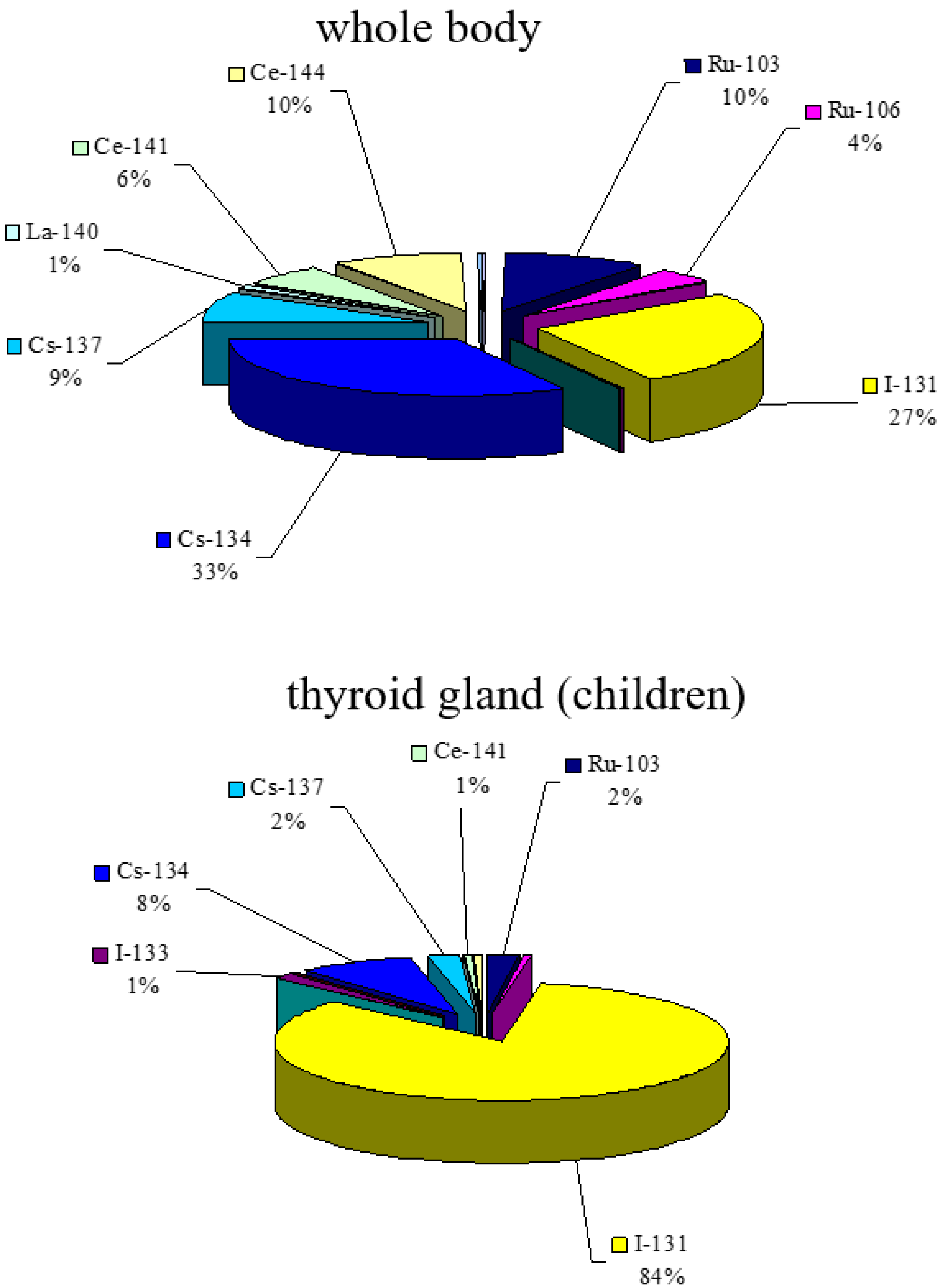


Figure 6.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

6.2.1 Radiation impact estimates for HLD-SFP as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 6.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens , gonad and fetus.

Table 6.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	HLD-SFP estimates, Gy
Entire body (bone marrow)[1]	1	1.34E-05 (7.88E-06)
Lungs	6	2.19E-05
Skin	3	1.09E-03
Thyroid gland	5	9.64E-05
Eye lens	2	8.81E-06
Gonad	2	7.40E-06
Fetus	0.1	1.38E-05

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 6.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 6.7, while calculation results for standardized values for HLD-SFP are given in Table 6.8.

Table 6.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 6.8 - Dose estimates over the first 2 weeks following the HLD-SFP

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.063	0.44	4.35

Based on the calculation results given in Table 6.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the HLD-SFP upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

6.2.2Radiation impact estimates for HLD-SFP as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during HLD-SFP shall be 0.0010 Sv/year, and for the entire body due to external radiation - 0.00021 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

6.3 Calculation results for HLD-SFP at the border of the OZ (30 km)

Table 6.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during HLD-SFP.

Table 6.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during HLD-SFP

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Sr-90	5.31E+00	5.31E+03
Ru-103	4.06E+01	4.07E+04
Ru-106	4.64E+00	4.63E+03
I-131	1.09E+03	4.71E+05
I-133	9.33E+01	4.04E+04
Cs-134	1.05E+01	1.05E+04
Cs-137	6.56E+00	6.55E+03
La-140	2.07E+01	2.07E+04
Ce-141	7.44E+01	7.46E+04
Ce-144	1.58E+01	1.58E+04
Xe-133	1.96E+05	0.00E+00
Total	**1.97E+05**	**6.90E+05**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 196 kBq/m^3 for xenon-133 isotopes. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 471 kBq/m^2 for ^{131}I and up to 74.6 kBq/m^2 for ^{141}Ce.

Tables 6.10–6.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 6.4–6.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.11 mSv.

Table 6.10 - Human organ and tissue radiation doses during HLD-SFP over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	4.46E-10	2.88E-10	6.25E-11	5.45E-10	2.53E-09	1.12E-15	6.25E-11	1.07E-07	1.88E-10	0.00E+00
Ru-103	4.14E-07	4.68E-07	4.75E-07	4.03E-07	3.78E-07	4.54E-07	3.82E-07	2.67E-07	4.94E-07	4.06E-07
Ru-106	2.30E-08	3.45E-08	2.30E-08	1.96E-08	3.17E-08	2.20E-08	1.85E-08	1.55E-12	3.00E-08	1.96E-08
I-131	4.33E-06	3.96E-06	1.50E-05	3.73E-06	3.38E-06	4.18E-06	3.52E-06	1.22E-04	1.83E-05	3.85E-06
I-133	2.39E-07	2.12E-07	9.62E-07	2.00E-07	1.80E-07	2.22E-07	1.88E-07	5.73E-06	1.25E-06	2.03E-07
Cs-134	3.33E-07	3.47E-07	3.86E-07	3.28E-07	2.98E-07	3.68E-07	3.10E-07	1.05E-07	3.86E-07	3.33E-07
Cs-137	7.66E-08	8.00E-08	8.87E-08	7.54E-08	6.84E-08	8.47E-08	7.13E-08	8.76E-08	9.05E-08	7.58E-08
La-140	4.83E-07	5.19E-07	5.53E-07	4.71E-07	4.47E-07	5.28E-07	4.45E-07	2.38E-07	5.75E-07	4.73E-07
Ce-141	1.27E-07	2.26E-07	1.29E-07	1.10E-07	1.28E-07	1.23E-07	1.04E-07	9.77E-07	1.66E-07	1.10E-07
Ce-144	2.45E-08	7.06E-08	1.50E-08	1.28E-08	5.67E-08	1.44E-08	1.21E-08	1.05E-07	2.97E-08	1.25E-08
Xe-133	1.81E-07	1.76E-07	2.10E-07	1.30E-07	1.30E-07	2.43E-07	1.13E-07	0.00E+00	2.10E-07	1.81E-07
Total	**6.23E-06**	**6.09E-06**	**1.79E-05**	**5.48E-06**	**5.10E-06**	**6.24E-06**	**5.16E-06**	**1.30E-04**	**2.16E-05**	**5.66E-06**

Table 6.11 - Human organ and tissue radiation doses during HLD-SFP over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	1.79E-09	8.88E-10	4.12E-10	4.79E-09	9.45E-09	2.43E-14	4.12E-10	8.84E-07	1.24E-09	0.00E+00
Ru-103	2.57E-06	2.84E-06	2.95E-06	2.51E-06	2.30E-06	2.82E-06	2.37E-06	1.48E-06	3.01E-06	2.54E-06
Ru-106	1.48E-07	2.26E-07	1.57E-07	1.34E-07	1.59E-07	1.50E-07	1.26E-07	9.35E-12	1.88E-07	1.34E-07
I-131	1.90E-05	1.72E-05	7.03E-05	1.63E-05	1.48E-05	1.83E-05	1.54E-05	4.89E-04	8.72E-05	1.67E-05
I-133	3.35E-07	2.76E-07	1.70E-06	2.60E-07	2.36E-07	2.91E-07	2.46E-07	7.10E-06	2.34E-06	2.71E-07
Cs-134	2.28E-06	2.38E-06	2.64E-06	2.25E-06	2.04E-06	2.52E-06	2.13E-06	6.41E-07	2.64E-06	2.28E-06
Cs-137	5.27E-07	5.50E-07	6.09E-07	5.20E-07	4.72E-07	5.80E-07	4.91E-07	5.36E-07	6.09E-07	5.27E-07
La-140	8.53E-07	9.22E-07	9.79E-07	8.34E-07	7.92E-07	9.35E-07	7.87E-07	4.05E-07	1.02E-06	8.36E-07
Ce-141	7.52E-07	1.21E-06	7.99E-07	6.80E-07	6.86E-07	7.59E-07	6.41E-07	5.31E-06	9.42E-07	6.85E-07
Ce-144	1.39E-07	4.24E-07	1.04E-07	8.85E-08	2.03E-07	9.91E-08	8.34E-08	6.37E-07	1.81E-07	8.75E-08
Xe-133	1.81E-07	1.76E-07	2.10E-07	1.30E-07	1.30E-07	2.43E-07	1.13E-07	0.00E+00	2.10E-07	1.81E-07
Total	**2.68E-05**	**2.62E-05**	**8.05E-05**	**2.37E-05**	**2.18E-05**	**2.67E-05**	**2.24E-05**	**5.06E-04**	**9.83E-05**	**2.42E-05**

Table 6.12 - Human organ and tissue radiation doses during HLD-SFP over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	1.72E-08	1.87E-09	1.33E-09	1.11E-07	1.59E-08	7.52E-13	1.33E-09	3.53E-06	3.99E-09	0.00E+00
Ru-103	1.07E-05	1.17E-05	1.24E-05	1.05E-05	9.61E-06	1.18E-05	9.97E-06	3.42E-06	1.26E-05	1.06E-05
Ru-106	2.17E-06	3.18E-06	2.37E-06	2.01E-06	1.88E-06	2.26E-06	1.90E-06	3.17E-11	2.65E-06	2.04E-06
I-131	2.74E-05	2.43E-05	1.12E-04	2.29E-05	2.08E-05	2.58E-05	2.16E-05	6.22E-04	1.43E-04	2.36E-05
I-133	3.38E-07	2.79E-07	1.71E-06	2.63E-07	2.39E-07	2.94E-07	2.49E-07	7.10E-06	2.36E-06	2.73E-07
Cs-134	3.94E-05	4.11E-05	4.58E-05	3.90E-05	3.53E-05	4.36E-05	3.67E-05	2.24E-06	4.58E-05	3.94E-05
Cs-137	1.04E-05	1.08E-05	1.21E-05	1.03E-05	9.34E-06	1.15E-05	9.69E-06	1.94E-06	1.21E-05	1.04E-05
La-140	8.57E-07	9.25E-07	9.80E-07	8.36E-07	7.94E-07	9.37E-07	7.90E-07	4.07E-07	1.02E-06	8.40E-07
Ce-141	2.78E-06	3.97E-06	3.04E-06	2.59E-06	2.43E-06	2.91E-06	2.45E-06	1.15E-05	3.41E-06	2.61E-06
Ce-144	1.89E-06	4.72E-06	1.74E-06	1.48E-06	1.51E-06	1.65E-06	1.40E-06	2.11E-06	2.29E-06	1.53E-06
Xe-133	1.81E-07	1.76E-07	2.10E-07	1.30E-07	1.30E-07	2.43E-07	1.13E-07	0.00E+00	2.10E-07	1.81E-07
Total	**9.62E-05**	**1.01E-04**	**1.92E-04**	**9.02E-05**	**8.21E-05**	**1.01E-04**	**8.49E-05**	**6.55E-04**	**2.25E-04**	**9.15E-05**

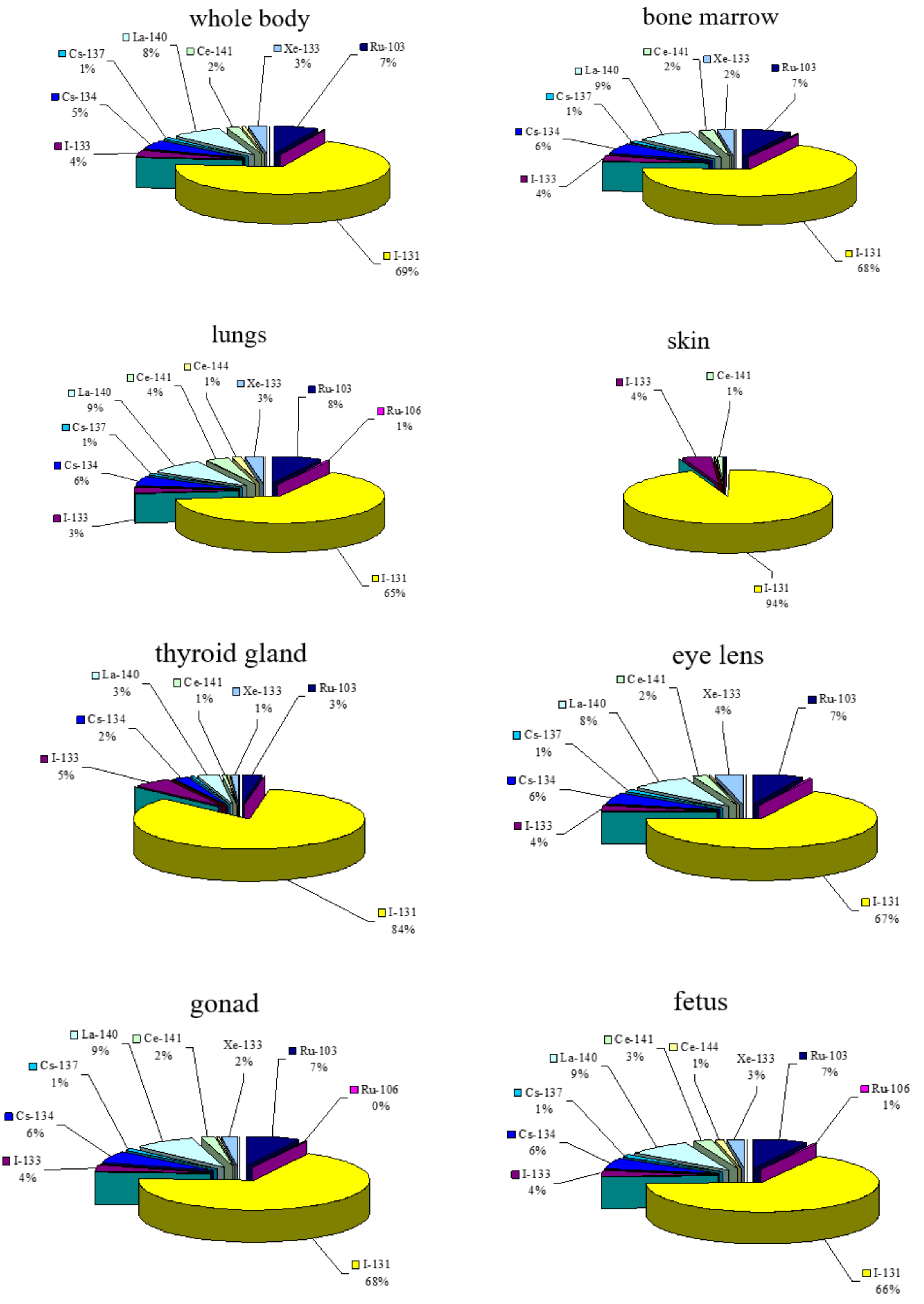


Figure 6.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

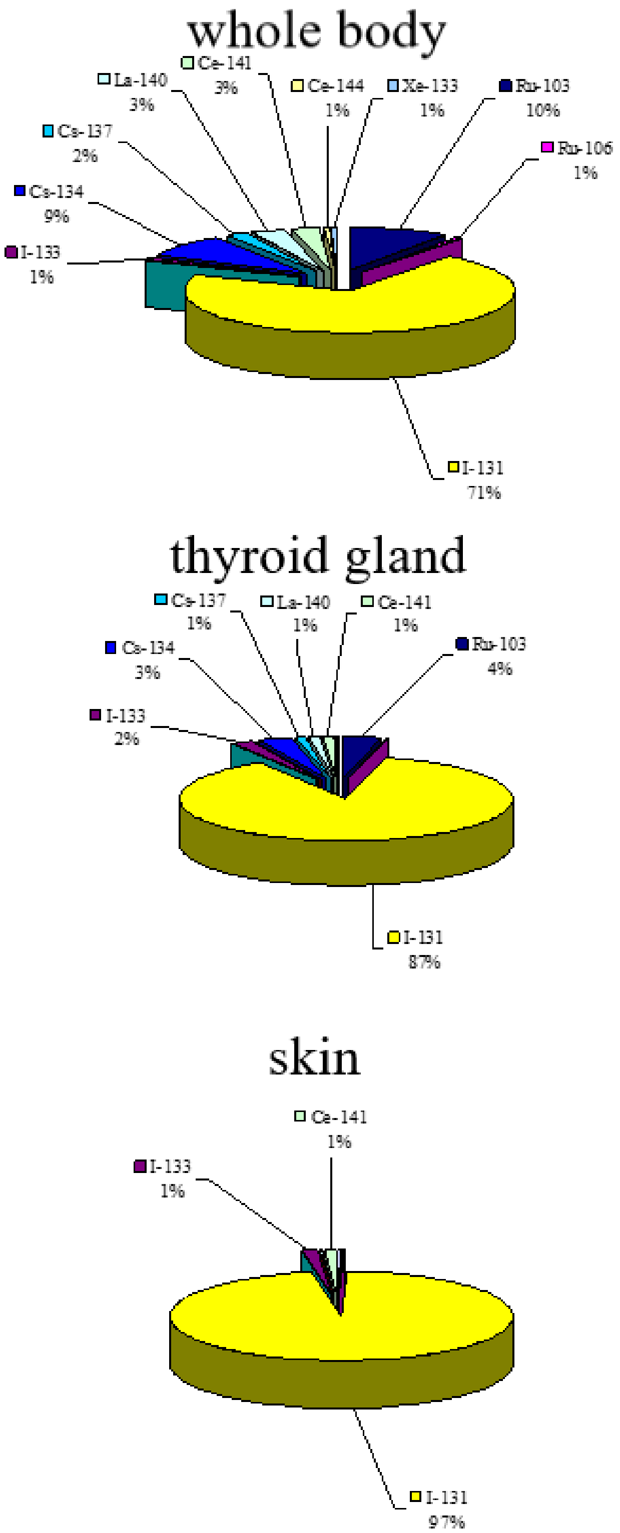
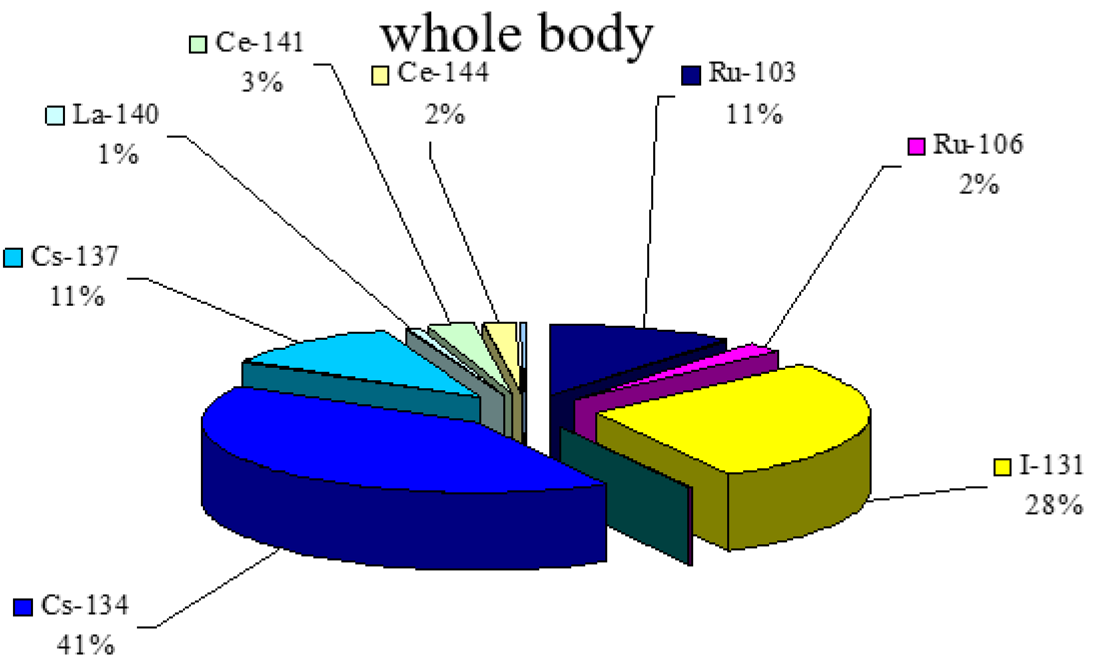


Figure 6.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



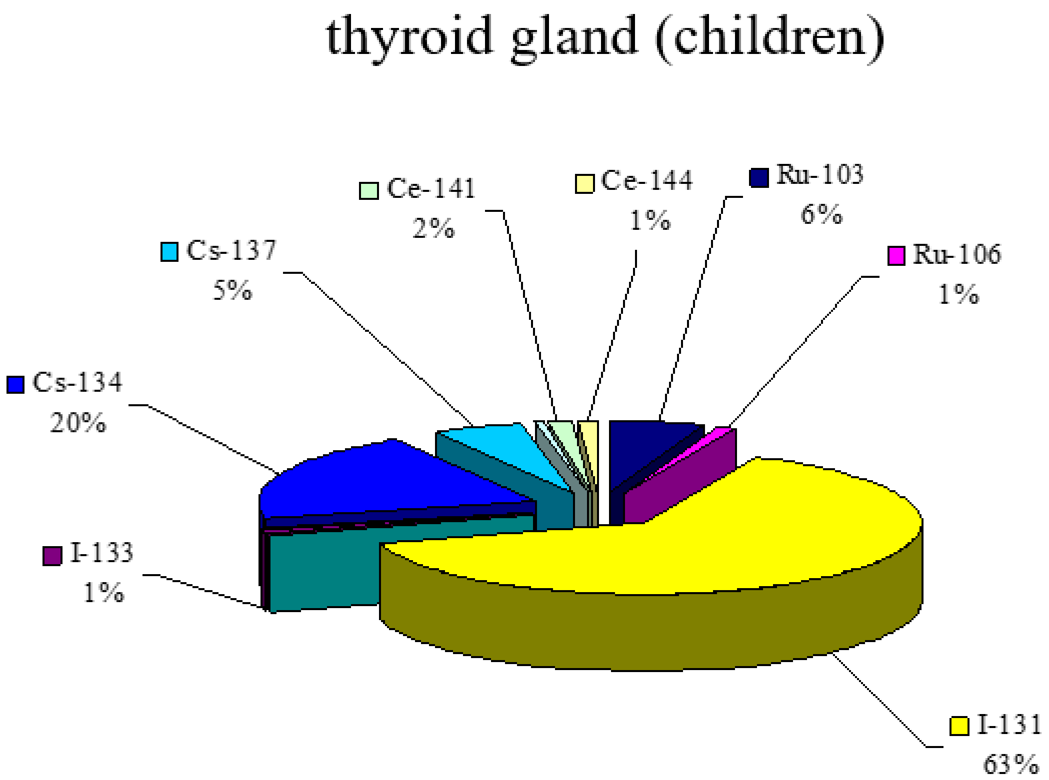


Figure 6.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

6.3.1 Radiation impact estimates for HLD-SFP as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 6.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 6.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	HLD-SFP estimates, Gy
Entire body (bone marrow)[1]	1	5.66E-06 (5.48E-06)
Lungs	6	6.09E-06
Skin	3	1.30E-04
Thyroid gland	5	1.79E-05
Eye lens	2	6.24E-06
Gonad	2	5.16E-06
Fetus	0.1	5.10E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 6.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 6.14, while calculation results for standardized values for HLD-SFP are given in Table 6.15.

Table 6.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 6.15 — Dose estimates over the first 2 weeks following the HLD-SFP

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.0062	0.018	0.13

Based on the calculation results given in Table 6.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the HLD-SFP upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

6.3.2 Radiation impact estimates for HLD-SFP as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
    - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
    - 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during HLD-SFP shall be 0.00023 Sv/year, and for the entire body due to external radiation - 0.000092 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

7 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT "FUEL ASSEMBLY DROP ON THE REACTOR CORE AND FA TOP NOZZLES IN THE SPENT FUEL POOL" (FAD-SFP)

7.1 Input data for calculating radiation exposure during FAD-SFP

Effective values of the total environmental radioactive release are shown in Table 7.1.

Table 7.1 - Radioactive release during FAD-SFP

Radionuclide	Environmental release, Bq
Kr-87	1.10E+13
Kr-88	1.70E+13
Sr-90	3.90E+10
Ru-103	4.50E+11
Ru-106	6.90E+10
I-131	3.80E+11
I-133	2.60E+11
Cs-134	8.30E+10
Cs-137	6.50E+10
La-140	8.40E+11
Ce-144	9.70E+11
Xe-133	7.40E+13
Total activity	1.05E+14

7.2 Calculation results for FAD-SFP at the border of the SPZ (2.5 km)

Table 7.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during FAD-SFP.

Table 7.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during FAD-SFP

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-87	1.82E+03	0.00E+00
Kr-88	6.71E+03	0.00E+00
Sr-90	2.46E+01	8.00E+02
Ru-103	2.84E+02	9.23E+03
Ru-106	4.35E+01	1.41E+03
I-131	1.92E+02	1.27E+04
I-133	1.21E+02	7.96E+03
Cs-134	5.23E+01	1.70E+03
Cs-137	4.10E+01	1.33E+03
La-140	5.04E+02	1.64E+04
Ce-144	6.12E+02	1.99E+04
Xe-133	5.78E+04	0.00E+00
Total	**6.82E+04**	**7.13E+04**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 57.8 kBq/m^3 for xenon-133 isotopes. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 19.9 kBq/m^2 for ^{144}Ce and up to 16.4 kBq/m^2 for ^{140}La.

Tables 7.3–7.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 7.1–7.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.21 mSv.

Table 7.3 - Human organ and tissue radiation doses during FAD-SFP over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	4.97E-08	5.05E-08	5.83E-08	4.66E-08	4.27E-08	5.43E-08	4.27E-08	0.00E+00	5.83E-08	4.97E-08
Kr-88	6.85E-07	7.58E-07	7.23E-07	5.98E-07	5.76E-07	6.85E-07	5.41E-07	6.44E-07	7.95E-07	6.51E-07
Sr-90	2.15E-09	1.70E-09	2.89E-10	2.52E-09	1.21E-08	1.97E-16	2.89E-10	4.99E-07	8.67E-10	0.00E+00
Ru-103	1.48E-07	3.82E-07	1.14E-07	9.90E-08	1.68E-07	1.08E-07	9.41E-08	1.86E-06	1.19E-07	1.45E-07
Ru-106	3.60E-08	1.37E-07	7.59E-09	6.59E-09	1.37E-07	7.04E-09	6.27E-09	1.46E-11	9.87E-09	3.06E-08
I-131	2.00E-07	1.11E-07	2.00E-06	1.03E-07	9.39E-08	1.15E-07	9.73E-08	2.16E-05	2.44E-06	1.78E-07
I-133	9.10E-08	4.58E-08	9.91E-07	4.19E-08	3.82E-08	4.60E-08	3.95E-08	7.41E-06	1.29E-06	7.74E-08
Cs-134	6.24E-08	6.21E-08	6.86E-08	5.86E-08	5.40E-08	6.27E-08	5.54E-08	5.25E-07	6.86E-08	6.24E-08
Cs-137	1.89E-08	1.88E-08	2.02E-08	1.74E-08	1.64E-08	1.81E-08	1.65E-08	5.49E-07	2.06E-08	1.87E-08
La-140	5.85E-07	9.41E-07	4.92E-07	4.29E-07	8.38E-07	4.62E-07	4.10E-07	5.75E-06	5.12E-07	5.74E-07
Ce-144	4.63E-07	2.22E-06	1.97E-08	1.74E-08	1.76E-06	1.85E-08	1.65E-08	4.08E-06	3.90E-08	2.36E-07
Xe-133	5.33E-08	5.19E-08	6.17E-08	3.83E-08	3.83E-08	7.16E-08	3.34E-08	0.00E+00	6.17E-08	5.33E-08
Total	**2.39E-06**	**4.78E-06**	**4.56E-06**	**1.46E-06**	**3.77E-06**	**1.65E-06**	**1.35E-06**	**4.30E-05**	**5.42E-06**	**2.08E-06**

Table 7.4 - Human organ and tissue radiation doses during FAD-SFP over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	4.97E-08	5.05E-08	5.83E-08	4.66E-08	4.27E-08	5.43E-08	4.27E-08	0.00E+00	5.83E-08	4.97E-08
Kr-88	6.85E-07	7.58E-07	7.23E-07	5.98E-07	5.76E-07	6.85E-07	5.41E-07	6.44E-07	7.95E-07	6.51E-07
Sr-90	8.35E-09	4.99E-09	1.88E-09	2.18E-08	4.41E-08	3.71E-15	1.88E-09	4.10E-06	5.64E-09	0.00E+00
Ru-103	7.65E-07	1.90E-06	6.84E-07	5.85E-07	7.34E-07	6.44E-07	5.49E-07	1.04E-05	6.98E-07	7.57E-07
Ru-106	1.64E-07	8.28E-07	4.95E-08	4.26E-08	3.86E-07	4.62E-08	4.00E-08	8.83E-11	5.95E-08	1.48E-07
I-131	9.01E-07	4.67E-07	9.54E-06	4.41E-07	3.99E-07	4.94E-07	4.14E-07	8.63E-05	1.18E-05	7.93E-07
I-133	1.47E-07	5.85E-08	1.87E-06	5.41E-08	4.94E-08	5.93E-08	5.10E-08	9.18E-06	2.58E-06	1.19E-07
Cs-134	3.93E-07	4.05E-07	4.49E-07	3.84E-07	3.55E-07	4.13E-07	3.66E-07	3.20E-06	4.49E-07	3.93E-07
Cs-137	1.18E-07	1.21E-07	1.33E-07	1.14E-07	1.09E-07	1.20E-07	1.10E-07	3.36E-06	1.33E-07	1.18E-07
La-140	9.91E-07	1.75E-06	8.36E-07	7.31E-07	1.54E-06	7.84E-07	6.92E-07	9.83E-06	8.69E-07	9.71E-07
Ce-144	2.00E-06	1.27E-05	1.33E-07	1.16E-07	4.76E-06	1.25E-07	1.08E-07	2.46E-05	2.31E-07	1.26E-06
Xe-133	5.33E-08	5.19E-08	6.17E-08	3.83E-08	3.83E-08	7.16E-08	3.34E-08	0.00E+00	6.17E-08	5.33E-08
Total	**6.27E-06**	**1.91E-05**	**1.45E-05**	**3.17E-06**	**9.03E-06**	**3.50E-06**	**2.95E-06**	**1.52E-04**	**1.78E-05**	**5.31E-06**

Table 7.5 - Human organ and tissue radiation doses during FAD-SFP over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	4.97E-08	5.05E-08	5.83E-08	4.66E-08	4.27E-08	5.43E-08	4.27E-08	0.00E+00	5.83E-08	4.97E-08
Kr-88	6.85E-07	7.58E-07	7.23E-07	5.98E-07	5.76E-07	6.85E-07	5.41E-07	6.44E-07	7.95E-07	6.51E-07
Sr-90	6.51E-08	8.42E-09	5.03E-09	4.17E-07	6.08E-08	1.13E-13	5.03E-09	1.64E-05	1.51E-08	0.00E+00
Ru-103	2.88E-06	5.90E-06	2.85E-06	2.44E-06	2.42E-06	2.70E-06	2.28E-06	2.39E-05	2.91E-06	2.85E-06
Ru-106	1.68E-06	9.04E-06	7.38E-07	6.31E-07	1.00E-06	6.90E-07	5.91E-07	2.98E-10	8.27E-07	1.58E-06
I-131	1.38E-06	6.61E-07	1.57E-05	6.23E-07	5.62E-07	6.95E-07	5.85E-07	1.10E-04	2.00E-05	1.18E-06
I-133	1.47E-07	5.93E-08	1.87E-06	5.46E-08	4.99E-08	6.01E-08	5.15E-08	9.18E-06	2.58E-06	1.19E-07
Cs-134	6.57E-06	6.84E-06	7.59E-06	6.48E-06	5.93E-06	7.10E-06	6.16E-06	1.12E-05	7.59E-06	6.57E-06
Cs-137	2.21E-06	2.29E-06	2.54E-06	2.18E-06	2.01E-06	2.35E-06	2.07E-06	1.21E-05	2.54E-06	2.21E-06
La-140	9.91E-07	1.78E-06	8.38E-07	7.34E-07	1.54E-06	7.85E-07	6.95E-07	9.91E-06	8.72E-07	9.71E-07
Ce-144	1.49E-05	1.07E-04	2.21E-06	2.01E-06	7.42E-06	2.10E-06	1.78E-06	8.21E-05	2.92E-06	1.21E-05
Xe-133	5.33E-08	5.19E-08	6.17E-08	3.83E-08	3.83E-08	7.16E-08	3.34E-08	0.00E+00	6.17E-08	5.33E-08
Total	**3.16E-05**	**1.34E-04**	**3.51E-05**	**1.63E-05**	**2.16E-05**	**1.73E-05**	**1.48E-05**	**2.75E-04**	**4.12E-05**	**2.83E-05**

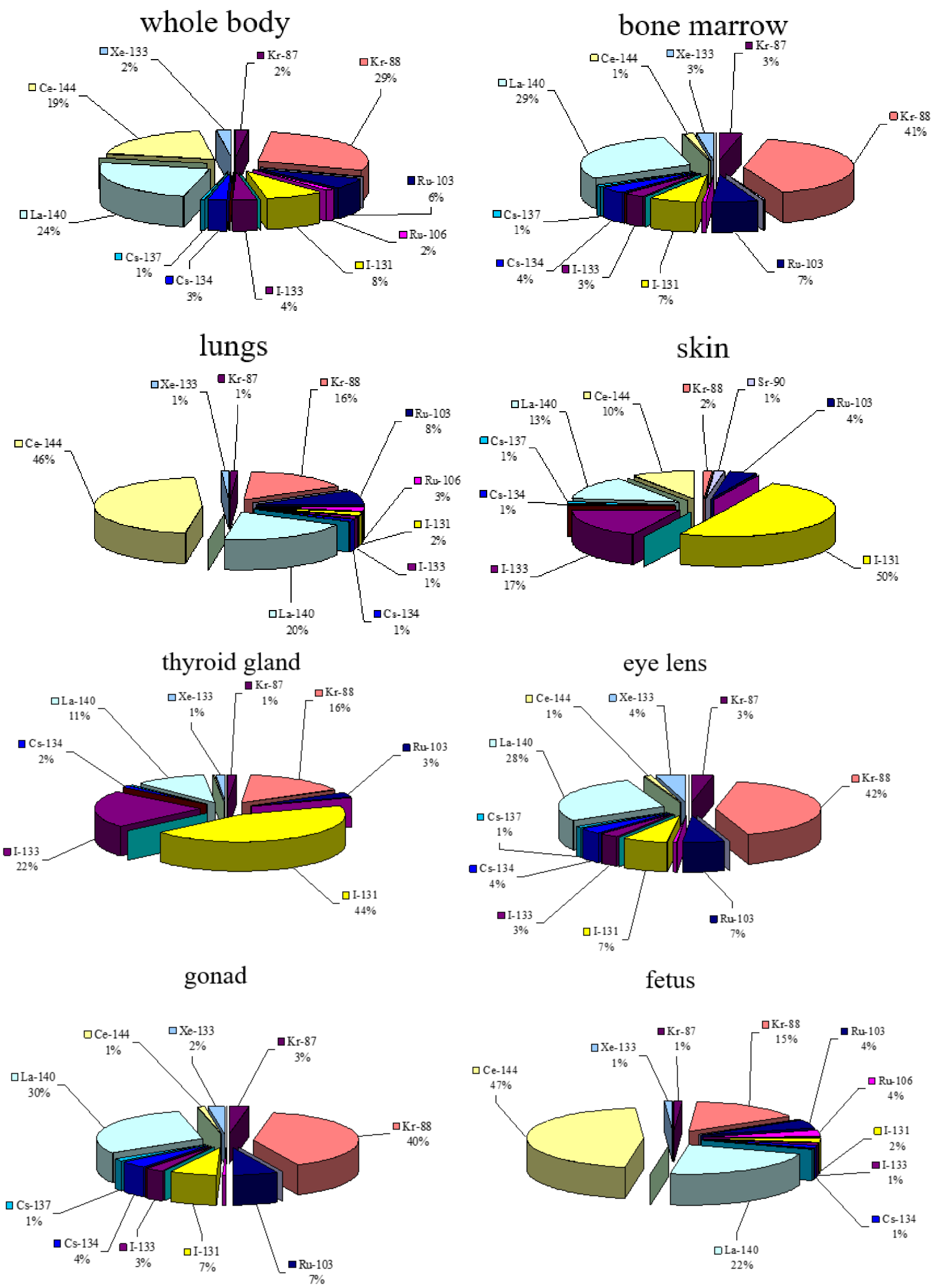


Figure 7.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

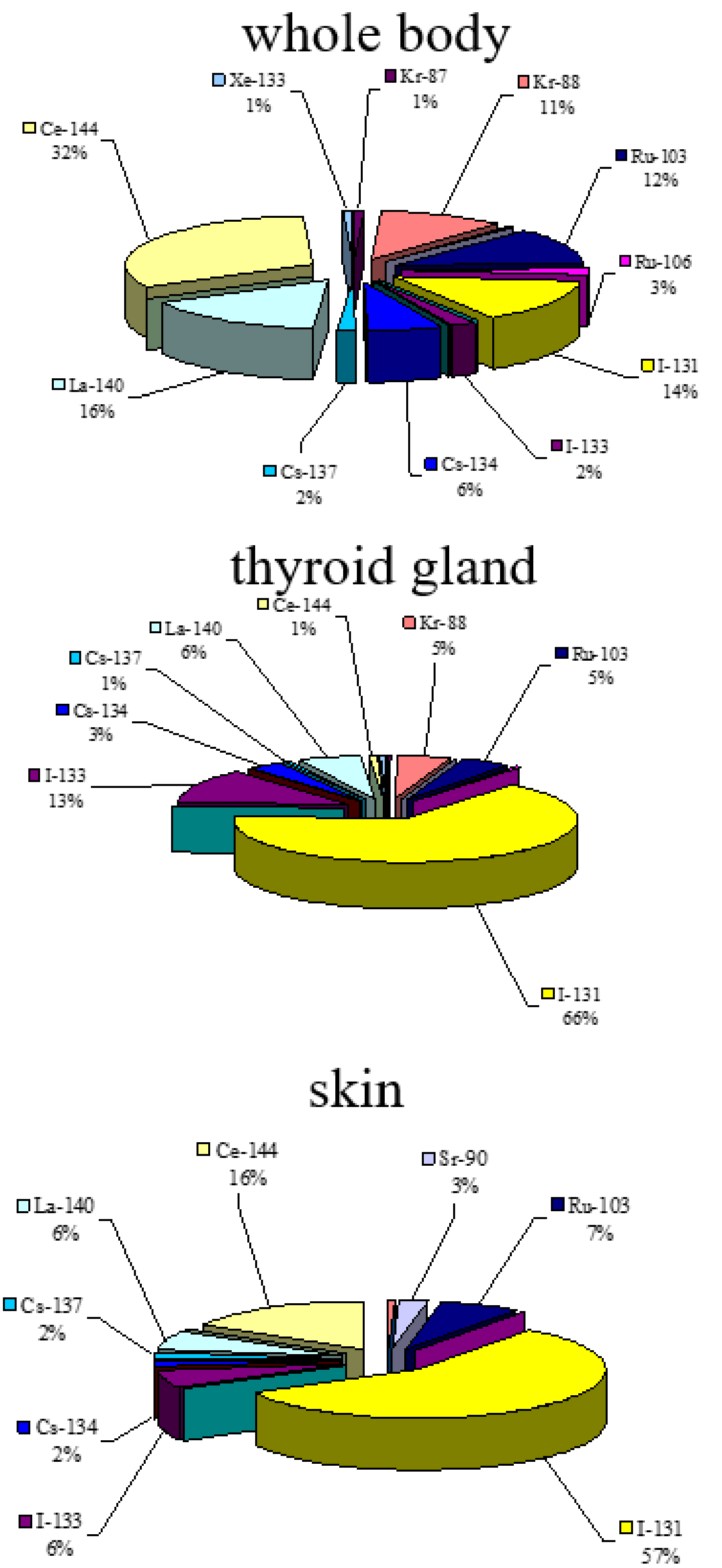
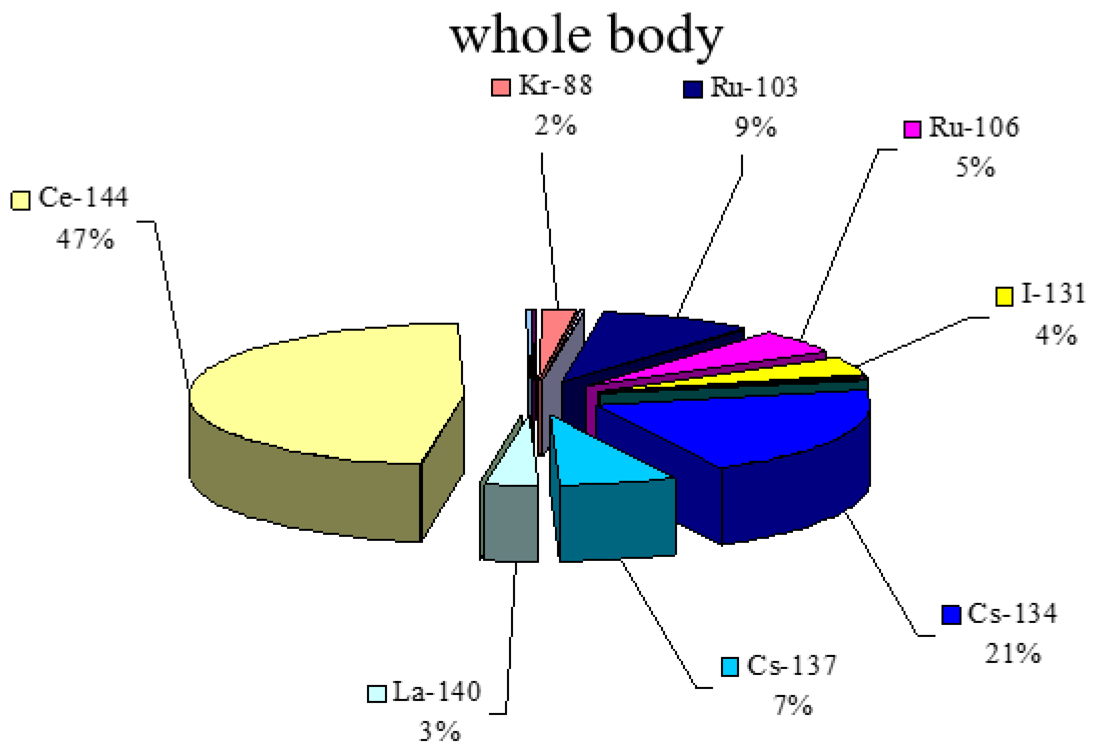


Figure 7.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



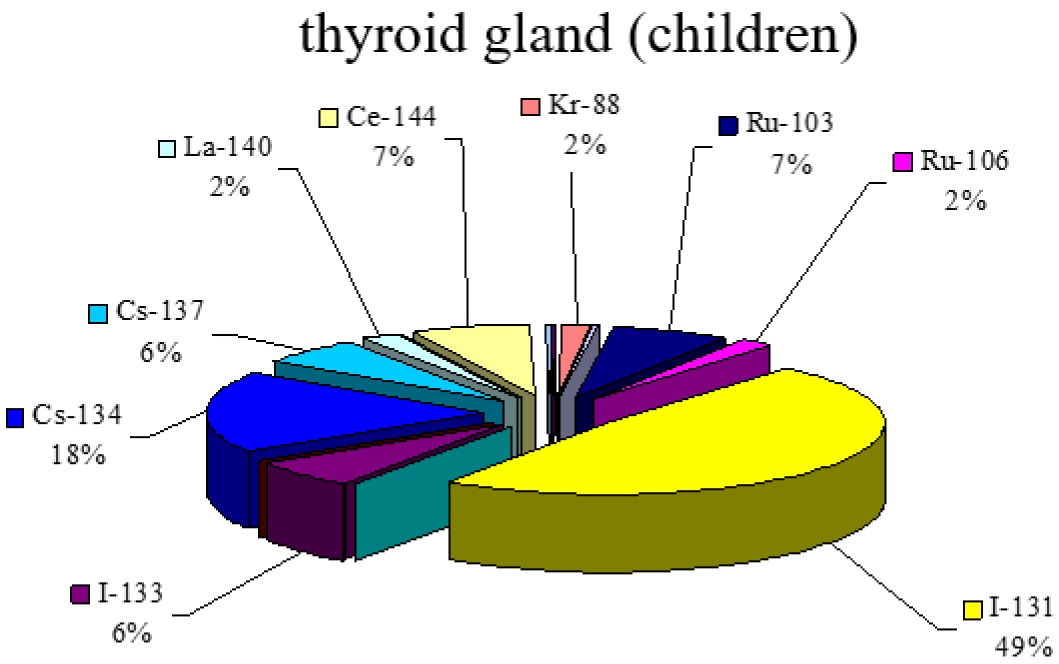


Figure 7.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

7.2.1Radiation impact estimates for FAD-SFP as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 7.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 7.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	FAD-SFP estimates, Gy
Entire body (bone marrow)[1]	1	2.08E-06 (1.46E-06)
Lungs	6	4.78E-06
Skin	3	4.30E-05
Thyroid gland	5	4.56E-06
Eye lens	2	1.65E-06
Gonad	2	1.35E-06
Fetus	0.1	3.77E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 7.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 7.7, while calculation results for standardized values for FAD-SFP are given in Table 7.8.

Table 7.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 7.8 - Dose estimates over the first 2 weeks following the FAD-SFP

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.0063	0.015	0.15

Based on the calculation results given in Table 7.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the FAD-SFP upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

7.2.2 Radiation impact estimates for FAD-SFP as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during FAD-SFP shall be 0.000041 Sv/year, and for the entire body due to external radiation - 0.000028 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

7.3 Calculation results for FAD-SFP at the border of the OZ (30 km)

Table 7.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during FAD-SFP.

Table 7.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during FAD-SFP

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-87	1.52E+03	0.00E+00
Kr-88	4.20E+03	0.00E+00
Sr-90	4.41E-01	4.41E+02
Ru-103	5.08E+00	5.09E+03
Ru-106	7.80E-01	7.80E+02
I-131	2.50E+01	1.08E+04
I-133	1.62E+01	6.99E+03
Cs-134	9.38E-01	9.38E+02
Cs-137	7.35E-01	7.35E+02
La-140	9.17E+00	9.16E+03
Ce-144	1.10E+01	1.10E+04
Xe-133	2.90E+04	0.00E+00
Total	**3.48E+04**	**4.59E+04**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 29.0 kBq/m^3 for xenon-133 isotopes. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 11.0 kBq/m^2 for ^{144}Ce and up to 10.8 kBq/m^2 for ^{131}I.

Tables 7.10–7.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 7.4–7.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.076 mSv.

Table 7.10 - Human organ and tissue radiation doses during FAD-SFP over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	4.15E-08	4.21E-08	4.86E-08	3.88E-08	3.56E-08	4.53E-08	3.56E-08	0.00E+00	4.86E-08	4.15E-08
Kr-88	4.64E-07	4.95E-07	5.17E-07	4.34E-07	4.10E-07	4.96E-07	3.96E-07	1.53E-07	5.68E-07	4.41E-07
Sr-90	3.70E-11	2.39E-11	5.19E-12	4.52E-11	2.10E-10	9.32E-17	5.19E-12	8.85E-09	1.56E-11	0.00E+00
Ru-103	5.18E-08	5.85E-08	5.94E-08	5.04E-08	4.73E-08	5.67E-08	4.77E-08	3.33E-08	6.18E-08	5.07E-08
Ru-106	3.87E-09	5.81E-09	3.88E-09	3.30E-09	5.34E-09	3.70E-09	3.12E-09	2.60E-13	5.04E-09	3.29E-09
I-131	9.96E-08	9.12E-08	3.46E-07	8.59E-08	7.79E-08	9.61E-08	8.09E-08	2.82E-06	4.22E-07	8.86E-08
I-133	4.13E-08	3.67E-08	1.67E-07	3.46E-08	3.12E-08	3.85E-08	3.25E-08	9.93E-07	2.17E-07	3.51E-08
Cs-134	2.97E-08	3.10E-08	3.44E-08	2.93E-08	2.66E-08	3.29E-08	2.76E-08	9.38E-09	3.44E-08	2.97E-08
Cs-137	8.58E-09	8.97E-09	9.95E-09	8.45E-09	7.67E-09	9.49E-09	8.00E-09	9.82E-09	1.01E-08	8.49E-09
La-140	2.13E-07	2.29E-07	2.44E-07	2.08E-07	1.97E-07	2.34E-07	1.97E-07	1.05E-07	2.54E-07	2.09E-07
Ce-144	1.70E-08	4.89E-08	1.04E-08	8.88E-09	3.93E-08	9.99E-09	8.38E-09	7.30E-08	2.06E-08	8.66E-09
Xe-133	2.68E-08	2.60E-08	3.10E-08	1.92E-08	1.92E-08	3.60E-08	1.67E-08	0.00E+00	3.10E-08	2.68E-08
Total	**9.98E-07**	**1.07E-06**	**1.47E-06**	**9.21E-07**	**8.97E-07**	**1.06E-06**	**8.53E-07**	**4.20E-06**	**1.67E-06**	**9.43E-07**

Table 7.11 - Human organ and tissue radiation doses during FAD-SFP over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	4.15E-08	4.21E-08	4.86E-08	3.88E-08	3.56E-08	4.53E-08	3.56E-08	0.00E+00	4.86E-08	4.15E-08
Kr-88	4.64E-07	4.95E-07	5.17E-07	4.34E-07	4.10E-07	4.96E-07	3.96E-07	1.53E-07	5.68E-07	4.41E-07
Sr-90	1.48E-10	7.37E-11	3.42E-11	3.98E-10	7.84E-10	2.02E-15	3.42E-11	7.33E-08	1.02E-10	0.00E+00
Ru-103	3.21E-07	3.55E-07	3.69E-07	3.14E-07	2.88E-07	3.52E-07	2.97E-07	1.85E-07	3.76E-07	3.18E-07
Ru-106	2.50E-08	3.80E-08	2.64E-08	2.25E-08	2.67E-08	2.53E-08	2.13E-08	1.57E-12	3.17E-08	2.25E-08
I-131	4.37E-07	3.95E-07	1.62E-06	3.75E-07	3.40E-07	4.22E-07	3.54E-07	1.12E-05	2.01E-06	3.85E-07
I-133	5.80E-08	4.78E-08	2.94E-07	4.50E-08	4.08E-08	5.04E-08	4.26E-08	1.23E-06	4.05E-07	4.70E-08
Cs-134	2.03E-07	2.12E-07	2.36E-07	2.01E-07	1.82E-07	2.25E-07	1.90E-07	5.72E-08	2.36E-07	2.03E-07
Cs-137	5.90E-08	6.16E-08	6.83E-08	5.83E-08	5.29E-08	6.50E-08	5.51E-08	6.01E-08	6.83E-08	5.90E-08
La-140	3.77E-07	4.07E-07	4.33E-07	3.69E-07	3.50E-07	4.13E-07	3.48E-07	1.79E-07	4.50E-07	3.70E-07
Ce-144	9.62E-08	2.94E-07	7.20E-08	6.13E-08	1.41E-07	6.87E-08	5.78E-08	4.41E-07	1.25E-07	6.06E-08
Xe-133	2.68E-08	2.60E-08	3.10E-08	1.92E-08	1.92E-08	3.60E-08	1.67E-08	0.00E+00	3.10E-08	2.68E-08
Total	**2.11E-06**	**2.37E-06**	**3.71E-06**	**1.94E-06**	**1.89E-06**	**2.20E-06**	**1.81E-06**	**1.36E-05**	**4.35E-06**	**1.97E-06**

Table 7.12 - Human organ and tissue radiation doses during FAD-SFP over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-87	4.15E-08	4.21E-08	4.86E-08	3.88E-08	3.56E-08	4.53E-08	3.56E-08	0.00E+00	4.86E-08	4.15E-08
Kr-88	4.64E-07	4.95E-07	5.17E-07	4.34E-07	4.10E-07	4.96E-07	3.96E-07	1.53E-07	5.68E-07	4.41E-07
Sr-90	1.43E-09	1.55E-10	1.10E-10	9.20E-09	1.32E-09	6.24E-14	1.10E-10	2.93E-07	3.31E-10	0.00E+00
Ru-103	1.34E-06	1.46E-06	1.55E-06	1.32E-06	1.20E-06	1.48E-06	1.25E-06	4.27E-07	1.58E-06	1.33E-06
Ru-106	3.65E-07	5.35E-07	3.98E-07	3.39E-07	3.17E-07	3.80E-07	3.20E-07	5.33E-12	4.46E-07	3.43E-07
I-131	6.31E-07	5.59E-07	2.57E-06	5.28E-07	4.79E-07	5.93E-07	4.98E-07	1.43E-05	3.29E-06	5.42E-07
I-133	5.85E-08	4.84E-08	2.96E-07	4.55E-08	4.13E-08	5.10E-08	4.32E-08	1.23E-06	4.09E-07	4.74E-08
Cs-134	3.52E-06	3.67E-06	4.08E-06	3.48E-06	3.15E-06	3.89E-06	3.28E-06	2.00E-07	4.08E-06	3.52E-06
Cs-137	1.16E-06	1.22E-06	1.35E-06	1.15E-06	1.05E-06	1.29E-06	1.09E-06	2.17E-07	1.35E-06	1.16E-06
La-140	3.79E-07	4.09E-07	4.33E-07	3.70E-07	3.51E-07	4.14E-07	3.49E-07	1.80E-07	4.51E-07	3.71E-07
Ce-144	1.31E-06	3.27E-06	1.20E-06	1.03E-06	1.05E-06	1.14E-06	9.67E-07	1.46E-06	1.59E-06	1.06E-06
Xe-133	2.68E-08	2.60E-08	3.10E-08	1.92E-08	1.92E-08	3.60E-08	1.67E-08	0.00E+00	3.10E-08	2.68E-08
Total	**9.30E-06**	**1.17E-05**	**1.25E-05**	**8.76E-06**	**8.10E-06**	**9.82E-06**	**8.24E-06**	**1.85E-05**	**1.38E-05**	**8.88E-06**

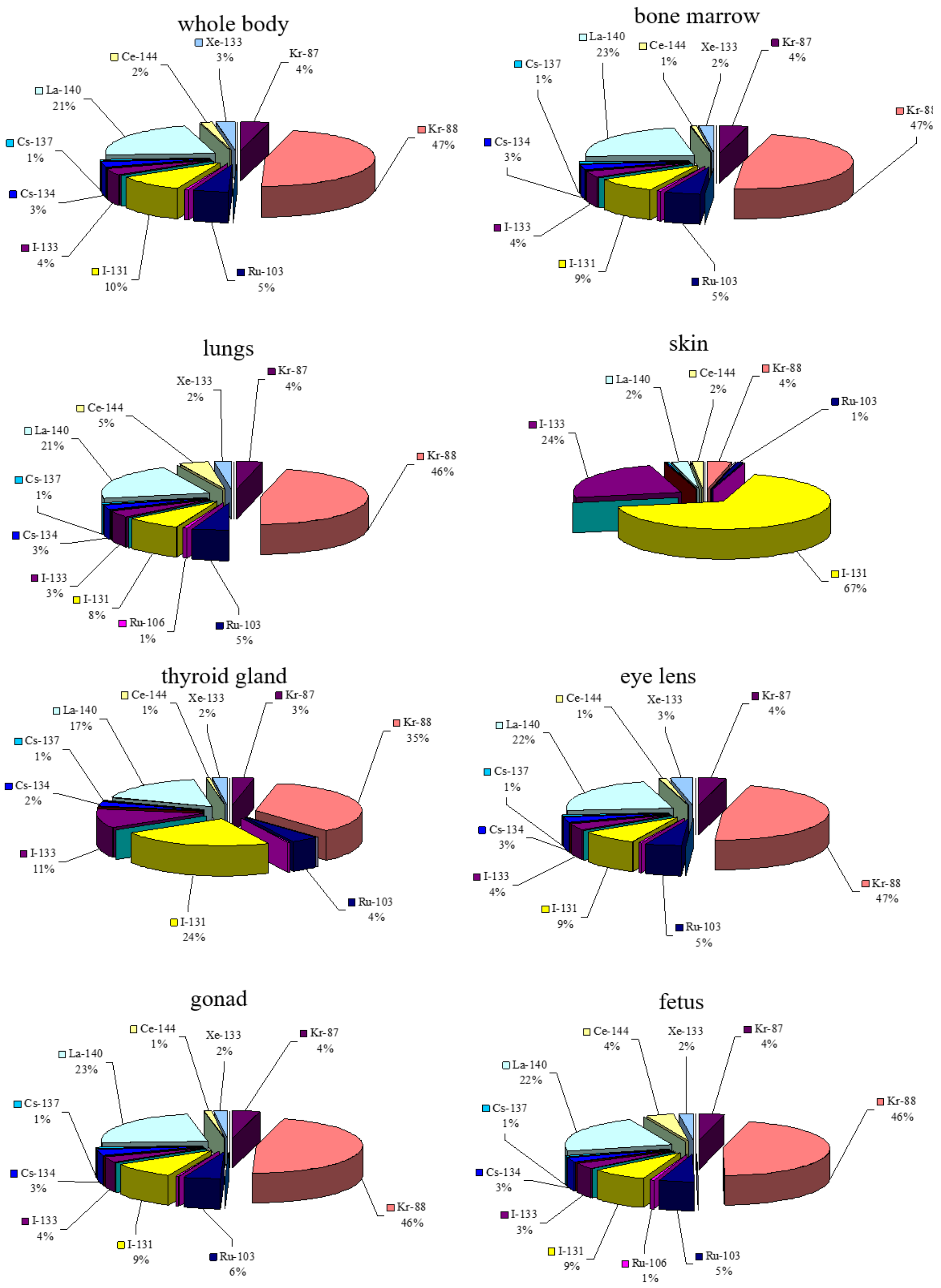


Figure 7.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

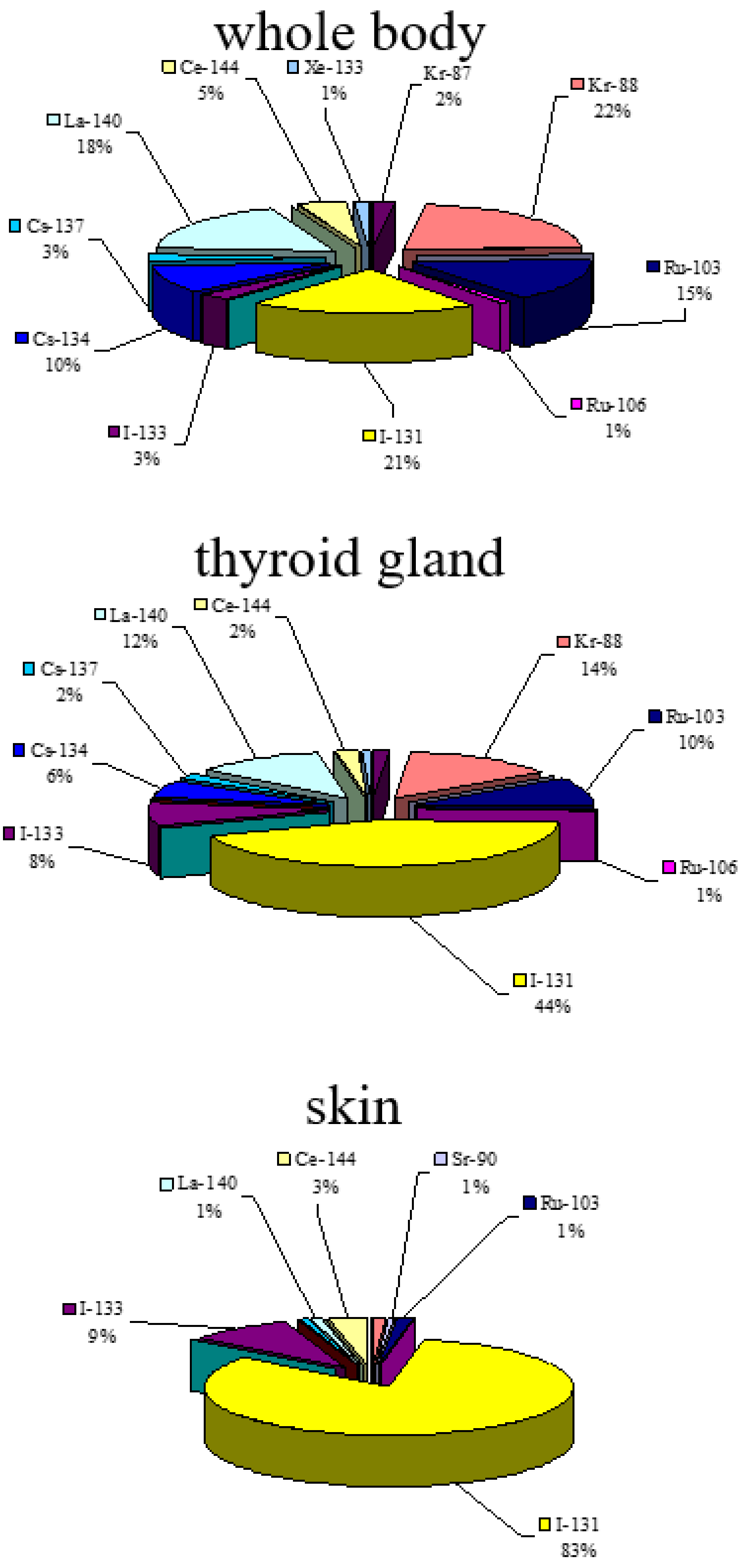
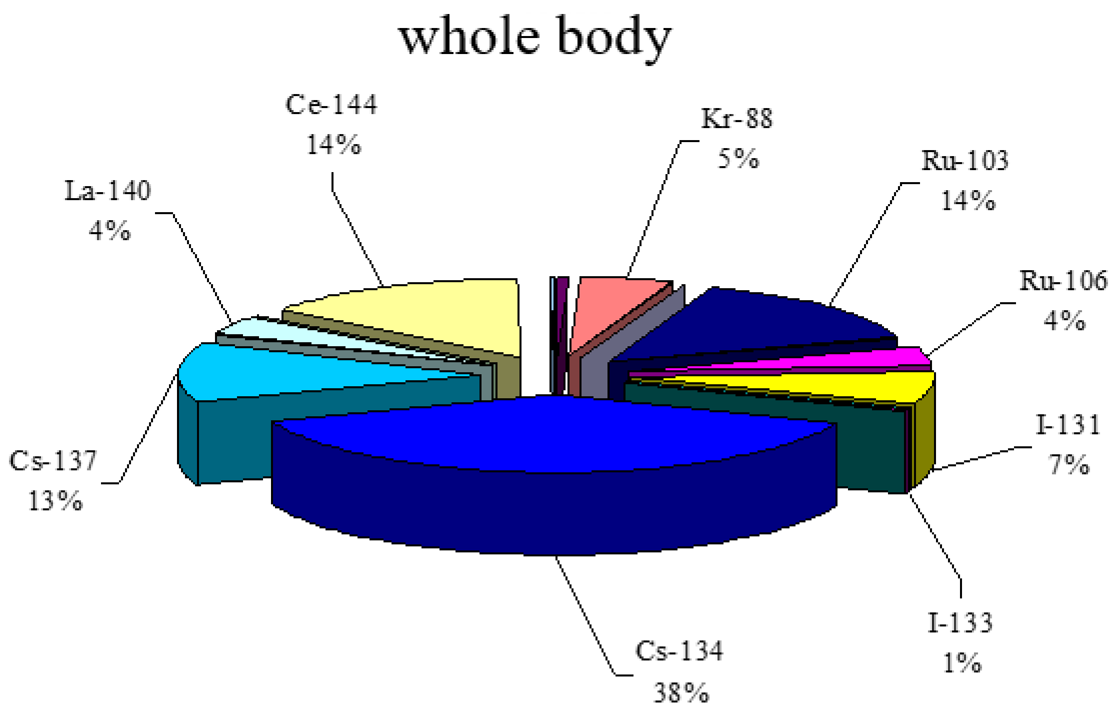


Figure 7.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



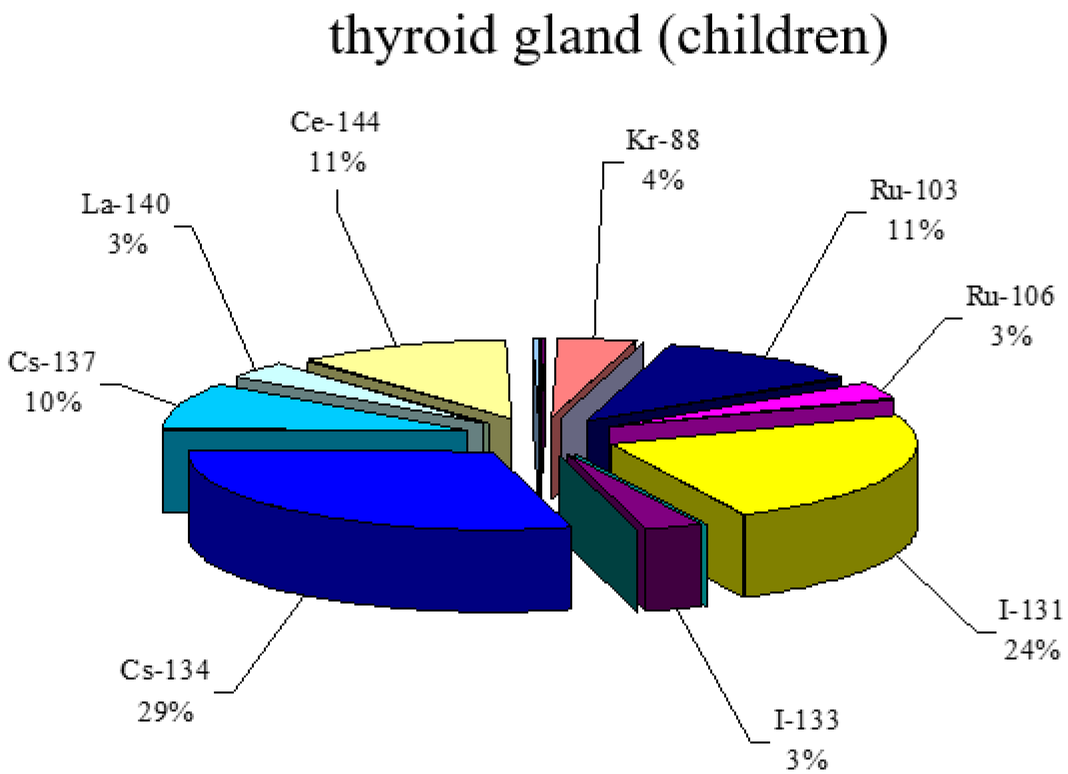


Figure 7.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

7.3.1 Radiation impact estimates for FAD-SFP as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 7.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens , gonad and fetus.

Table 7.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	FAD-SFP estimates, Gy
Entire body (bone marrow)[1]	1	9.47E-07 (9.21E-07)
Lungs	6	1.07E-06
Skin	3	4.20E-06
Thyroid gland	5	1.47E-06
Eye lens	2	1.06E-06
Gonad	2	8.53E-07
Fetus	0.1	8.97E-07

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 7.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 7.14, while calculation results for standardized values for FAD-SFP are given in Table 7.15.

Table 7.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 7.15 - Dose estimates over the first 2 weeks following the FAD-SFP

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.021	0.037	0.014

Based on the calculation results given in Table 7.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the FAD-SFP upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

7.3.2 Radiation impact estimates for FAD-SFP as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
  - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
  - 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during FAD-SFP shall be 0.00014 Sv/year, and for the entire body due to external radiation - 0.0000089 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

8 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT "SPENT FUEL CONTAINER DROP FROM HEIGHT OF MORE THAN 9 METERS" (SFCD)

8.1 Input data for calculating radiation exposure during SFCD

Effective values of the total environmental radioactive release are shown in Table 8.1.

Table 8.1 - Radioactive release during SFCD

Radionuclide	Environmental release, Bq
Sr-90	4.40E+11
Ru-106	1.00E+11
Cs-134	3.50E+11
Cs-137	7.30E+11
Ce-144	8.30E+11
Total activity	2.45E+12

8.2 Calculation results for SFCD at the border of the SPZ (2.5 km)

Table 8.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during SFCD.

Table 8.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during SFCD

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Sr-90	2.77E+02	9.02E+03
Ru-106	6.31E+01	2.05E+03
Cs-134	2.21E+02	7.18E+03
Cs-137	4.60E+02	1.50E+04
Ce-144	5.23E+02	1.70E+04
Total	**1.54E+03**	**5.02E+04**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 523 Bq/m^3 for cerium-144 isotopes. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 17.0 kBq/m^2 for ^{144}Ce.

Tables 8.3–8.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 8.1–8.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 1.21 mSv.

Table 8.3 - Human organ and tissue radiation doses during SFCD over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	2.43E-08	1.91E-08	3.26E-09	2.84E-08	1.36E-07	2.23E-15	3.26E-09	5.63E-06	9.78E-09	0.00E+00
Ru-106	5.22E-08	1.98E-07	1.10E-08	9.55E-09	1.98E-07	1.02E-08	9.08E-09	2.11E-11	1.43E-08	4.44E-08
Cs-134	2.63E-07	2.62E-07	2.89E-07	2.47E-07	2.28E-07	2.64E-07	2.34E-07	2.22E-06	2.89E-07	2.63E-07
Cs-137	2.12E-07	2.11E-07	2.27E-07	1.95E-07	1.85E-07	2.03E-07	1.85E-07	6.16E-06	2.32E-07	2.10E-07
Ce-144	3.96E-07	1.90E-06	1.68E-08	1.49E-08	1.50E-06	1.59E-08	1.41E-08	3.49E-06	3.34E-08	2.02E-07
Total	**9.48E-07**	**2.59E-06**	**5.48E-07**	**4.95E-07**	**2.25E-06**	**4.93E-07**	**4.46E-07**	**1.75E-05**	**5.78E-07**	**7.20E-07**

Table 8.4 - Human organ and tissue radiation doses during SFCD over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	9.42E-08	5.63E-08	2.12E-08	2.46E-07	4.97E-07	4.19E-14	2.12E-08	4.62E-05	6.36E-08	0.00E+00
Ru-106	2.38E-07	1.20E-06	7.18E-08	6.18E-08	5.60E-07	6.70E-08	5.80E-08	1.28E-10	8.62E-08	2.14E-07
Cs-134	1.66E-06	1.71E-06	1.89E-06	1.62E-06	1.50E-06	1.74E-06	1.54E-06	1.35E-05	1.89E-06	1.66E-06
Cs-137	1.33E-06	1.36E-06	1.50E-06	1.28E-06	1.22E-06	1.34E-06	1.23E-06	3.77E-05	1.50E-06	1.33E-06
Ce-144	1.71E-06	1.09E-05	1.14E-07	9.96E-08	4.08E-06	1.07E-07	9.21E-08	2.11E-05	1.98E-07	1.08E-06
Total	**5.03E-06**	**1.52E-05**	**3.60E-06**	**3.31E-06**	**7.85E-06**	**3.26E-06**	**2.95E-06**	**1.18E-04**	**3.74E-06**	**4.28E-06**

Table 8.5 - Human organ and tissue radiation doses during SFCD over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	7.35E-07	9.50E-08	5.68E-08	4.71E-06	6.86E-07	1.28E-12	5.68E-08	1.85E-04	1.70E-07	0.00E+00
Ru-106	2.43E-06	1.31E-05	1.07E-06	9.15E-07	1.45E-06	1.00E-06	8.56E-07	4.32E-10	1.20E-06	2.28E-06
Cs-134	2.77E-05	2.88E-05	3.20E-05	2.73E-05	2.50E-05	2.99E-05	2.60E-05	4.73E-05	3.20E-05	2.77E-05
Cs-137	2.48E-05	2.58E-05	2.85E-05	2.45E-05	2.26E-05	2.64E-05	2.32E-05	1.36E-04	2.85E-05	2.48E-05
Ce-144	1.28E-05	9.13E-05	1.89E-06	1.72E-06	6.35E-06	1.79E-06	1.52E-06	7.02E-05	2.50E-06	1.04E-05
Total	**6.85E-05**	**1.59E-04**	**6.36E-05**	**5.91E-05**	**5.60E-05**	**5.91E-05**	**5.16E-05**	**4.38E-04**	**6.44E-05**	**6.51E-05**

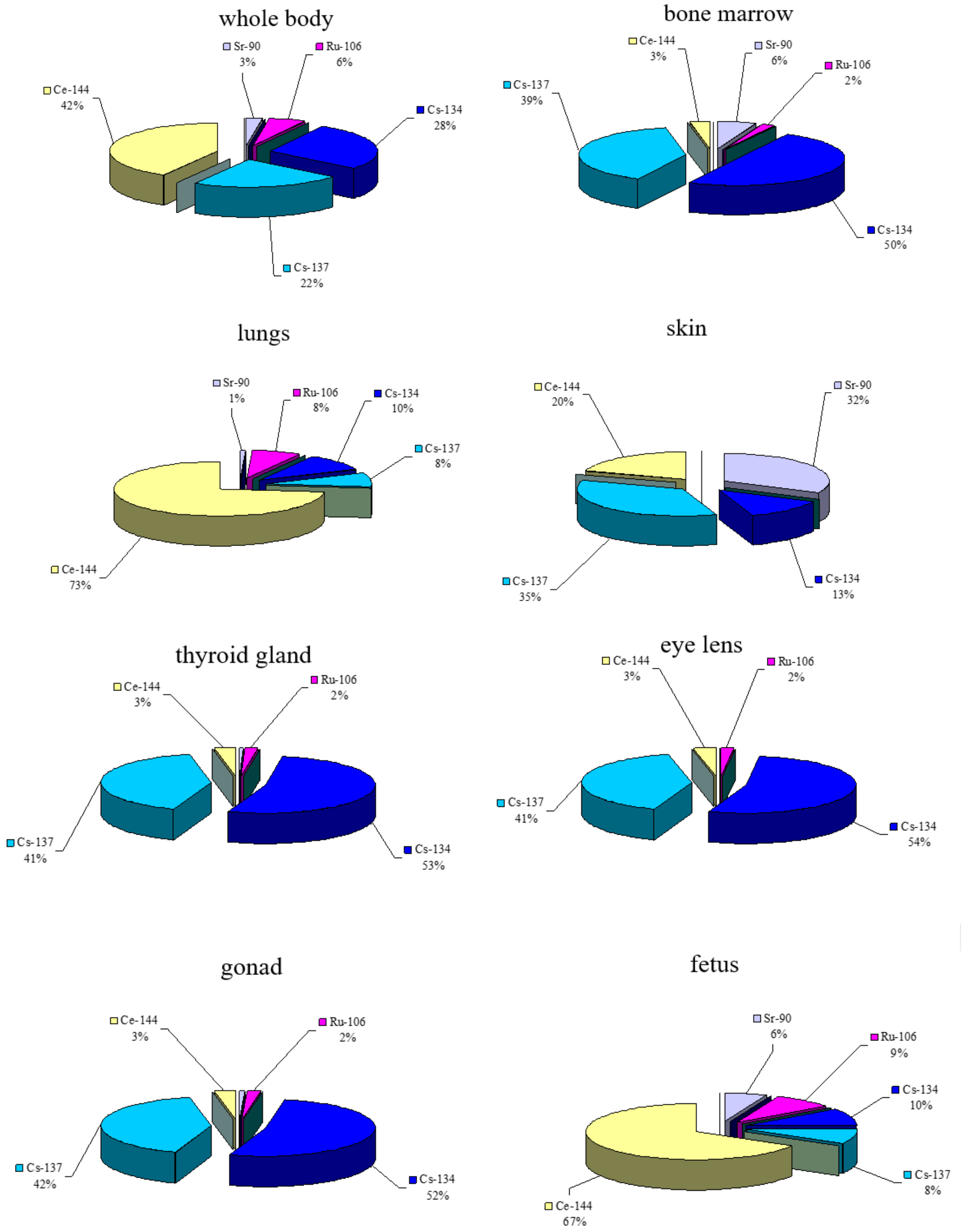


Figure 8.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

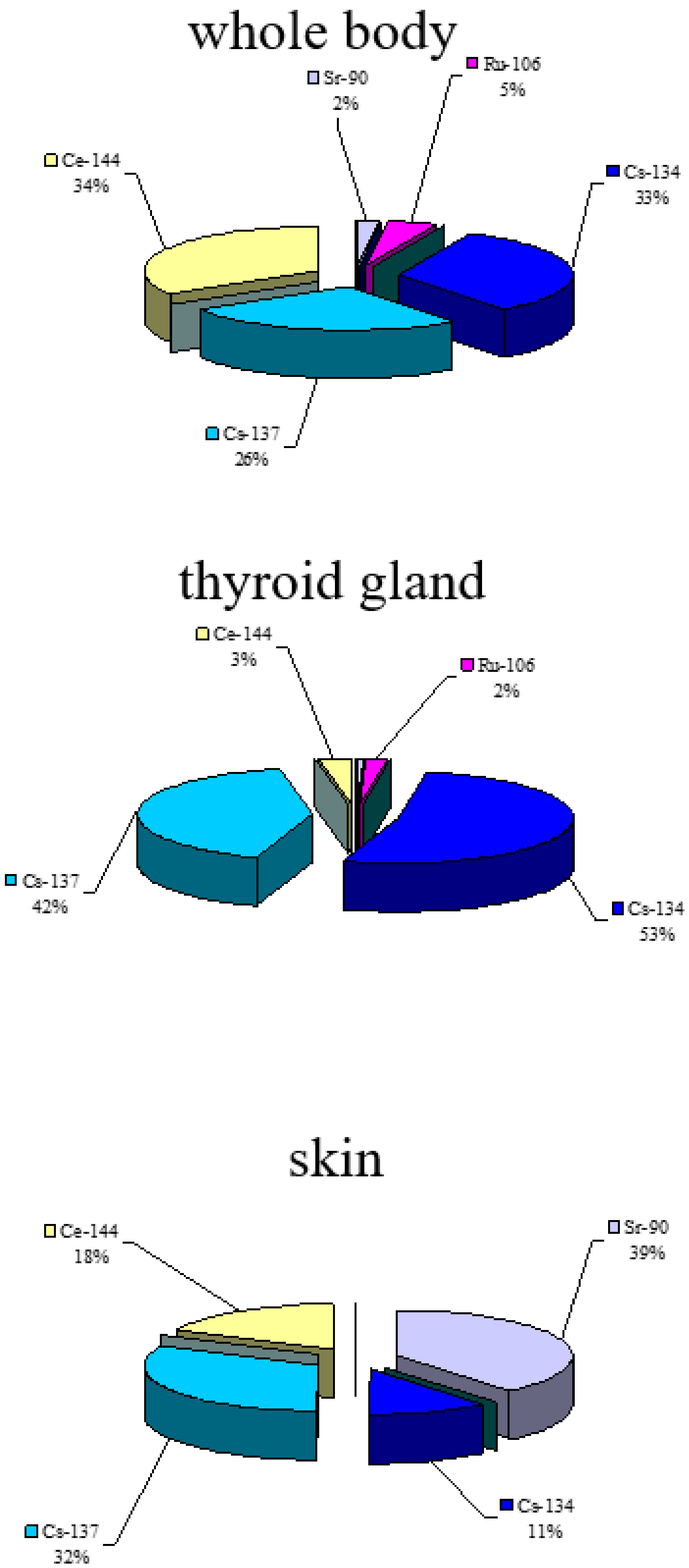
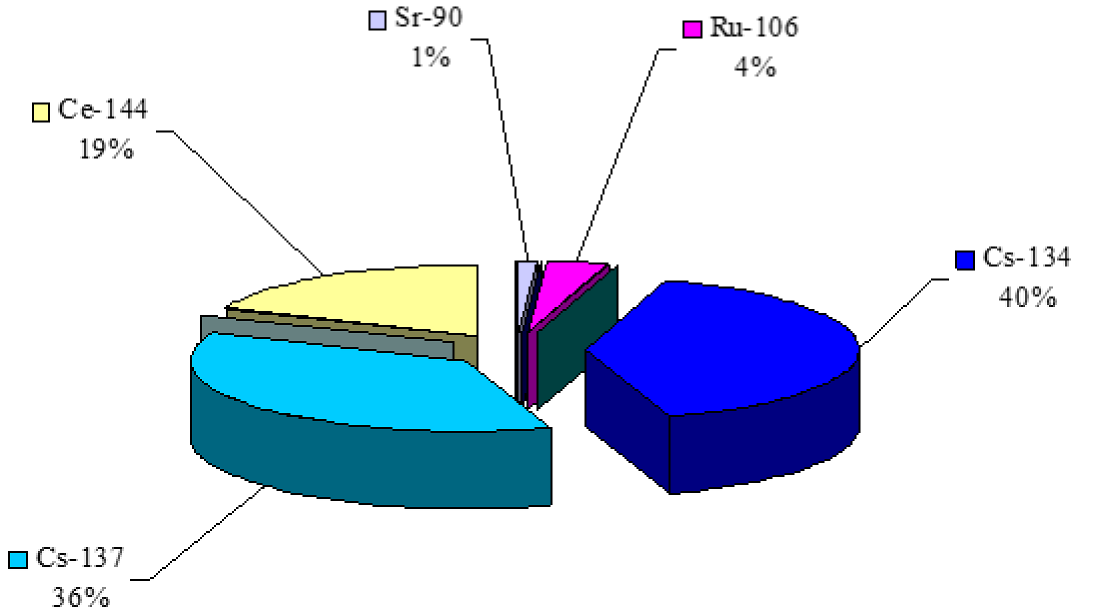


Figure 8.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

whole body



thyroid gland (children)

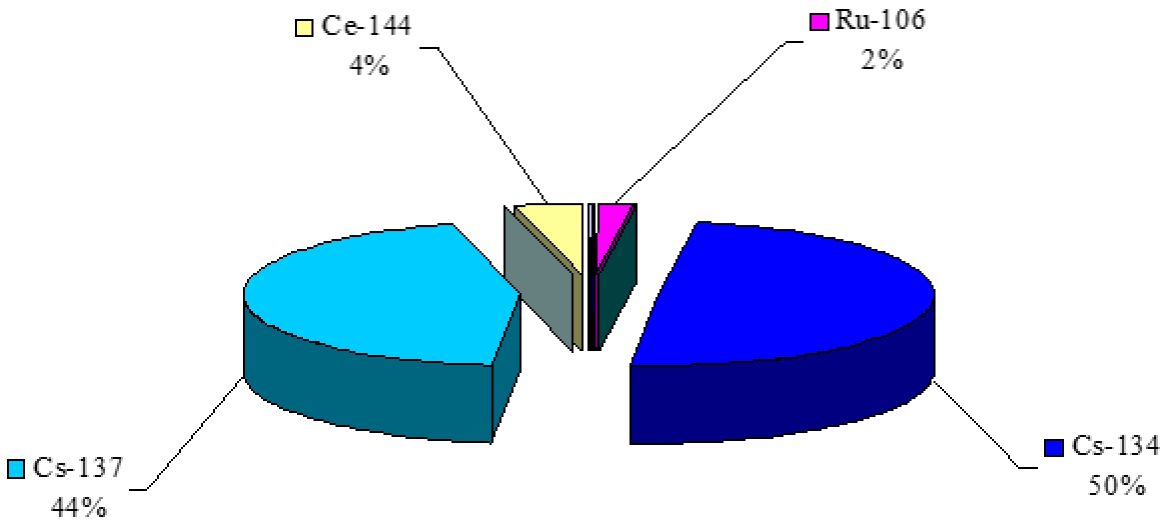


Figure 8.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

8.2.1 Radiation impact estimates for SFCD as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 8.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 8.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	SFCD estimates, Gy
entire body (bone marrow)[1]	1	7.20E-07 (4.95E-07)
Lungs	6	2.59E-06
Skin	3	1.75E-05
Thyroid gland	5	5.48E-07
Eye lens	2	4.93E-07
Gonad	2	4.46E-07
Fetus	0.1	2.25E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 8.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 8.7, while calculation results for standardized values for SFCD are given in Table 8.8.

Table 8.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 8.8 - Dose estimates over the first 2 weeks following the SFCD

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.0050	0.0036	0.12

Based on the calculation results given in Table 8.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the SFCD upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

8.2.2 Radiation impact estimates for SFCD as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during SFCD shall be 0.000064 Sv/year, and for the entire body due to external radiation - 0.000065 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

8.3 Calculation results for SFCD at the border of the OZ (30 km)

Table 8.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during SFCD.

Table 8.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during SFCD

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Sr-90	4.97E+00	4.97E+03
Ru-106	1.13E+00	1.13E+03
Cs-134	3.96E+00	3.96E+03
Cs-137	8.25E+00	8.25E+03
Ce-144	9.38E+00	9.38E+03
Total	**2.77E+01**	**2.77E+04**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 9.38 Bq/m^3 for cerium-144 isotopes. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 9.38 kBq/m^2 for ^{144}Ce.

Tables 8.10–8.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 8.4–8.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.28 mSv.

Table 8.10 - Human organ and tissue radiation doses during SFCD over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	4.18E-10	2.69E-10	5.85E-11	5.10E-10	2.37E-09	1.05E-15	5.85E-11	9.99E-08	1.76E-10	0.00E+00
Ru-106	5.61E-09	8.42E-09	5.62E-09	4.78E-09	7.74E-09	5.36E-09	4.52E-09	3.77E-13	7.31E-09	4.77E-09
Cs-134	1.25E-07	1.31E-07	1.45E-07	1.24E-07	1.12E-07	1.39E-07	1.17E-07	3.96E-08	1.45E-07	1.25E-07
Cs-137	9.64E-08	1.01E-07	1.12E-07	9.49E-08	8.61E-08	1.07E-07	8.98E-08	1.10E-07	1.14E-07	9.54E-08
Ce-144	1.45E-08	4.18E-08	8.88E-09	7.59E-09	3.36E-08	8.55E-09	7.17E-09	6.25E-08	1.76E-08	7.41E-09
Total	**2.42E-07**	**2.82E-07**	**2.71E-07**	**2.31E-07**	**2.42E-07**	**2.59E-07**	**2.18E-07**	**3.12E-07**	**2.84E-07**	**2.33E-07**

Table 8.11 - Human organ and tissue radiation doses during SFCD over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	1.67E-09	8.32E-10	3.85E-10	4.49E-09	8.84E-09	2.28E-14	3.85E-10	8.27E-07	1.16E-09	0.00E+00
Ru-106	3.62E-08	5.50E-08	3.83E-08	3.26E-08	3.87E-08	3.66E-08	3.08E-08	2.28E-12	4.60E-08	3.26E-08
Cs-134	8.58E-07	8.96E-07	9.94E-07	8.47E-07	7.67E-07	9.49E-07	8.02E-07	2.41E-07	9.94E-07	8.58E-07
Cs-137	6.63E-07	6.92E-07	7.67E-07	6.55E-07	5.94E-07	7.30E-07	6.18E-07	6.75E-07	7.67E-07	6.63E-07
Ce-144	8.23E-08	2.51E-07	6.16E-08	5.25E-08	1.20E-07	5.88E-08	4.95E-08	3.78E-07	1.07E-07	5.19E-08
Total	**1.64E-06**	**1.90E-06**	**1.86E-06**	**1.59E-06**	**1.53E-06**	**1.77E-06**	**1.50E-06**	**2.12E-06**	**1.91E-06**	**1.60E-06**

Table 8.12 - Human organ and tissue radiation doses during SFCD over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	1.61E-08	1.75E-09	1.25E-09	1.04E-07	1.49E-08	7.04E-13	1.25E-09	3.30E-06	3.74E-09	0.00E+00
Ru-106	5.29E-07	7.75E-07	5.77E-07	4.91E-07	4.59E-07	5.51E-07	4.64E-07	7.73E-12	6.46E-07	4.97E-07
Cs-134	1.48E-05	1.55E-05	1.72E-05	1.47E-05	1.33E-05	1.64E-05	1.38E-05	8.44E-07	1.72E-05	1.48E-05
Cs-137	1.31E-05	1.37E-05	1.52E-05	1.29E-05	1.18E-05	1.45E-05	1.22E-05	2.44E-06	1.52E-05	1.31E-05
Ce-144	1.12E-06	2.80E-06	1.03E-06	8.80E-07	8.96E-07	9.79E-07	8.28E-07	1.25E-06	1.36E-06	9.08E-07
Total	**2.96E-05**	**3.27E-05**	**3.40E-05**	**2.91E-05**	**2.64E-05**	**3.24E-05**	**2.73E-05**	**7.84E-06**	**3.44E-05**	**2.93E-05**

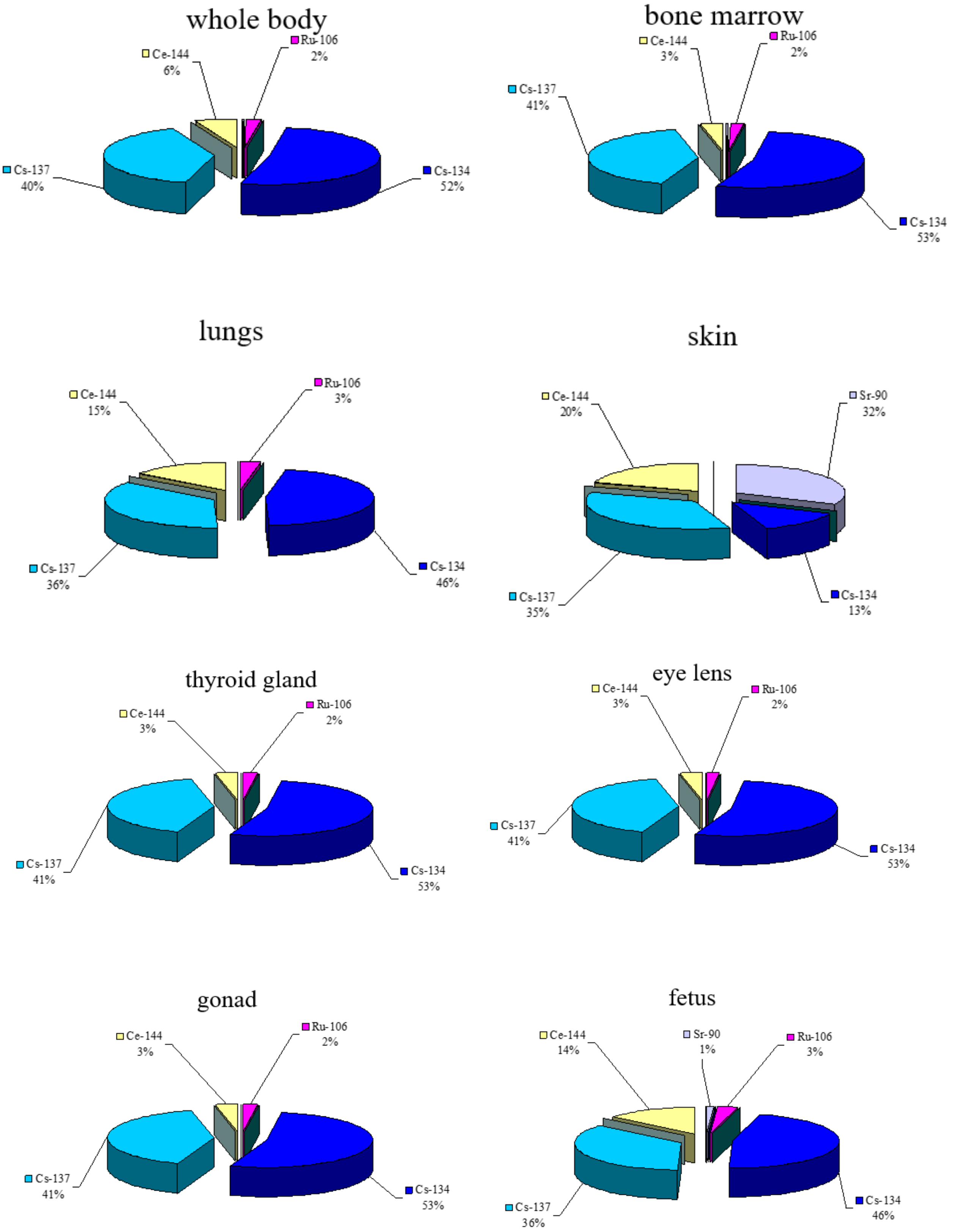


Figure 8.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

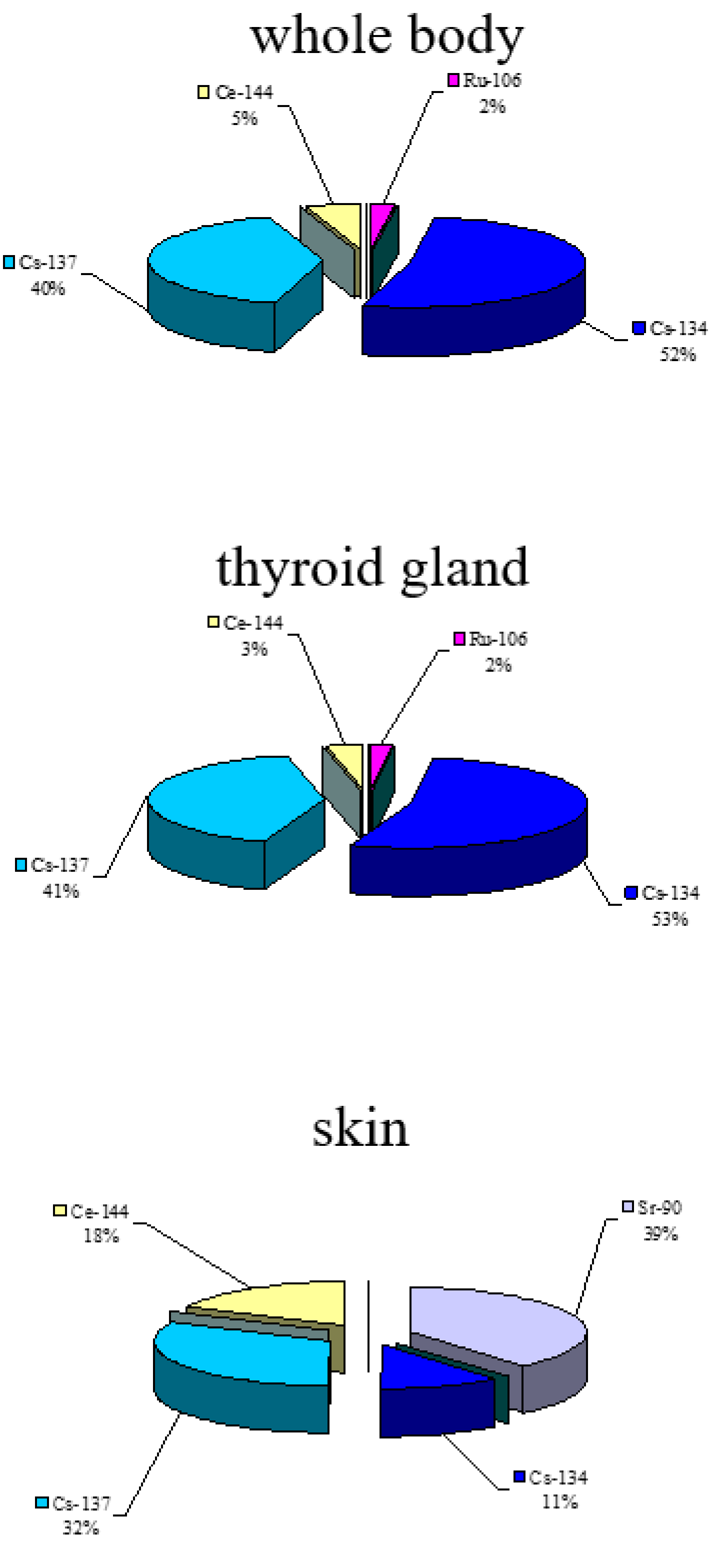
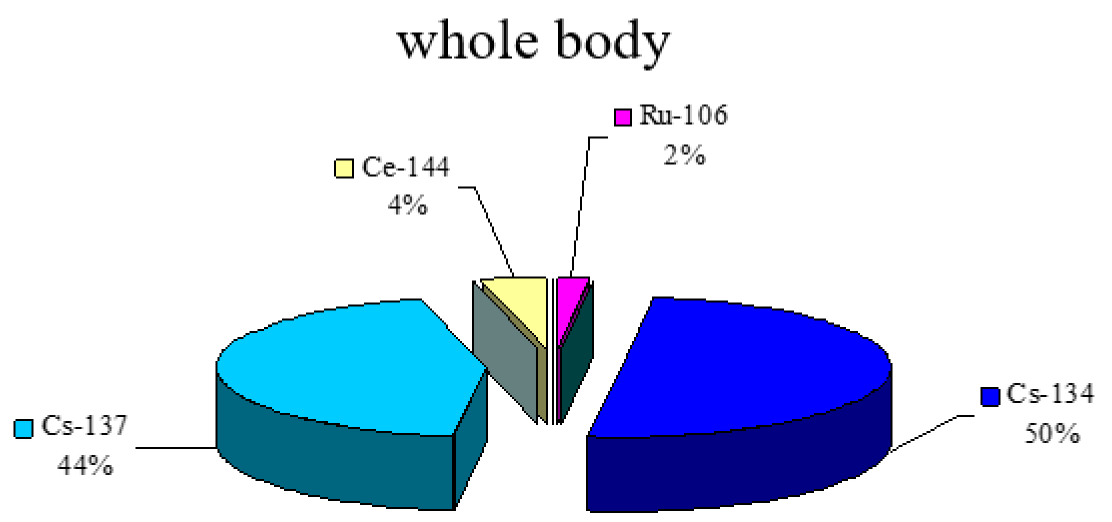


Figure 8.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



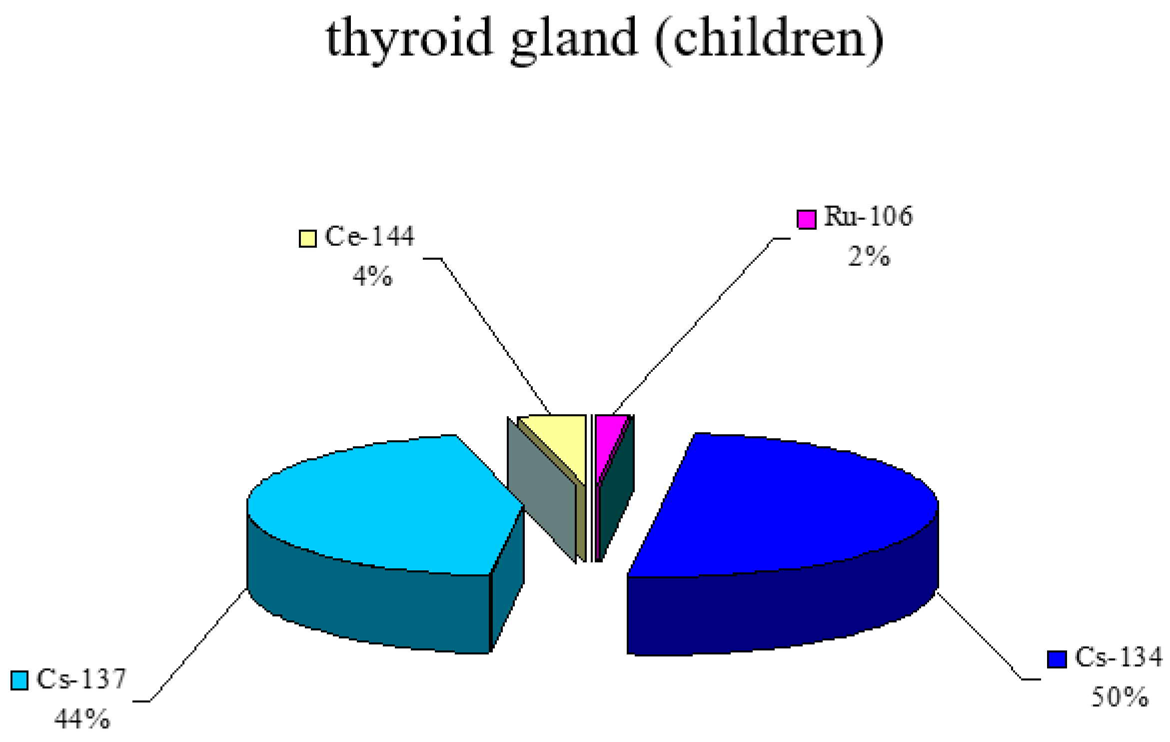


Figure 8.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

8.3.1Radiation impact estimates for SFCD as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 8.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 8.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	SFCD estimates, Gy
Entire body (bone marrow)[1]	1	2.33E-07 (2.31E-07)
Lungs	6	2.82E-07
Skin	3	3.12E-07
Thyroid gland	5	2.71E-07
Eye lens	2	2.59E-07
Gonad	2	2.18E-07
Fetus	0.1	2.42E-07

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 8.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 8.14, while calculation results for standardized values for SFCD are given in Table 8.15.

Table 8.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 8.15 - Dose estimates over the first 2 weeks following the SFCD

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.00024	0.00027	0.00031

Based on the calculation results given in Table 8.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the SFCD upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

8.3.2 Radiation impact estimates for SFCD as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during SFCD shall be 0.000034 Sv/year, and for the entire body due to external radiation - 0.000029 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

9 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT "FUEL ASSEMBLY DROP ON THE REACTOR CORE IN THE RECTOR" (FADR)

9.1 Input data for calculating radiation exposure during FADR

Effective values of the total environmental radioactive release are shown in Table 9.1.

Table 9.1 - Radioactive release during FADR

Radionuclide	Environmental release, Bq
Sr-90	1.20E+12
Ru-103	2.30E+12
Ru-106	4.30E+11
I-131	4.63E+12
Cs-134	1.60E+12
Cs-137	8.20E+11
Ce-144	4.10E+10
Xe-133	1.10E+14
Total activity	1.21E+14

9.2 Calculation results for FADR at the border of the SPZ (2.5 km)

Table 9.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during FADR.

Table 9.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during FADR

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Sr-90	7.57E+02	2.46E+04
Ru-103	1.45E+03	4.72E+04
Ru-106	2.71E+02	8.82E+03
I-131	2.34E+03	1.54E+05
Cs-134	1.01E+03	3.28E+04

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Cs-137	5.17E+02	1.68E+04
Ce-144	2.59E+01	8.41E+02
Xe-133	8.59E+04	0.00E+00
Total	**9.22E+04**	**2.85E+05**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 85.9 kBq/m^3 for xenon-133. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 154 kBq/m^2 for ^{131}I.

Tables 9.3–9.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 9.1–9.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 3.18 mSv.

Table 9.3 - Human organ and tissue radiation doses during FADR over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	6.62E-08	5.22E-08	8.89E-09	7.74E-08	3.72E-07	6.07E-15	8.89E-09	1.54E-05	2.67E-08	0.00E+00
Ru-103	7.54E-07	1.95E-06	5.84E-07	5.06E-07	8.60E-07	5.50E-07	4.81E-07	9.52E-06	6.08E-07	7.39E-07
Ru-106	2.24E-07	8.51E-07	4.73E-08	4.11E-08	8.51E-07	4.39E-08	3.90E-08	9.07E-11	6.15E-08	1.91E-07
I-131	2.44E-06	1.36E-06	2.44E-05	1.26E-06	1.14E-06	1.40E-06	1.19E-06	2.63E-04	2.98E-05	2.17E-06
Cs-134	1.20E-06	1.20E-06	1.32E-06	1.13E-06	1.04E-06	1.21E-06	1.07E-06	1.01E-05	1.32E-06	1.20E-06
Cs-137	2.39E-07	2.37E-07	2.55E-07	2.19E-07	2.07E-07	2.28E-07	2.08E-07	6.92E-06	2.60E-07	2.36E-07
Ce-144	1.96E-08	9.39E-08	8.32E-10	7.34E-10	7.42E-08	7.83E-10	6.97E-10	1.73E-07	1.65E-09	9.97E-09
Xe-133	7.92E-08	7.71E-08	9.17E-08	5.69E-08	5.69E-08	1.06E-07	4.96E-08	0.00E+00	9.17E-08	7.92E-08
Total	**5.03E-06**	**5.82E-06**	**2.67E-05**	**3.29E-06**	**4.61E-06**	**3.54E-06**	**3.04E-06**	**3.06E-04**	**3.21E-05**	**4.63E-06**

Table 9.4 - Human organ and tissue radiation doses during FADR over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	2.57E-07	1.54E-07	5.78E-08	6.72E-07	1.36E-06	1.14E-13	5.78E-08	1.26E-04	1.74E-07	0.00E+00
Ru-103	3.91E-06	9.71E-06	3.50E-06	2.99E-06	3.75E-06	3.29E-06	2.81E-06	5.29E-05	3.57E-06	3.87E-06
Ru-106	1.02E-06	5.16E-06	3.09E-07	2.66E-07	2.41E-06	2.88E-07	2.49E-07	5.50E-10	3.70E-07	9.21E-07
I-131	1.10E-05	5.69E-06	1.16E-04	5.37E-06	4.86E-06	6.02E-06	5.05E-06	1.05E-03	1.44E-04	9.66E-06
Cs-134	7.58E-06	7.81E-06	8.66E-06	7.41E-06	6.85E-06	7.95E-06	7.06E-06	6.16E-05	8.66E-06	7.58E-06
Cs-137	1.49E-06	1.53E-06	1.68E-06	1.44E-06	1.37E-06	1.51E-06	1.39E-06	4.24E-05	1.68E-06	1.49E-06
Ce-144	8.45E-08	5.37E-07	5.62E-09	4.92E-09	2.01E-07	5.29E-09	4.55E-09	1.04E-06	9.77E-09	5.32E-08
Xe-133	7.92E-08	7.71E-08	9.17E-08	5.69E-08	5.69E-08	1.06E-07	4.96E-08	0.00E+00	9.17E-08	7.92E-08
Total	**2.54E-05**	**3.07E-05**	**1.31E-04**	**1.82E-05**	**2.09E-05**	**1.92E-05**	**1.67E-05**	**1.33E-03**	**1.59E-04**	**2.37E-05**

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	2.00E-06	2.59E-07	1.55E-07	1.28E-05	1.87E-06	3.49E-12	1.55E-07	5.04E-04	4.64E-07	0.00E+00
Ru-103	1.47E-05	3.01E-05	1.46E-05	1.25E-05	1.24E-05	1.38E-05	1.17E-05	1.22E-04	1.49E-05	1.46E-05
Ru-106	1.04E-05	5.63E-05	4.60E-06	3.93E-06	6.24E-06	4.30E-06	3.68E-06	1.86E-09	5.15E-06	9.82E-06
I-131	1.68E-05	8.06E-06	1.91E-04	7.59E-06	6.85E-06	8.47E-06	7.13E-06	1.34E-03	2.44E-04	1.44E-05
Cs-134	1.27E-04	1.32E-04	1.46E-04	1.25E-04	1.14E-04	1.37E-04	1.19E-04	2.16E-04	1.46E-04	1.27E-04
Cs-137	2.79E-05	2.89E-05	3.21E-05	2.75E-05	2.53E-05	2.96E-05	2.61E-05	1.53E-04	3.21E-05	2.79E-05
Ce-144	6.31E-07	4.51E-06	9.35E-08	8.49E-08	3.14E-07	8.86E-08	7.50E-08	3.47E-06	1.23E-07	5.11E-07
Xe-133	7.92E-08	7.71E-08	9.17E-08	5.69E-08	5.69E-08	1.06E-07	4.96E-08	0.00E+00	9.17E-08	7.92E-08
Total	**1.99E-04**	**2.60E-04**	**3.89E-04**	**1.89E-04**	**1.67E-04**	**1.93E-04**	**1.68E-04**	**2.34E-03**	**4.43E-04**	**1.94E-04**

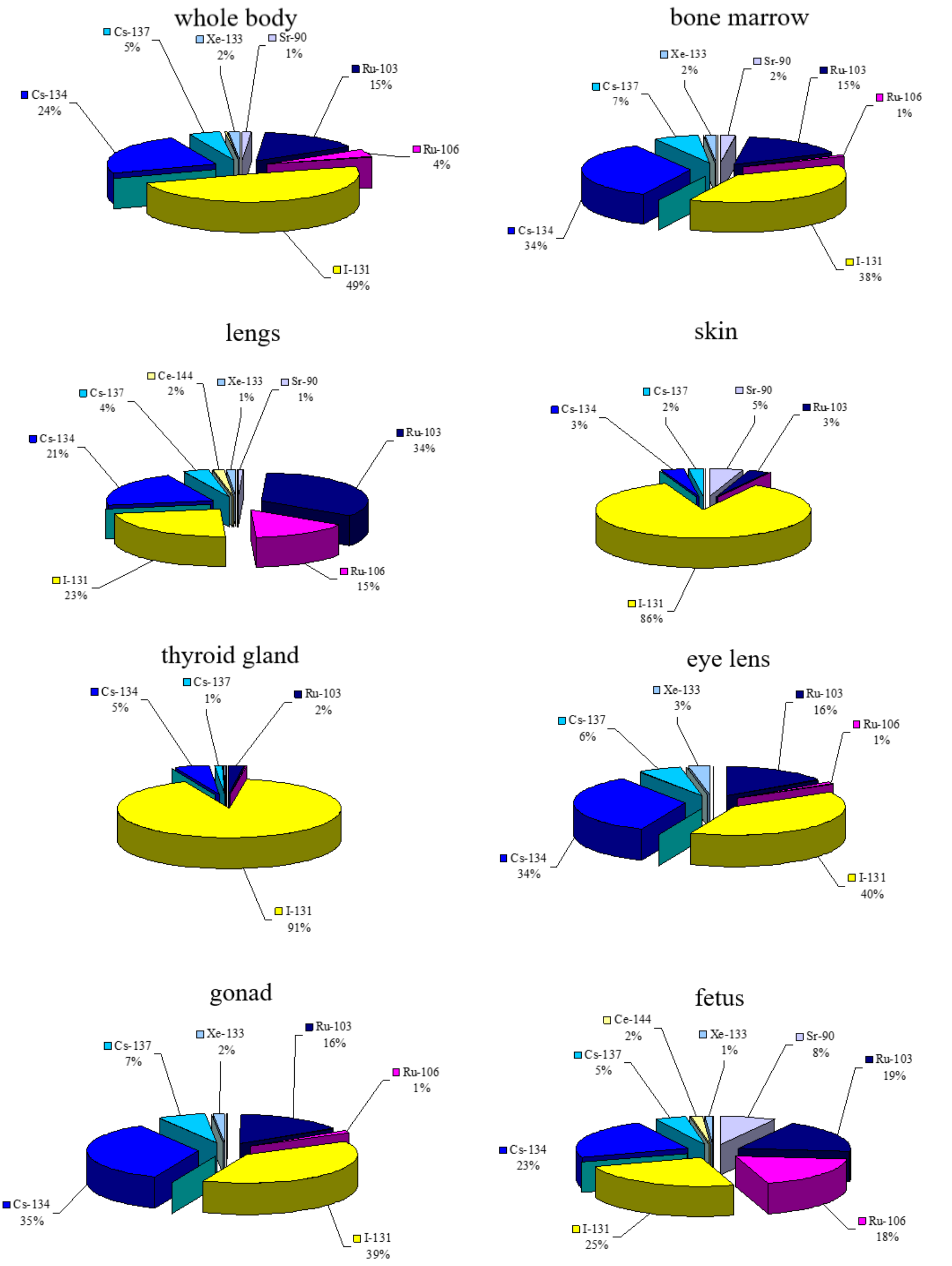


Figure 9.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

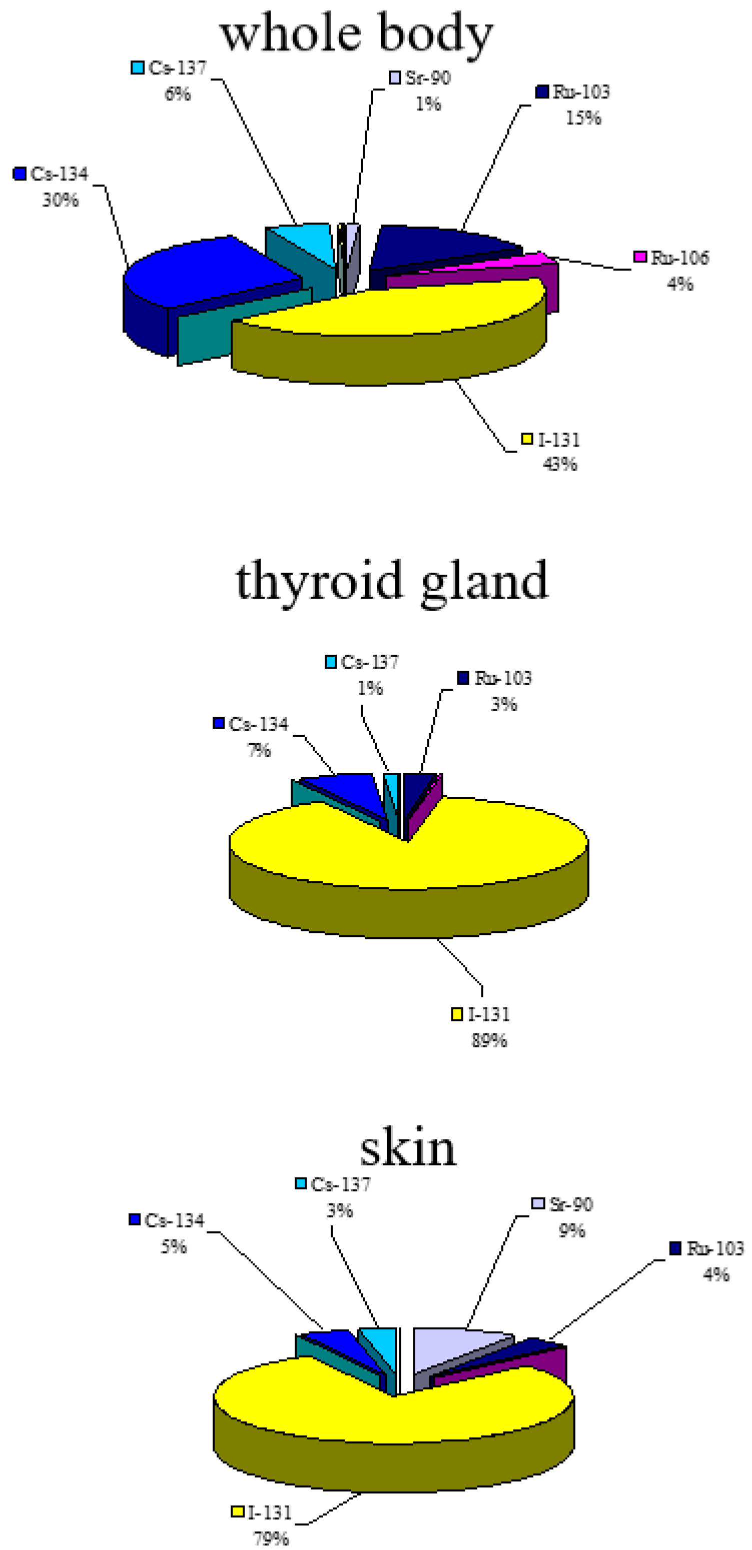
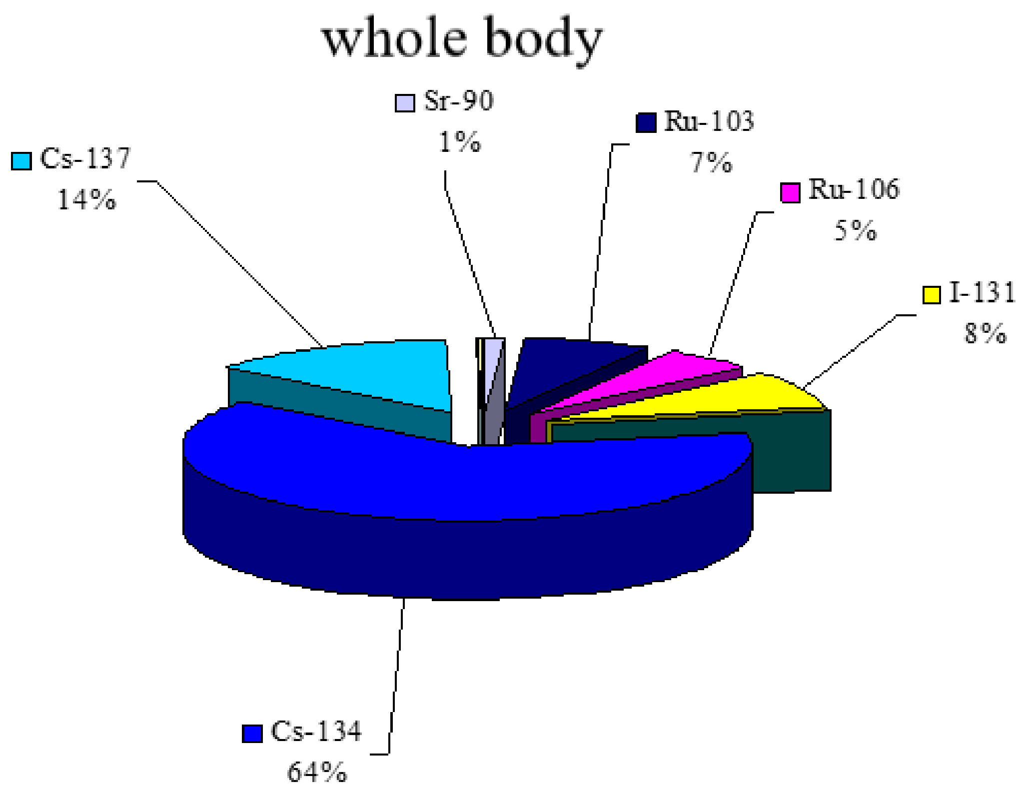


Figure 9.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



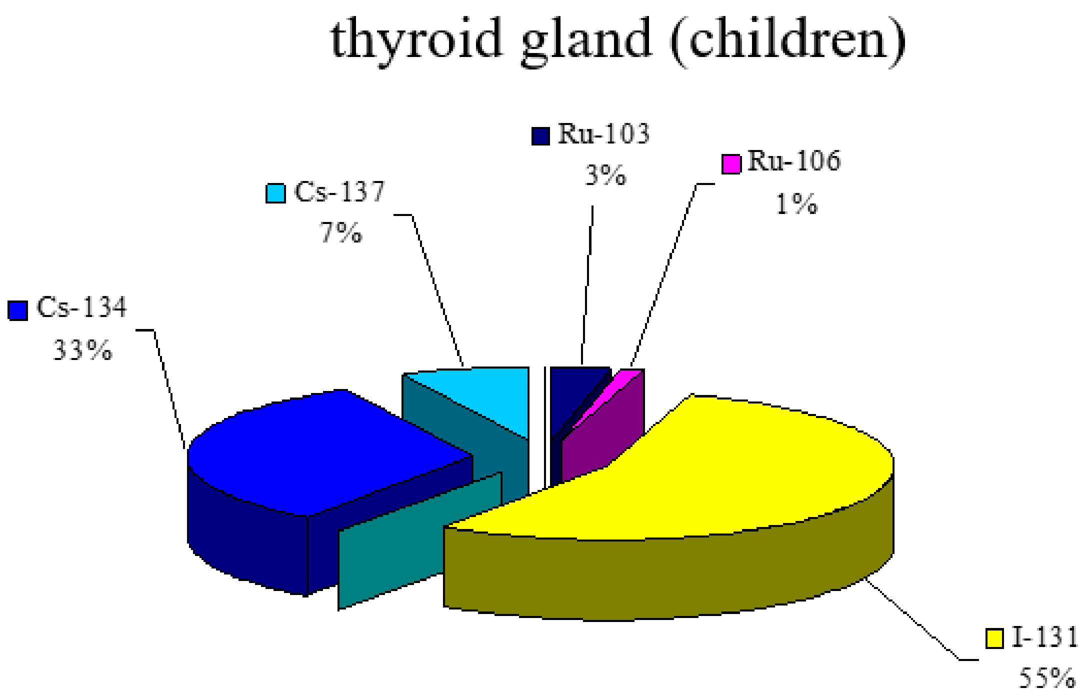


Figure 9.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

9.2.1Radiation impact estimates for FADR as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 9.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 9.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	FADR estimates, Gy
Entire body (bone marrow)[1]	1	4.63E-06 (3.29E-06)
Lungs	6	5.82E-06
Skin	3	3.06E-04
Thyroid gland	5	2.67E-05
Eye lens	2	3.54E-06
Gonad	2	3.04E-06
Fetus	0.1	4.61E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 9.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 9.7, while calculation results for standardized values for FADR are given in Table 9.8.

Table 9.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 9.8 - Dose estimates over the first 2 weeks following the FADR

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.025	0.13	1.33

Based on the calculation results given in Table 9.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the FADR upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

9.2.2 Radiation impact estimates for FADR as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during FADR shall be 0.00044 Sv/year, and for the entire body due to external radiation - 0.00019 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

9.3 Calculation results for FADR at the border of the OZ (30 km)

Table 9.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during FADR.

Table 9.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during FADR

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Sr-90	1.36E+01	1.36E+04
Ru-103	2.59E+01	2.60E+04
Ru-106	4.86E+00	4.86E+03
I-131	3.05E+02	1.32E+05
Cs-134	1.81E+01	1.81E+04
Cs-137	9.27E+00	9.27E+03
Ce-144	4.64E-01	4.63E+02
Xe-133	4.31E+04	0.00E+00
Total	**4.35E+04**	**2.04E+05**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 43.5 kBq/m^3 for xenon-133. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 132 kBq/m^2 for ^{131}I.

Tables 9.10–9.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 9.4–9.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.78 mSv.

Table 9.10 - Human organ and tissue radiation doses during FADR over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	1.14E-09	7.34E-10	1.60E-10	1.39E-09	6.46E-09	2.87E-15	1.60E-10	2.72E-07	4.79E-10	0.00E+00
Ru-103	2.65E-07	2.99E-07	3.04E-07	2.58E-07	2.42E-07	2.90E-07	2.44E-07	1.70E-07	3.16E-07	2.59E-07
Ru-106	2.41E-08	3.62E-08	2.42E-08	2.06E-08	3.33E-08	2.30E-08	1.94E-08	1.62E-12	3.14E-08	2.05E-08
I-131	1.21E-06	1.11E-06	4.22E-06	1.05E-06	9.49E-07	1.17E-06	9.86E-07	3.43E-05	5.15E-06	1.08E-06
Cs-134	5.73E-07	5.97E-07	6.64E-07	5.65E-07	5.12E-07	6.34E-07	5.33E-07	1.81E-07	6.64E-07	5.73E-07
Cs-137	1.08E-07	1.13E-07	1.25E-07	1.07E-07	9.68E-08	1.20E-07	1.01E-07	1.24E-07	1.28E-07	1.07E-07
Ce-144	7.18E-10	2.07E-09	4.39E-10	3.75E-10	1.66E-09	4.22E-10	3.54E-10	3.09E-09	8.69E-10	3.66E-10
Xe-133	3.98E-08	3.87E-08	4.61E-08	2.86E-08	2.86E-08	5.35E-08	2.49E-08	0.00E+00	4.61E-08	3.98E-08
Total	**2.22E-06**	**2.20E-06**	**5.38E-06**	**2.03E-06**	**1.87E-06**	**2.29E-06**	**1.91E-06**	**3.51E-05**	**6.33E-06**	**2.08E-06**

Table 9.11 - Human organ and tissue radiation doses during FADR over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	4.56E-09	2.27E-09	1.05E-09	1.22E-08	2.41E-08	6.22E-14	1.05E-09	2.26E-06	3.15E-09	0.00E+00
Ru-103	1.64E-06	1.81E-06	1.88E-06	1.60E-06	1.47E-06	1.80E-06	1.52E-06	9.48E-07	1.92E-06	1.62E-06
Ru-106	1.56E-07	2.37E-07	1.65E-07	1.40E-07	1.66E-07	1.57E-07	1.32E-07	9.80E-12	1.98E-07	1.40E-07
I-131	5.32E-06	4.82E-06	1.97E-05	4.57E-06	4.14E-06	5.14E-06	4.31E-06	1.37E-04	2.45E-05	4.69E-06
Cs-134	3.92E-06	4.10E-06	4.54E-06	3.87E-06	3.50E-06	4.34E-06	3.66E-06	1.10E-06	4.54E-06	3.92E-06
Cs-137	7.45E-07	7.77E-07	8.61E-07	7.36E-07	6.67E-07	8.20E-07	6.95E-07	7.58E-07	8.61E-07	7.45E-07
Ce-144	4.07E-09	1.24E-08	3.04E-09	2.59E-09	5.95E-09	2.90E-09	2.44E-09	1.87E-08	5.29E-09	2.56E-09
Xe-133	3.98E-08	3.87E-08	4.61E-08	2.86E-08	2.86E-08	5.35E-08	2.49E-08	0.00E+00	4.61E-08	3.98E-08
Total	**1.18E-05**	**1.18E-05**	**2.72E-05**	**1.10E-05**	**1.00E-05**	**1.23E-05**	**1.03E-05**	**1.42E-04**	**3.20E-05**	**1.12E-05**

Table 9.12 - Human organ and tissue radiation doses during FADR over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Sr-90	4.40E-08	4.78E-09	3.40E-09	2.83E-07	4.06E-08	1.92E-12	3.40E-09	9.01E-06	1.02E-08	0.00E+00
Ru-103	6.85E-06	7.45E-06	7.91E-06	6.74E-06	6.14E-06	7.57E-06	6.37E-06	2.18E-06	8.07E-06	6.79E-06
Ru-106	2.27E-06	3.33E-06	2.48E-06	2.11E-06	1.97E-06	2.37E-06	2.00E-06	3.32E-11	2.78E-06	2.14E-06
I-131	7.69E-06	6.81E-06	3.13E-05	6.44E-06	5.83E-06	7.22E-06	6.07E-06	1.75E-04	4.01E-05	6.61E-06
Cs-134	6.78E-05	7.07E-05	7.87E-05	6.70E-05	6.08E-05	7.50E-05	6.32E-05	3.86E-06	7.87E-05	6.78E-05
Cs-137	1.47E-05	1.53E-05	1.71E-05	1.45E-05	1.32E-05	1.62E-05	1.37E-05	2.74E-06	1.71E-05	1.47E-05
Ce-144	5.54E-08	1.38E-07	5.08E-08	4.35E-08	4.43E-08	4.84E-08	4.09E-08	6.19E-08	6.71E-08	4.48E-08
Xe-133	3.98E-08	3.87E-08	4.61E-08	2.86E-08	2.86E-08	5.35E-08	2.49E-08	0.00E+00	4.61E-08	3.98E-08
Total	**9.95E-05**	**1.04E-04**	**1.38E-04**	**9.72E-05**	**8.81E-05**	**1.09E-04**	**9.14E-05**	**1.92E-04**	**1.47E-04**	**9.81E-05**

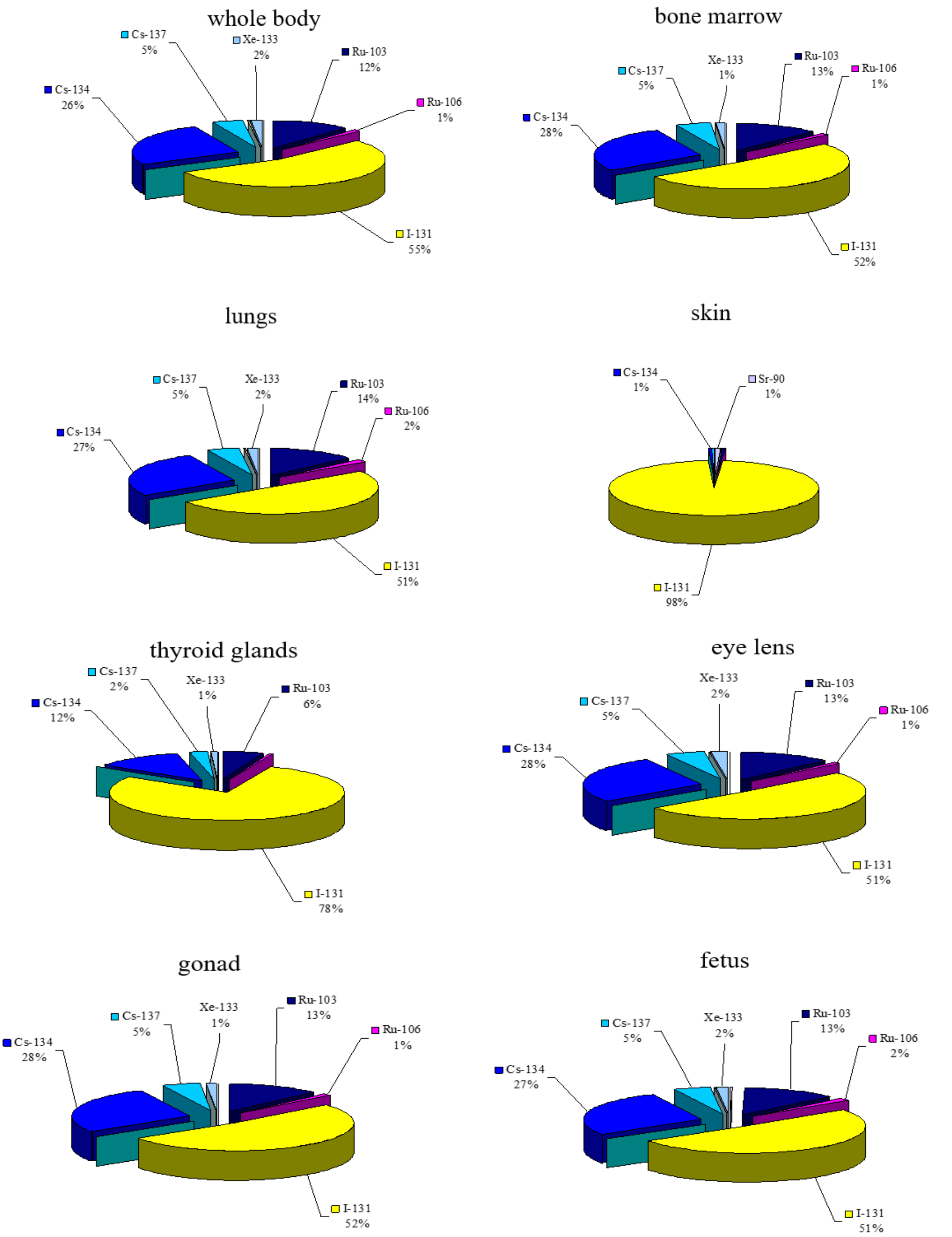


Figure 9.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

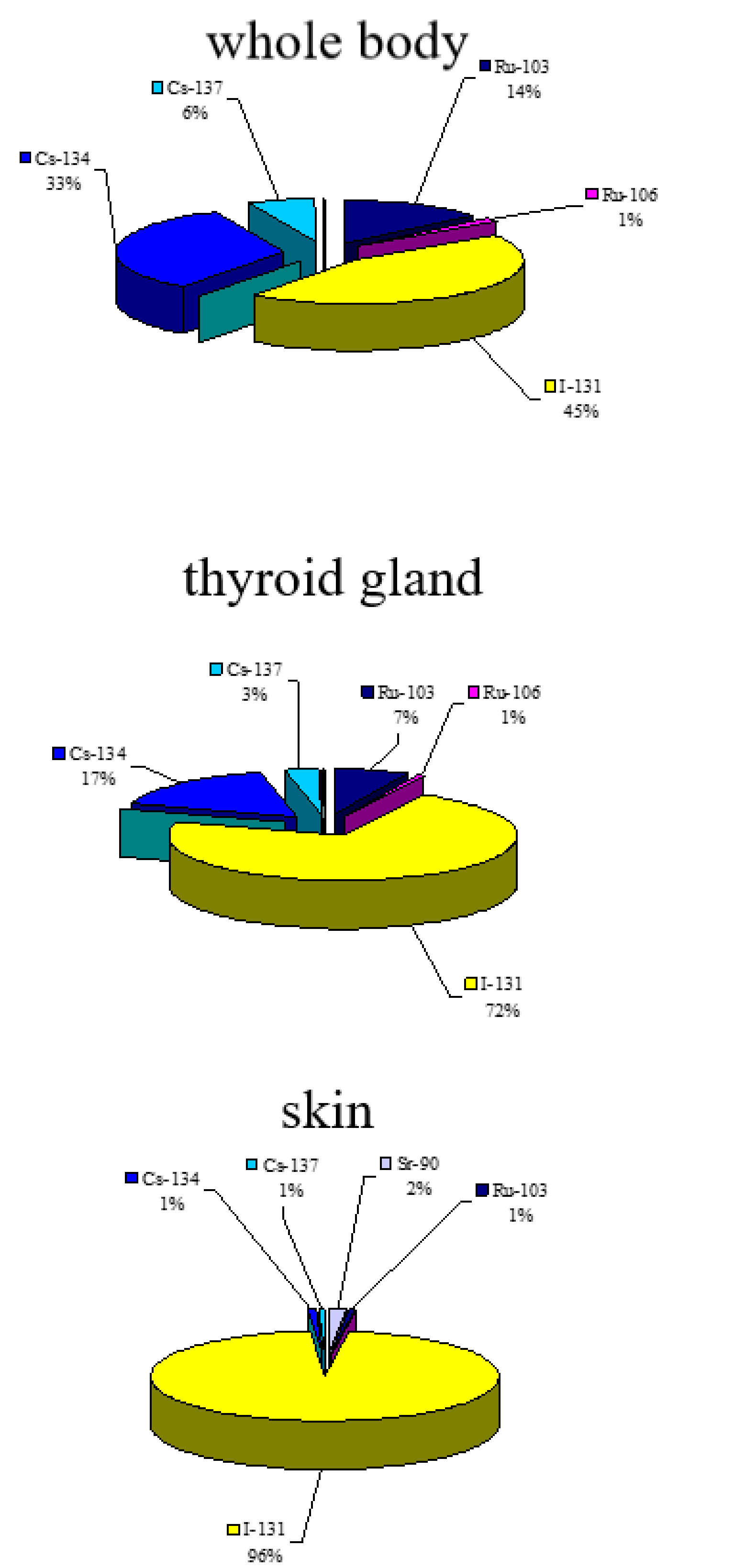
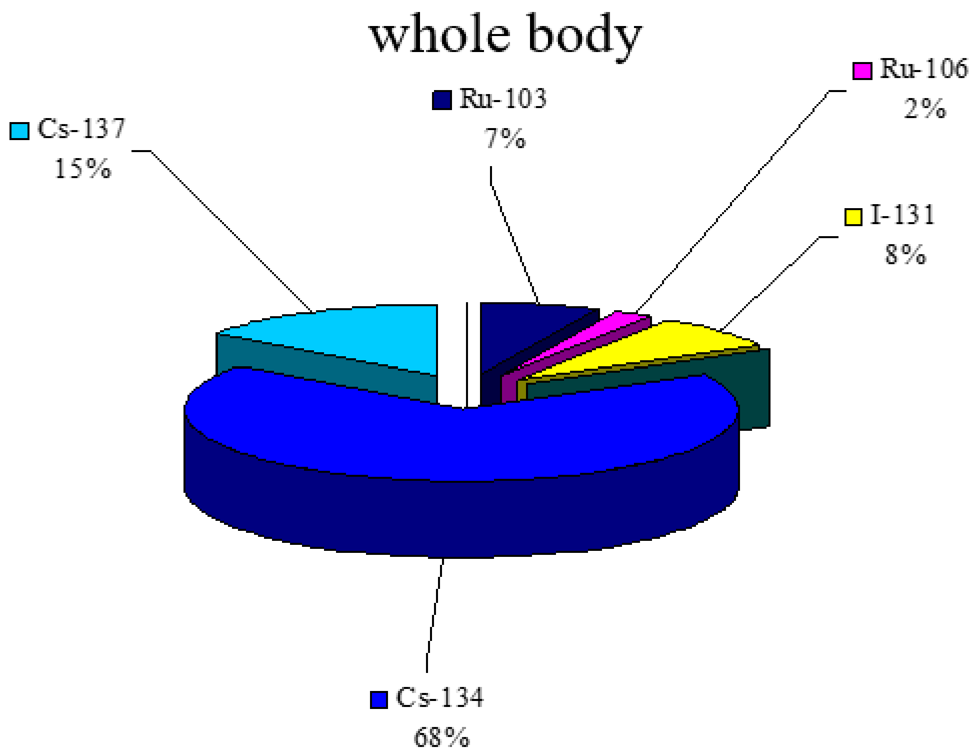


Figure 9.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



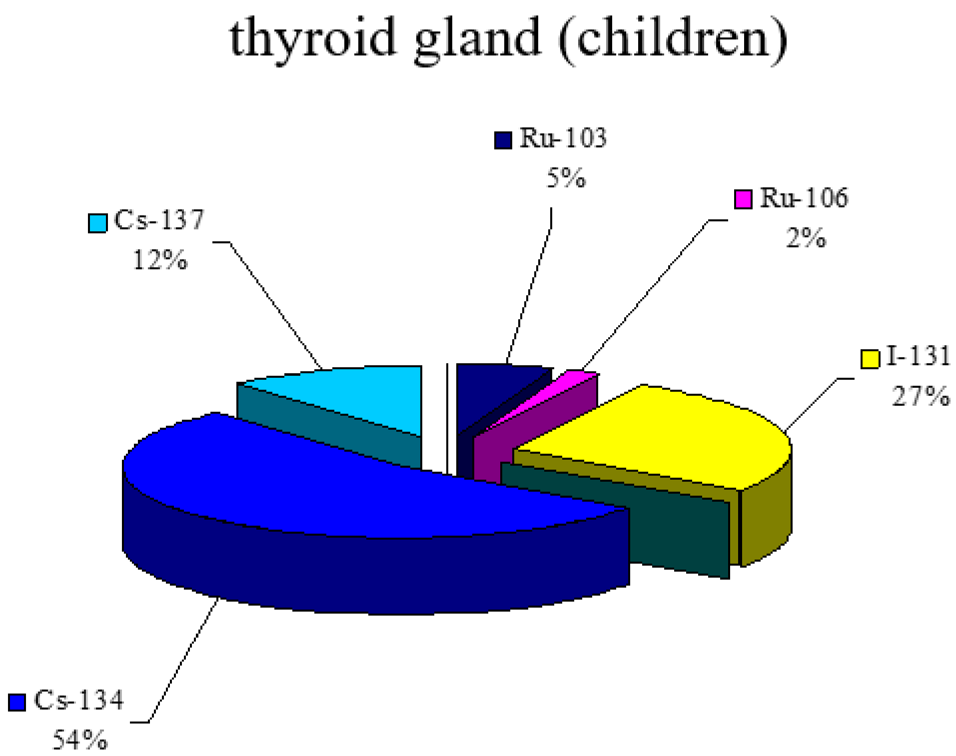


Figure 9.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

9.3.1 Radiation impact estimates for FADR as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 9.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 9.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	FADR estimates, Gy
Entire body (bone marrow)[1]	1	2.08E-06 (2.03E-06)
Lungs	6	2.20E-06
Skin	3	3.51E-05
Thyroid gland	5	5.38E-06
Eye lens	2	2.29E-06
Gonad	2	1.91E-06
Fetus	0.1	1.87E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 9.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 9.14, while calculation results for standardized values for FADR are given in Table 9.15.

Table 9.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 9.15 - Dose estimates over the first 2 weeks following the FADR

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.012	0.027	0.14

Based on the calculation results given in Table 9.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the FADR upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

9.3.2 Radiation impact estimates for FADR as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during FADR shall be 0.00015 Sv/year, and for the entire body due to external radiation - 0.000098 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

10 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT “IMPULSE TUBE RUPTURE BEYOND THE CONTAINMENT” (ITR)

10.1 Input data for calculating radiation exposure during ITR

Effective values of the total environmental radioactive release are shown in Table 10.1.

Table 10.1 - Radioactive release during ITR

Radionuclide	Environmental release, Bq
Kr-88	7.10E+11
I-131	6.70E+12
I-132	1.70E+13
I-133	1.30E+13
I-134	9.60E+12
I-135	1.10E+13
Cs-137	7.40E+09
Xe-133	6.40E+13
Xe-135	9.80E+12
Total activity	1.32E+14

10.2 Calculation results for ITR at the border of the SPZ (2.5 km)

Table 10.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during ITR.

Table 10.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during ITR

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-88	2.80E+02	0.00E+00
I-131	3.39E+03	2.23E+05
I-132	3.64E+03	2.40E+05

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
I-133	6.03E+03	3.98E+05
I-134	5.04E+02	3.32E+04
I-135	4.16E+03	2.74E+05
Cs-137	4.67E+00	1.52E+02
Xe-133	5.00E+04	0.00E+00
Xe-135	6.23E+03	0.00E+00
Total	**7.42E+04**	**1.17E+06**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 50 kBq/m^3 for xenon-133. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 398 kBq/m^2 for ^{133}I, up to 274 kBq/m^2 for ^{135}I and up to 240 kBq/m^2 for ^{132}I.

Tables 10.3–10.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 10.1–10.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.35 mSv.

Table 10.3 - Human organ and tissue radiation doses during ITR over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	2.86E-08	3.17E-08	3.02E-08	2.50E-08	2.41E-08	2.86E-08	2.26E-08	2.69E-08	3.32E-08	2.72E-08
I-131	3.53E-06	1.96E-06	3.53E-05	1.82E-06	1.65E-06	2.02E-06	1.72E-06	3.81E-04	4.31E-05	3.14E-06
I-132	1.03E-06	9.54E-07	3.59E-06	8.57E-07	7.80E-07	9.52E-07	7.91E-07	3.15E-05	3.87E-06	9.92E-07
I-133	4.55E-06	2.29E-06	4.95E-05	2.09E-06	1.91E-06	2.30E-06	1.98E-06	3.71E-04	6.44E-05	3.87E-06
I-134	9.03E-08	8.85E-08	1.60E-07	7.69E-08	7.16E-08	8.83E-08	6.97E-08	2.49E-06	1.73E-07	8.67E-08
I-135	2.38E-06	1.91E-06	1.30E-05	1.76E-06	1.61E-06	1.95E-06	1.66E-06	1.02E-04	1.45E-05	2.23E-06
Cs-137	2.15E-09	2.14E-09	2.30E-09	1.98E-09	1.87E-09	2.06E-09	1.88E-09	6.25E-08	2.35E-09	2.13E-09
Xe-133	4.61E-08	4.49E-08	5.34E-08	3.31E-08	3.31E-08	6.20E-08	2.89E-08	0.00E+00	5.34E-08	4.61E-08
Xe-135	4.76E-08	4.80E-08	5.48E-08	4.41E-08	4.01E-08	5.48E-08	3.73E-08	0.00E+00	5.48E-08	4.76E-08
Total	**1.17E-05**	**7.33E-06**	**1.02E-04**	**6.71E-06**	**6.12E-06**	**7.46E-06**	**6.30E-06**	**8.88E-04**	**1.26E-04**	**1.04E-05**

Table 10.4 - Human organ and tissue radiation doses during ITR over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	2.86E-08	3.17E-08	3.02E-08	2.50E-08	2.41E-08	2.86E-08	2.26E-08	2.69E-08	3.32E-08	2.72E-08
I-131	1.59E-05	8.24E-06	1.68E-04	7.77E-06	7.04E-06	8.71E-06	7.30E-06	1.52E-03	2.09E-04	1.40E-05
I-132	1.03E-06	9.54E-07	3.59E-06	8.57E-07	7.80E-07	9.52E-07	7.91E-07	3.15E-05	3.87E-06	9.92E-07
I-133	7.33E-06	2.93E-06	9.33E-05	2.70E-06	2.47E-06	2.96E-06	2.55E-06	4.59E-04	1.29E-04	5.94E-06
I-134	9.03E-08	8.85E-08	1.60E-07	7.69E-08	7.16E-08	8.83E-08	6.97E-08	2.49E-06	1.73E-07	8.67E-08
I-135	2.49E-06	1.95E-06	1.46E-05	1.79E-06	1.64E-06	1.98E-06	1.68E-06	1.02E-04	1.64E-05	2.34E-06
Cs-137	1.35E-08	1.38E-08	1.52E-08	1.30E-08	1.24E-08	1.36E-08	1.25E-08	3.83E-07	1.52E-08	1.35E-08
Xe-133	4.61E-08	4.49E-08	5.34E-08	3.31E-08	3.31E-08	6.20E-08	2.89E-08	0.00E+00	5.34E-08	4.61E-08
Xe-135	4.76E-08	4.80E-08	5.48E-08	4.41E-08	4.01E-08	5.48E-08	3.73E-08	0.00E+00	5.48E-08	4.76E-08
Total	**2.70E-05**	**1.43E-05**	**2.80E-04**	**1.33E-05**	**1.21E-05**	**1.49E-05**	**1.25E-05**	**2.12E-03**	**3.58E-04**	**2.35E-05**

Table 10.5 - Human organ and tissue radiation doses during ITR over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	2.86E-08	3.17E-08	3.02E-08	2.50E-08	2.41E-08	2.86E-08	2.26E-08	2.69E-08	3.32E-08	2.72E-08
I-131	2.43E-05	1.17E-05	2.76E-04	1.10E-05	9.92E-06	1.23E-05	1.03E-05	1.94E-03	3.53E-04	2.09E-05
I-132	1.03E-06	9.54E-07	3.59E-06	8.57E-07	7.80E-07	9.52E-07	7.91E-07	3.15E-05	3.87E-06	9.92E-07
I-133	7.36E-06	2.96E-06	9.36E-05	2.73E-06	2.50E-06	3.00E-06	2.57E-06	4.59E-04	1.29E-04	5.96E-06
I-134	9.03E-08	8.85E-08	1.60E-07	7.69E-08	7.16E-08	8.83E-08	6.97E-08	2.49E-06	1.73E-07	8.67E-08
I-135	2.49E-06	1.95E-06	1.46E-05	1.79E-06	1.64E-06	1.98E-06	1.68E-06	1.02E-04	1.64E-05	2.34E-06
Cs-137	2.52E-07	2.61E-07	2.89E-07	2.48E-07	2.29E-07	2.67E-07	2.35E-07	1.38E-06	2.89E-07	2.52E-07
Xe-133	4.61E-08	4.49E-08	5.34E-08	3.31E-08	3.31E-08	6.20E-08	2.89E-08	0.00E+00	5.34E-08	4.61E-08
Xe-135	4.76E-08	4.80E-08	5.48E-08	4.41E-08	4.01E-08	5.48E-08	3.73E-08	0.00E+00	5.48E-08	4.76E-08
Total	**3.56E-05**	**1.80E-05**	**3.88E-04**	**1.68E-05**	**1.52E-05**	**1.87E-05**	**1.58E-05**	**2.53E-03**	**5.03E-04**	**3.06E-05**

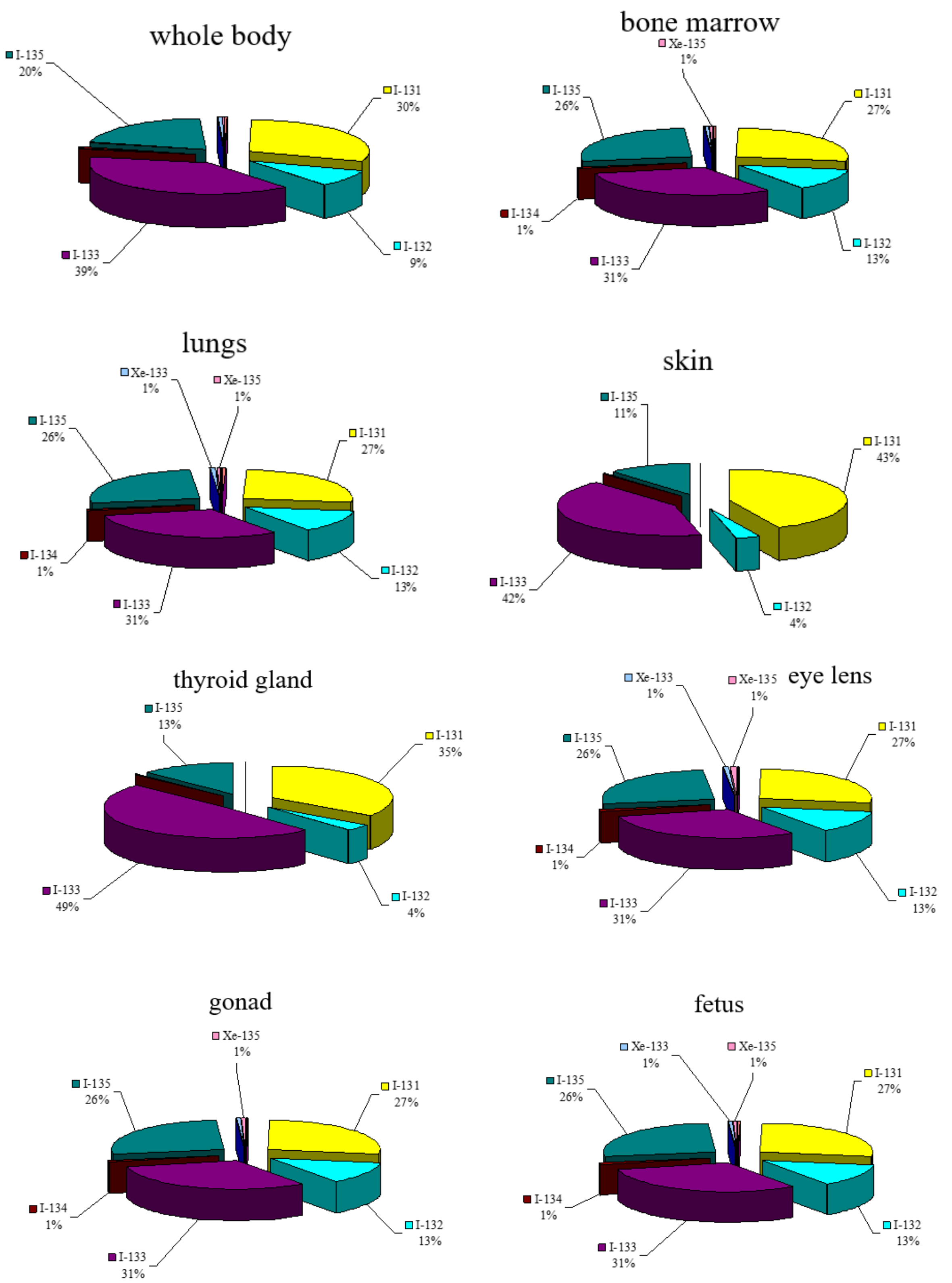


Figure 10.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

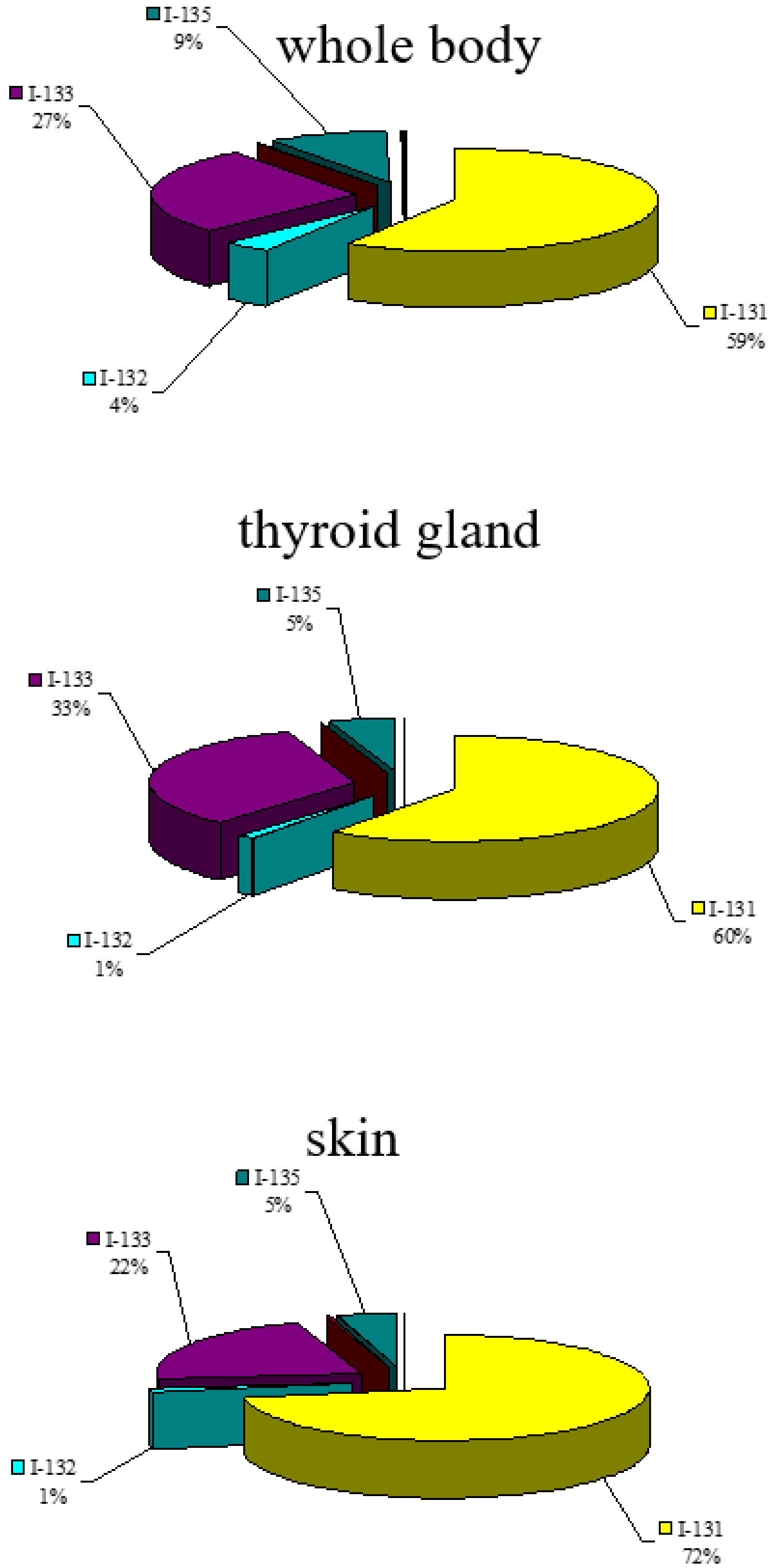
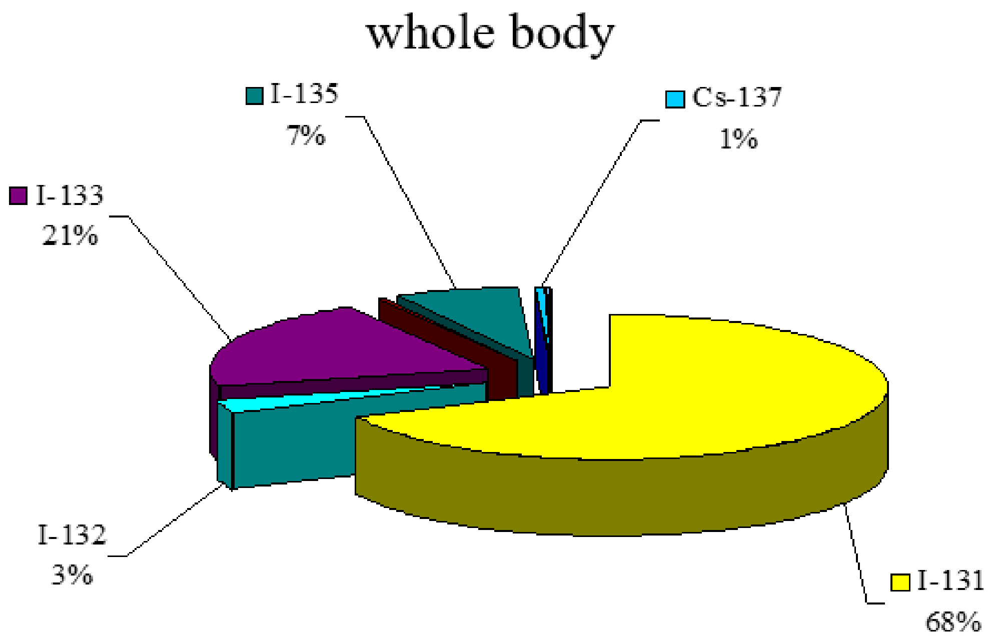


Figure 10.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



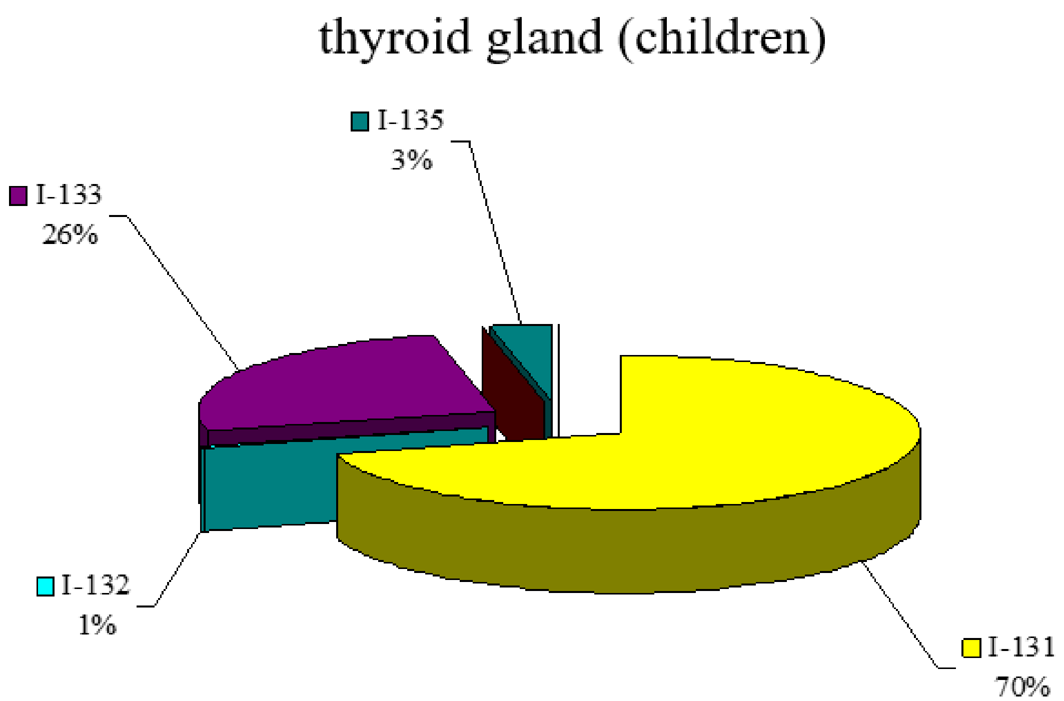


Figure 10.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

10.2.1 Radiation impact estimates for ITR as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 10.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens , gonad and fetus.

Table 10.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	ITR estimates, Gy
Entire body (bone marrow)[1]	1	1.04E-05 (6.71E-06)
Lungs	6	7.33E-06
Skin	3	8.88E-04
Thyroid gland	5	1.02E-04
Eye lens	2	7.46E-06
Gonad	2	6.30E-06
Fetus	0.1	6.12E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 10.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 10.7, while calculation results for standardized values for ITR are given in Table 10.8.

Table 10.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

<table>
<tr><th rowspan="4">Countermeasure</th><th colspan="6">Dose over the first 2 weeks following accident</th></tr>
<tr><th colspan="3">Lower justifiability limits</th><th colspan="3">Unconditional justifiability levels</th></tr>
<tr><th>mSv</th><th colspan="2">mGy</th><th>mSv</th><th colspan="2">mGy</th></tr>
<tr><th>For the entire body</th><th>For thyroid gland</th><th>For skin</th><th>For the entire body</th><th>For thyroid gland</th><th>For skin</th></tr>
<tr><td>Shelter</td><td>5</td><td>50</td><td>100</td><td>50</td><td>300</td><td>500</td></tr>
<tr><td>Evacuation</td><td>50</td><td>300</td><td>500</td><td>500</td><td>1000</td><td>3000</td></tr>
<tr><td colspan="7">Iodine prophylaxis</td></tr>
<tr><td>Children</td><td>-</td><td>50[1]</td><td>-</td><td>-</td><td>200[1]</td><td>-</td></tr>
<tr><td>Adults</td><td>-</td><td>200[1]</td><td>-</td><td>-</td><td>500[1]</td><td>-</td></tr>
<tr><td colspan="7">Limited stay outdoors</td></tr>
<tr><td>Children</td><td>1</td><td>20</td><td>50</td><td>10</td><td>100</td><td>300</td></tr>
<tr><td>Adults</td><td>2</td><td>100</td><td>200</td><td>20</td><td>300</td><td>1000</td></tr>
</table>

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 10.8 - Dose estimates over the first 2 weeks following the ITR

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.027	0.28	2.12

Based on the calculation results given in Table 10.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the ITR upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

10.2.2 Radiation impact estimates for ITR as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during ITR shall be 0.00050 Sv/year, and for the entire body due to external radiation - 0.00031 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

10.3 Calculation results for ITR at the border of the OZ (30 km)

Table 10.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during ITR.

Table 10.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during ITR

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-88	1.76E+02	0.00E+00
I-131	4.41E+02	1.91E+05
I-132	6.28E+02	2.72E+05
I-133	8.09E+02	3.50E+05
I-134	1.37E+02	5.95E+04
I-135	5.96E+02	2.57E+05
Cs-137	8.37E-02	8.36E+01
Xe-133	2.51E+04	0.00E+00
Xe-135	3.35E+03	0.00E+00
Total	**3.12E+04**	**1.13E+06**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 25.1 kBq/m^3 for xenon-133. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 350 kBq/m^2 for ^{133}I, up to 272 kBq/m^2 for ^{132}I and up to 257 kBq/m^2 for ^{135}I.

Tables 10.10 –10.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 10.4–10.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 0.28 mSv.

Table 10.10 - Human organ and tissue radiation doses during ITR over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	1.94E-08	2.07E-08	2.16E-08	1.81E-08	1.71E-08	2.07E-08	1.65E-08	6.40E-09	2.37E-08	1.84E-08
I-131	1.76E-06	1.61E-06	6.10E-06	1.51E-06	1.37E-06	1.70E-06	1.43E-06	4.96E-05	7.45E-06	1.56E-06
I-132	7.41E-07	7.51E-07	1.27E-06	7.04E-07	6.38E-07	7.87E-07	6.61E-07	5.41E-06	1.37E-06	7.12E-07
I-133	2.07E-06	1.83E-06	8.33E-06	1.73E-06	1.56E-06	1.92E-06	1.63E-06	4.97E-05	1.08E-05	1.76E-06
I-134	7.79E-08	7.98E-08	1.06E-07	7.35E-08	6.72E-08	8.31E-08	6.87E-08	6.80E-07	1.14E-07	7.47E-08
I-135	1.56E-06	1.55E-06	3.28E-06	1.46E-06	1.32E-06	1.63E-06	1.38E-06	1.46E-05	3.67E-06	1.47E-06
Cs-137	9.77E-10	1.02E-09	1.13E-09	9.62E-10	8.73E-10	1.08E-09	9.10E-10	1.12E-09	1.15E-09	9.67E-10
Xe-133	2.32E-08	2.25E-08	2.68E-08	1.66E-08	1.66E-08	3.11E-08	1.45E-08	0.00E+00	2.68E-08	2.32E-08
Xe-135	2.56E-08	2.58E-08	2.94E-08	2.36E-08	2.15E-08	2.94E-08	2.01E-08	0.00E+00	2.94E-08	2.56E-08
Total	**6.27E-06**	**5.89E-06**	**1.92E-05**	**5.54E-06**	**5.01E-06**	**6.20E-06**	**5.21E-06**	**1.20E-04**	**2.35E-05**	**5.64E-06**

Table 10.11 - Human organ and tissue radiation doses during ITR over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	1.94E-08	2.07E-08	2.16E-08	1.81E-08	1.71E-08	2.07E-08	1.65E-08	6.40E-09	2.37E-08	1.84E-08
I-131	7.71E-06	6.97E-06	2.85E-05	6.61E-06	5.99E-06	7.44E-06	6.24E-06	1.98E-04	3.54E-05	6.78E-06
I-132	7.41E-07	7.51E-07	1.27E-06	7.04E-07	6.38E-07	7.87E-07	6.61E-07	5.41E-06	1.37E-06	7.12E-07
I-133	2.90E-06	2.39E-06	1.47E-05	2.25E-06	2.04E-06	2.52E-06	2.13E-06	6.15E-05	2.03E-05	2.35E-06
I-134	7.79E-08	7.98E-08	1.06E-07	7.35E-08	6.72E-08	8.31E-08	6.87E-08	6.80E-07	1.14E-07	7.47E-08
I-135	1.60E-06	1.57E-06	3.54E-06	1.49E-06	1.34E-06	1.66E-06	1.40E-06	1.46E-05	3.97E-06	1.50E-06
Cs-137	6.72E-09	7.02E-09	7.77E-09	6.64E-09	6.02E-09	7.40E-09	6.27E-09	6.84E-09	7.77E-09	6.72E-09
Xe-133	2.32E-08	2.25E-08	2.68E-08	1.66E-08	1.66E-08	3.11E-08	1.45E-08	0.00E+00	2.68E-08	2.32E-08
Xe-135	2.56E-08	2.58E-08	2.94E-08	2.36E-08	2.15E-08	2.94E-08	2.01E-08	0.00E+00	2.94E-08	2.56E-08
Total	**1.31E-05**	**1.18E-05**	**4.82E-05**	**1.12E-05**	**1.01E-05**	**1.26E-05**	**1.06E-05**	**2.81E-04**	**6.12E-05**	**1.15E-05**

Table 10.12 - Human organ and tissue radiation doses during ITR over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-88	1.94E-08	2.07E-08	2.16E-08	1.81E-08	1.71E-08	2.07E-08	1.65E-08	6.40E-09	2.37E-08	1.84E-08
I-131	1.11E-05	9.85E-06	4.54E-05	9.31E-06	8.44E-06	1.05E-05	8.78E-06	2.53E-04	5.81E-05	9.56E-06
I-132	7.41E-07	7.51E-07	1.27E-06	7.04E-07	6.38E-07	7.87E-07	6.61E-07	5.41E-06	1.37E-06	7.12E-07
I-133	2.93E-06	2.42E-06	1.48E-05	2.28E-06	2.07E-06	2.55E-06	2.16E-06	6.15E-05	2.05E-05	2.37E-06
I-134	7.79E-08	7.98E-08	1.06E-07	7.35E-08	6.72E-08	8.31E-08	6.87E-08	6.80E-07	1.14E-07	7.47E-08
I-135	1.60E-06	1.57E-06	3.54E-06	1.49E-06	1.34E-06	1.66E-06	1.40E-06	1.46E-05	3.97E-06	1.50E-06
Cs-137	1.32E-07	1.38E-07	1.54E-07	1.31E-07	1.19E-07	1.47E-07	1.24E-07	2.47E-08	1.54E-07	1.32E-07
Xe-133	2.32E-08	2.25E-08	2.68E-08	1.66E-08	1.66E-08	3.11E-08	1.45E-08	0.00E+00	2.68E-08	2.32E-08
Xe-135	2.56E-08	2.58E-08	2.94E-08	2.36E-08	2.15E-08	2.94E-08	2.01E-08	0.00E+00	2.94E-08	2.56E-08
Total	**1.67E-05**	**1.49E-05**	**6.53E-05**	**1.40E-05**	**1.27E-05**	**1.58E-05**	**1.32E-05**	**3.35E-04**	**8.42E-05**	**1.44E-05**

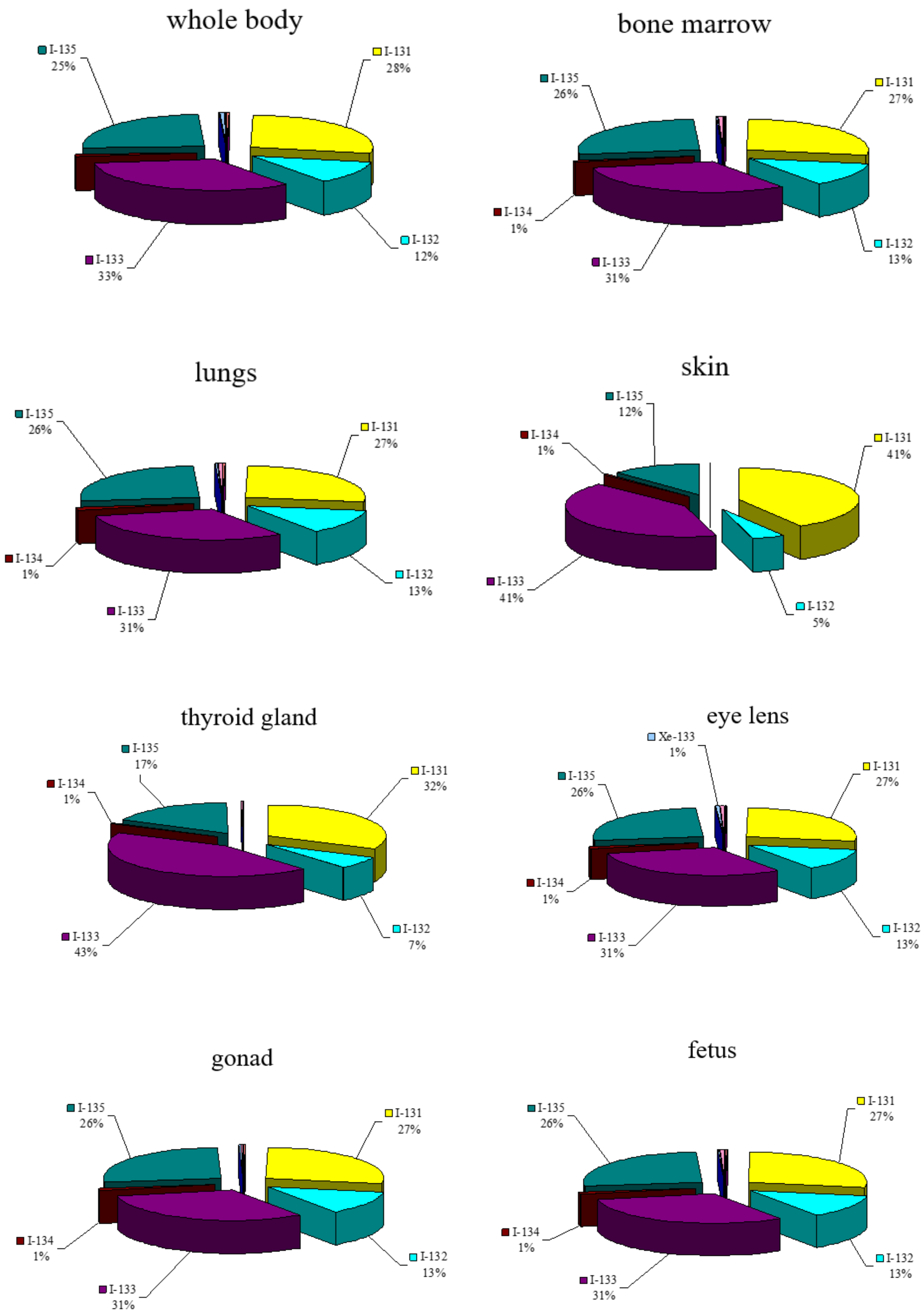


Figure 10.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

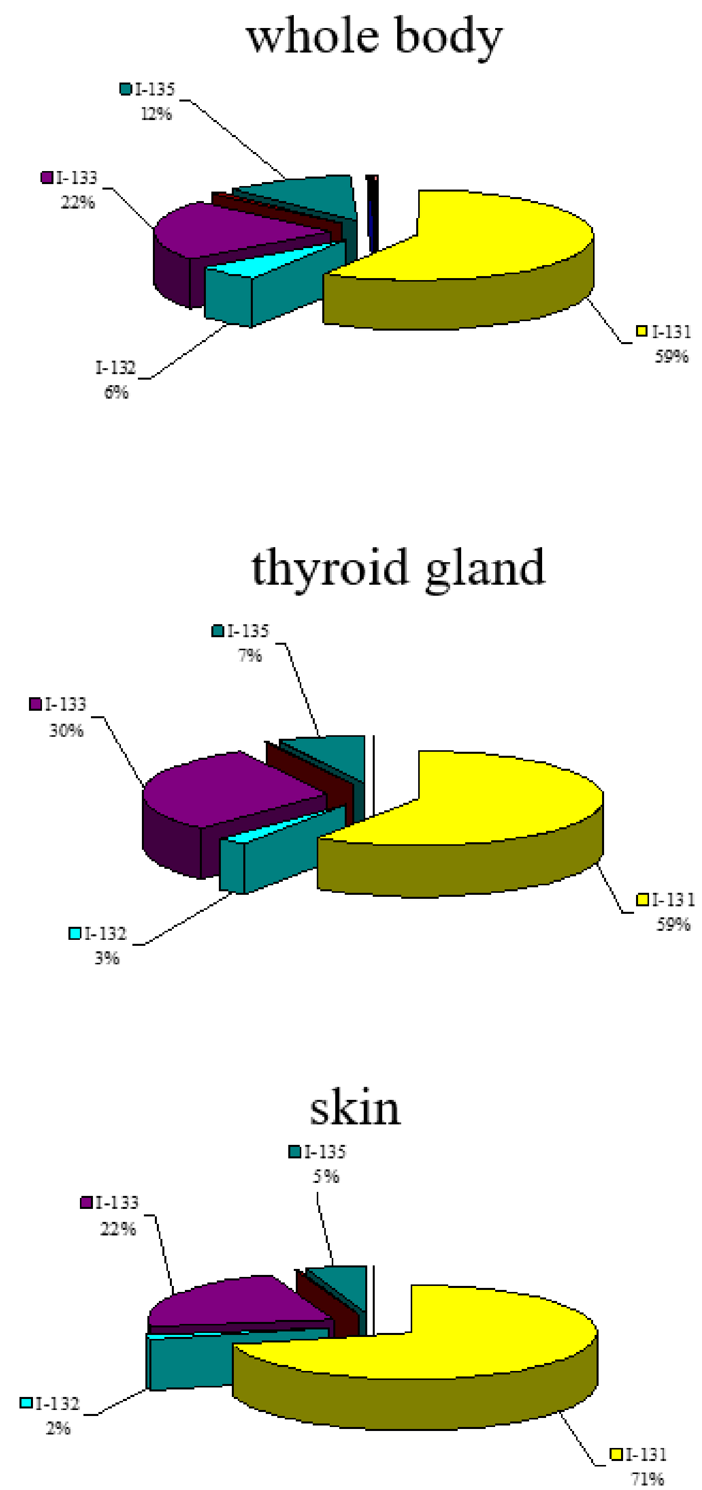
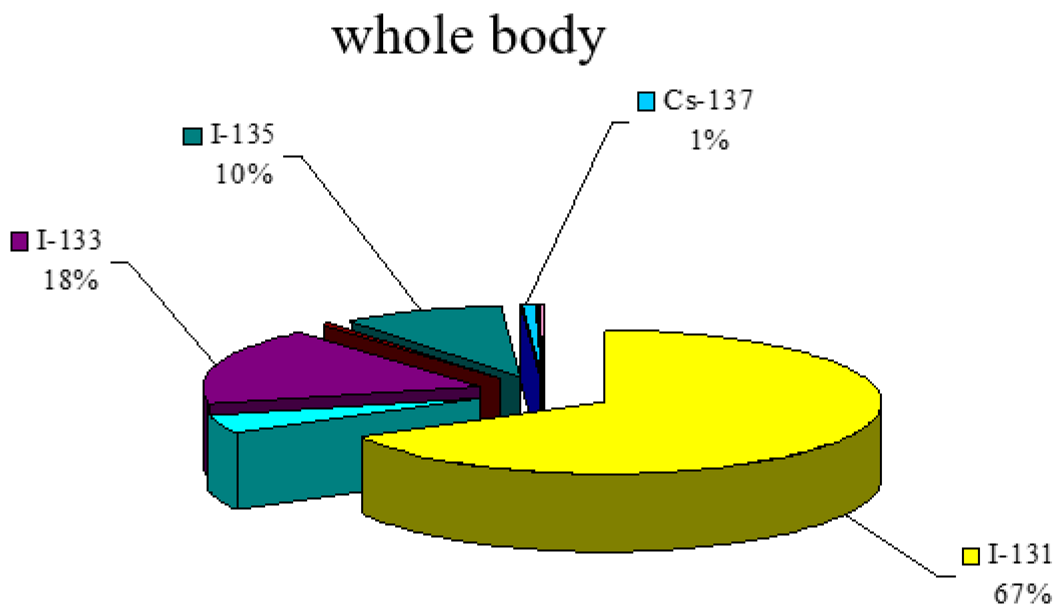


Figure 10.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



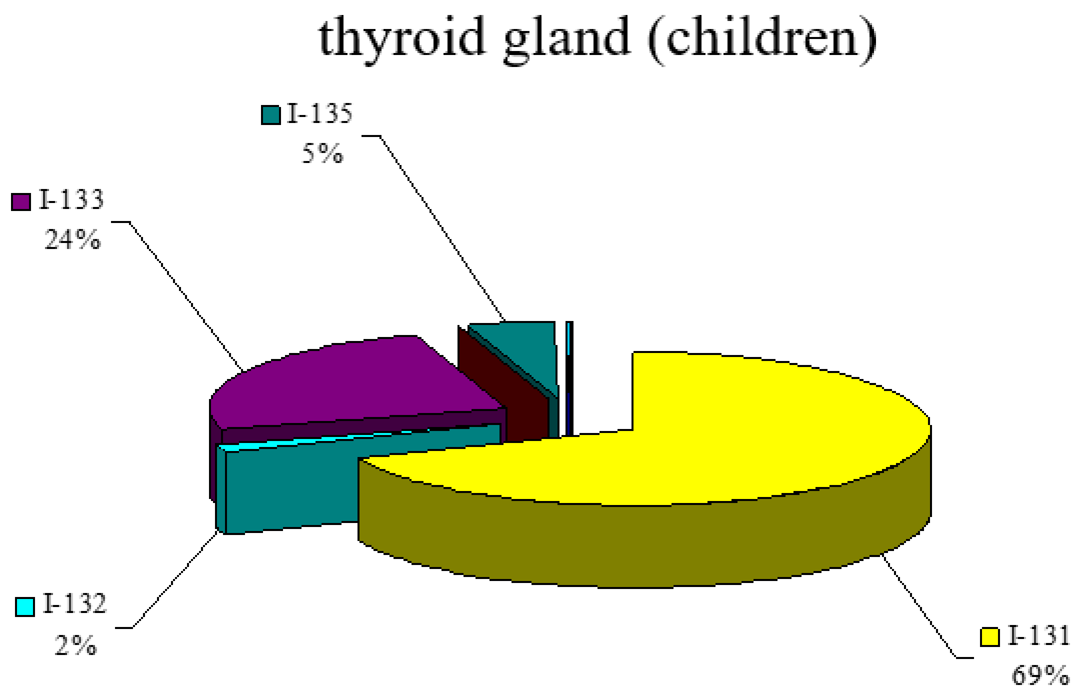


Figure 10.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

10.3.1 Radiation impact estimates for ITR as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 10.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 10.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	ITR estimates, Gy
Entire body (bone marrow)[1]	1	2.64E-06 (5.54E-06)
Lungs	6	5.89E-06
Skin	3	1.20E-04
Thyroid gland	5	1.92E-05
Eye lens	2	6.20E-06
Gonad	2	5.21E-06
Fetus	0.1	5.01E-06

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 10.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 10.14, while calculation results for standardized values for ITR are given in Table 10.15.

Table 10.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 10.15 - Dose estimates over the first 2 weeks following the ITR

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
0.013	0.048	0.28

Based on the calculation results given in Table 10.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the ITR upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

10.3.2 Radiation impact estimates for ITR as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during ITR shall be 0.000084 Sv/year, and for the entire body due to external radiation - 0.000014 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

11 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A DESIGN BASIS ACCIDENT "PLANNED COOL DOWN LINE RUPTURE" (PCDLR)

11.1 Input data for calculating radiation exposure during PCDLR

Effective values of the total environmental radioactive release are shown in Table 11.1.

Table 11.1 - Radioactive release during PCDLR

Radionuclide	Environmental release, Bq
I-131	6.42E+07
Cs-134	2.50E+07
Cs-137	3.70E+07
Xe-133	6.80E+12
Total activity	6.80E+12

11.2 Calculation results for PCDLR at the border of the SPZ (2.5 km)

Table 11.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during PCDLR.

Table 11.2 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during PCDLR

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
I-131	3.25E-02	2.14E+00
Cs-134	1.58E-02	5.13E-01
Cs-137	2.33E-02	7.59E-01
Xe-133	5.31E+03	0.00E+00
Total	**5.31E+03**	**3.41E+00**

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 5.31 kBq/m^3 for xenon-133. The maximum ground surface fallout densities at the border of the SPZ are expected to make up to 2.14 Bq/m^2 for ^{131}I.

Tables 11.3–11.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 11.1–11.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 33.8 mSv.

Table 11.3 - Human organ and tissue radiation doses during PCDLR over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
I-131	3.38E-11	1.88E-11	3.38E-10	1.75E-11	1.59E-11	1.94E-11	1.64E-11	3.65E-09	4.13E-10	3.01E-11
Cs-134	1.88E-11	1.87E-11	2.07E-11	1.77E-11	1.63E-11	1.89E-11	1.67E-11	1.58E-10	2.07E-11	1.88E-11
Cs-137	1.08E-11	1.07E-11	1.15E-11	9.88E-12	9.36E-12	1.03E-11	9.40E-12	3.12E-10	1.17E-11	1.07E-11
Xe-133	4.90E-09	4.77E-09	5.67E-09	3.52E-09	3.52E-09	6.58E-09	3.07E-09	0.00E+00	5.67E-09	4.90E-09
Total	**4.96E-09**	**4.82E-09**	**6.04E-09**	**3.56E-09**	**3.56E-09**	**6.63E-09**	**3.11E-09**	**4.12E-09**	**6.12E-09**	**4.96E-09**

Table 11.4 - Human organ and tissue radiation doses during PCDLR over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
I-131	1.52E-10	7.90E-11	1.61E-09	7.45E-11	6.74E-11	8.35E-11	7.00E-11	1.46E-08	2.00E-09	1.34E-10
Cs-134	1.19E-10	1.22E-10	1.35E-10	1.16E-10	1.07E-10	1.24E-10	1.10E-10	9.63E-10	1.35E-10	1.19E-10
Cs-137	6.73E-11	6.88E-11	7.59E-11	6.51E-11	6.18E-11	6.81E-11	6.25E-11	1.91E-09	7.59E-11	6.73E-11
Xe-133	4.90E-09	4.77E-09	5.67E-09	3.52E-09	3.52E-09	6.58E-09	3.07E-09	0.00E+00	5.67E-09	4.90E-09
Total	**5.23E-09**	**5.04E-09**	**7.49E-09**	**3.77E-09**	**3.75E-09**	**6.86E-09**	**3.31E-09**	**1.74E-08**	**7.88E-09**	**5.22E-09**

Table 11.5 - Human organ and tissue radiation doses during PCDLR over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
I-131	2.32E-10	1.12E-10	2.65E-09	1.05E-10	9.50E-11	1.17E-10	9.89E-11	1.86E-08	3.39E-09	2.00E-10
Cs-134	1.98E-09	2.06E-09	2.29E-09	1.95E-09	1.79E-09	2.14E-09	1.86E-09	3.38E-09	2.29E-09	1.98E-09
Cs-137	1.26E-09	1.31E-09	1.45E-09	1.24E-09	1.14E-09	1.34E-09	1.18E-09	6.88E-09	1.45E-09	1.26E-09
Xe-133	4.90E-09	4.77E-09	5.67E-09	3.52E-09	3.52E-09	6.58E-09	3.07E-09	0.00E+00	5.67E-09	4.90E-09
Total	**8.36E-09**	**8.24E-09**	**1.20E-08**	**6.81E-09**	**6.54E-09**	**1.02E-08**	**6.20E-09**	**2.88E-08**	**1.28E-08**	**8.33E-09**

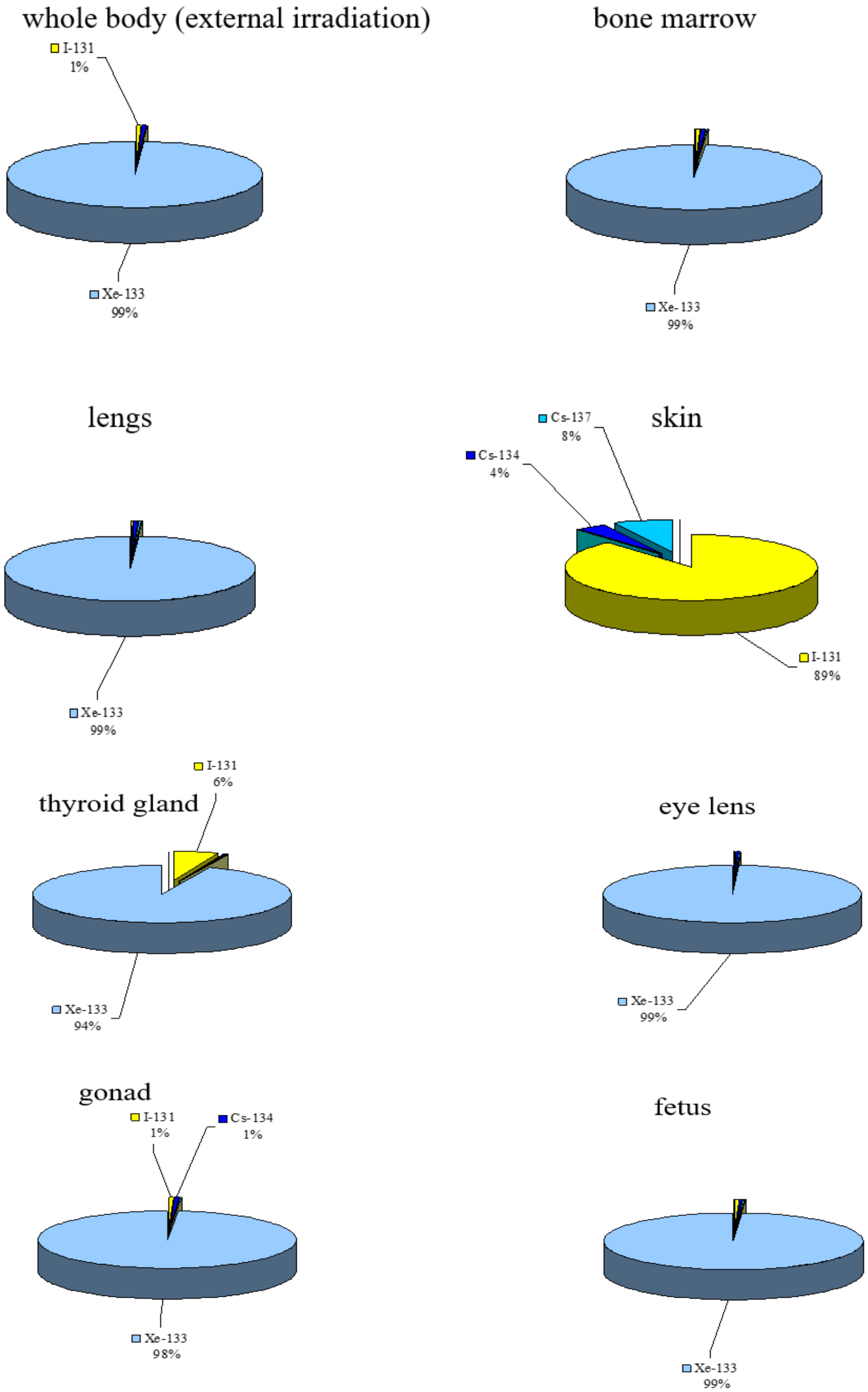


Figure 11.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

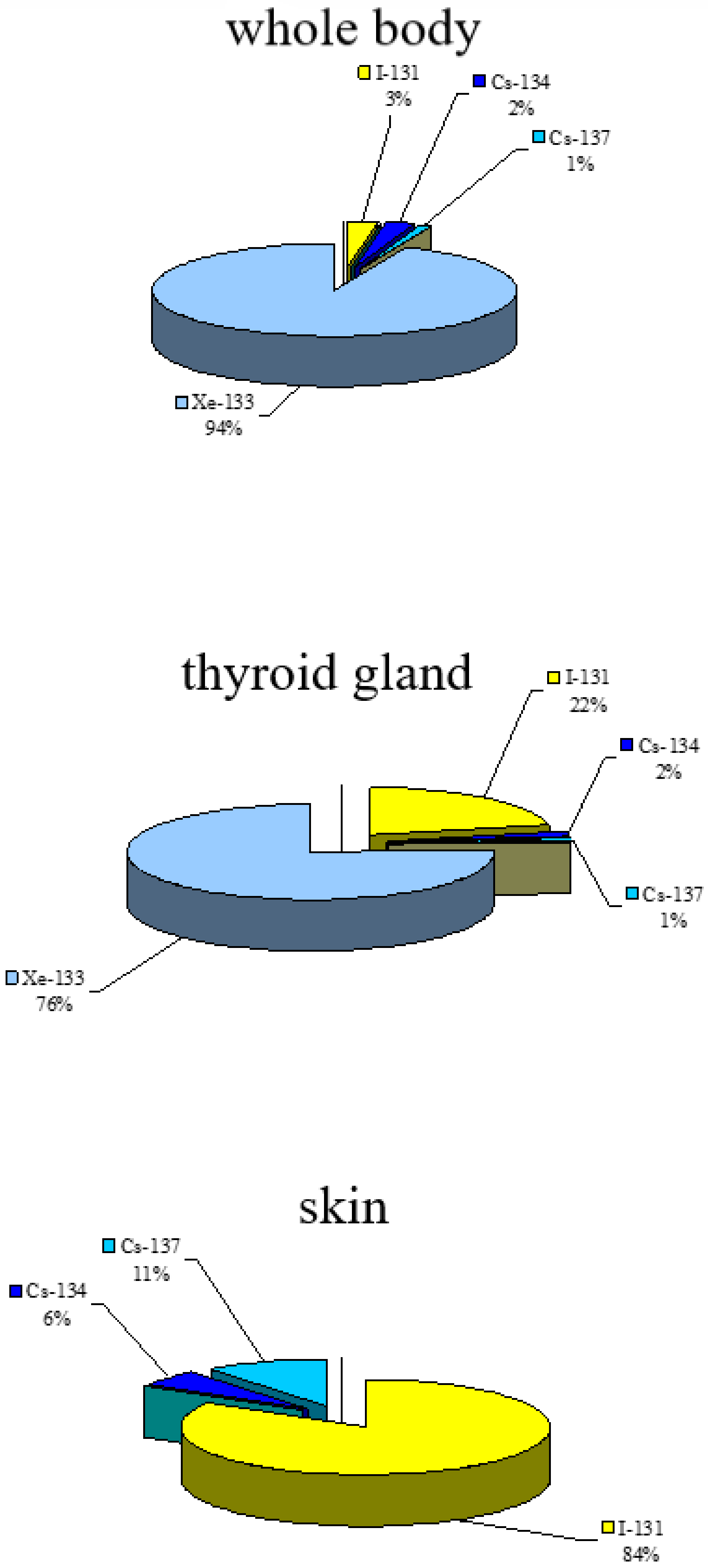
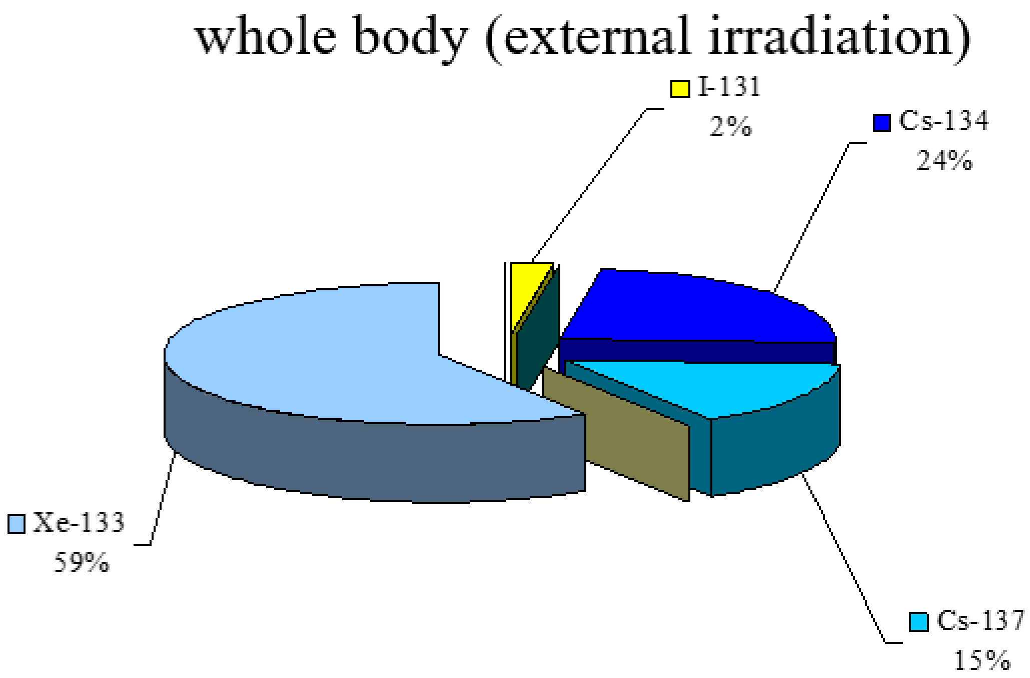


Figure 11.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



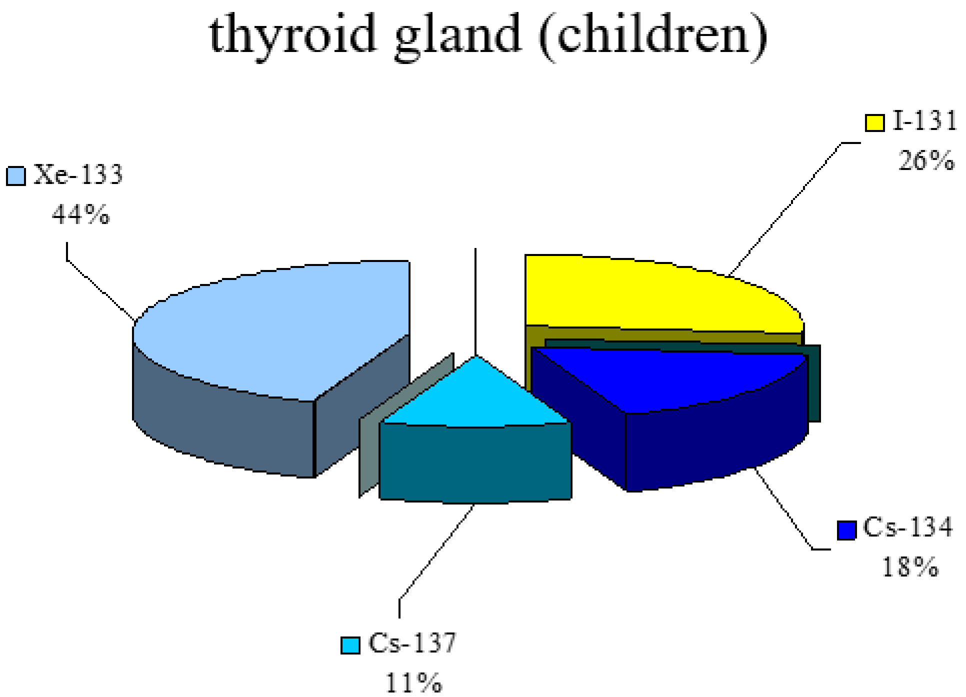


Figure 11.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

11.2.1 Radiation impact estimates for PCDLR as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 11.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 11.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	PCDLR estimates, Gy
Entire body (bone marrow)[1]	1	4.96E-09 (5.56E-09)
Lungs	6	4.82E-09
Skin	3	4.12E-09
Thyroid gland	5	6.04E-09
Eye lens	2	6.63E-09
Gonad	2	3.11E-09
Fetus	0.1	3.56E-09

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 11.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 11.7, while calculation results for standardized values for PCDLR are given in Table 11.8.

Table 11.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 11.8 - Dose estimates over the first 2 weeks following the PCDLR

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
5.23E-06	7.49E-06	1.74E-05

Based on the calculation results given in Table 11.8, the lower justifiability limit for basic urgent countermeasures is not exceeded during the PCDLR upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

11.2.2 Radiation impact estimates for PCDLR as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during PCDLR shall be 1.28E-08 Sv/year, and for the entire body due to external radiation - 8.33E-09 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

11.3 Calculation results for PCDLR at the border of the OZ (30 km)

Table 11.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during PCDLR.

Table 11.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during PCDLR

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
I-131	4.23E-03	1.83E+00
Cs-134	2.83E-04	2.83E-01
Cs-137	4.18E-04	4.18E-01
Xe-133	2.66E+03	0.00E+00
Total	**2.66E+03**	**2.53E+00**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 2.66 kBq/m^3 for xenon-133. The maximum ground surface fallout densities at the border of the OZ are expected to make up to 1.83 Bq/m^2 for ^{131}I.

Tables 11.10–11.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 11.4–11.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 19.2 mSv

Table 11.10 - Human organ and tissue radiation doses during PCDLR over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
I-131	1.68E-11	1.54E-11	5.85E-11	1.45E-11	1.32E-11	1.62E-11	1.37E-11	4.76E-10	7.14E-11	1.50E-11
Cs-134	8.95E-12	9.33E-12	1.04E-11	8.83E-12	8.00E-12	9.90E-12	8.33E-12	2.83E-12	1.04E-11	8.95E-12
Cs-137	4.88E-12	5.11E-12	5.66E-12	4.81E-12	4.37E-12	5.40E-12	4.55E-12	5.59E-12	5.77E-12	4.84E-12
Xe-133	2.46E-09	2.39E-09	2.85E-09	1.77E-09	1.77E-09	3.30E-09	1.54E-09	0.00E+00	2.85E-09	2.46E-09
Total	**2.49E-09**	**2.42E-09**	**2.92E-09**	**1.80E-09**	**1.79E-09**	**3.34E-09**	**1.56E-09**	**4.84E-10**	**2.94E-09**	**2.49E-09**

Table 11.11 - Human organ and tissue radiation doses during PCDLR over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
I-131	7.38E-11	6.68E-11	2.73E-10	6.33E-11	5.74E-11	7.13E-11	5.98E-11	1.90E-09	3.39E-10	6.50E-11
Cs-134	6.13E-11	6.40E-11	7.10E-11	6.05E-11	5.48E-11	6.78E-11	5.73E-11	1.72E-11	7.10E-11	6.13E-11
Cs-137	3.36E-11	3.51E-11	3.89E-11	3.32E-11	3.01E-11	3.70E-11	3.13E-11	3.42E-11	3.89E-11	3.36E-11
Xe-133	2.46E-09	2.39E-09	2.85E-09	1.77E-09	1.77E-09	3.30E-09	1.54E-09	0.00E+00	2.85E-09	2.46E-09
Total	**2.63E-09**	**2.56E-09**	**3.23E-09**	**1.92E-09**	**1.91E-09**	**3.48E-09**	**1.69E-09**	**1.95E-09**	**3.30E-09**	**2.62E-09**

Table 11.12 - Human organ and tissue radiation doses during PCDLR over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Foetus, Gy	Crystalline lens, Gy	Genital glands, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
I-131	1.07E-10	9.44E-11	4.35E-10	8.92E-11	8.09E-11	1.00E-10	8.41E-11	2.42E-09	5.56E-10	9.17E-11
Cs-134	1.06E-09	1.11E-09	1.23E-09	1.05E-09	9.50E-10	1.17E-09	9.88E-10	6.03E-11	1.23E-09	1.06E-09
Cs-137	6.62E-10	6.92E-10	7.70E-10	6.55E-10	5.96E-10	7.33E-10	6.18E-10	1.24E-10	7.70E-10	6.62E-10
Xe-133	2.46E-09	2.39E-09	2.85E-09	1.77E-09	1.77E-09	3.30E-09	1.54E-09	0.00E+00	2.85E-09	2.46E-09
Total	**4.29E-09**	**4.28E-09**	**5.28E-09**	**3.56E-09**	**3.39E-09**	**5.31E-09**	**3.23E-09**	**2.60E-09**	**5.41E-09**	**4.28E-09**

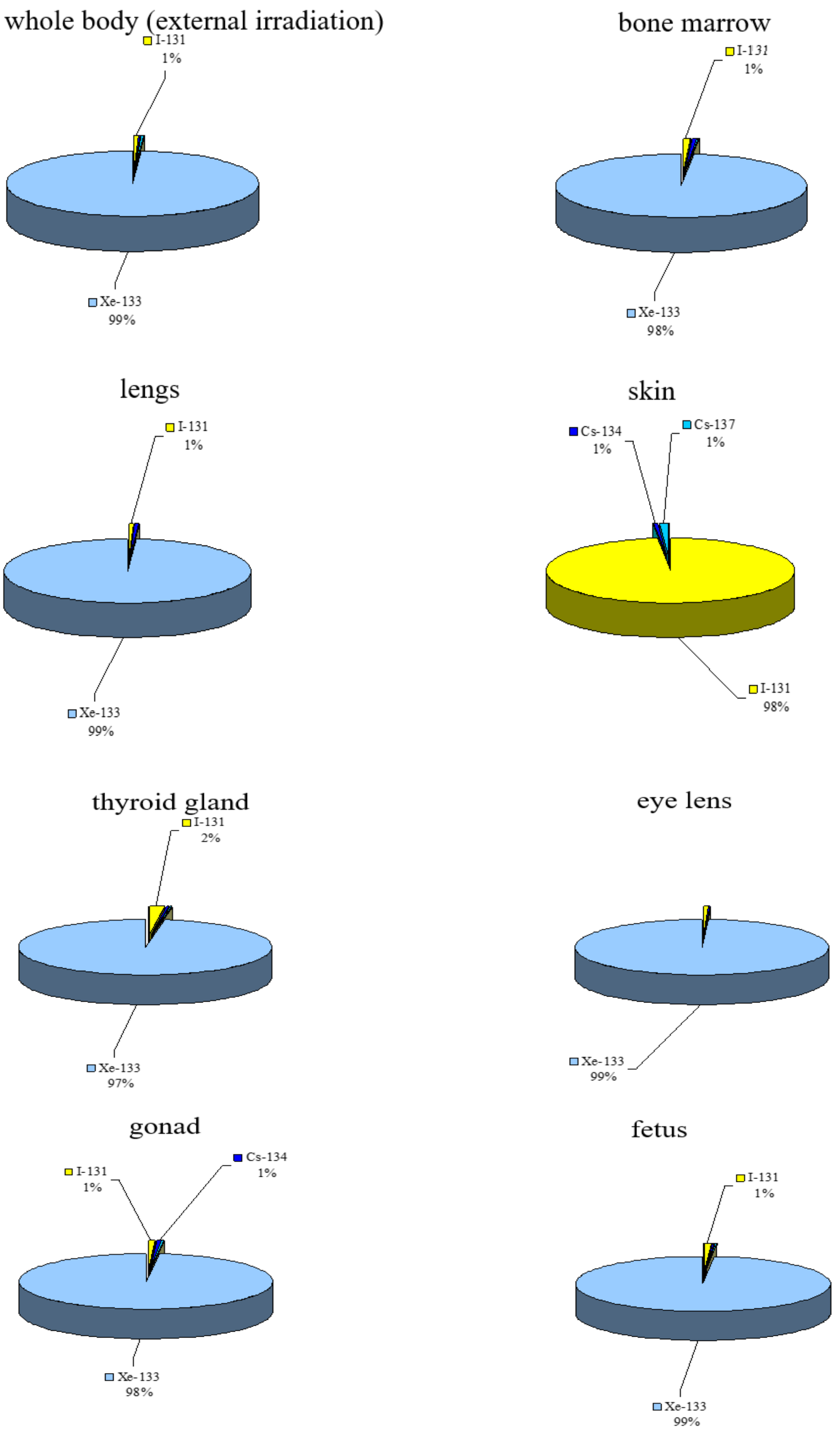


Figure 11.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

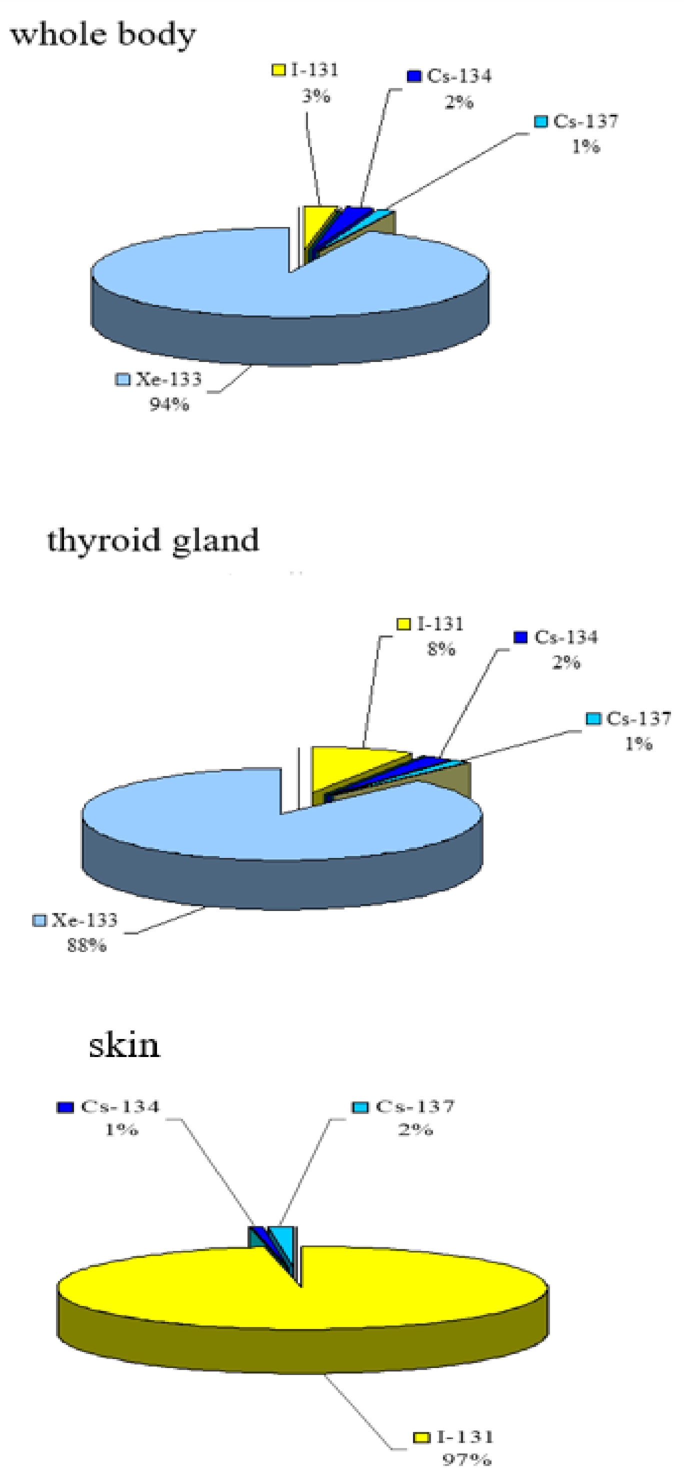
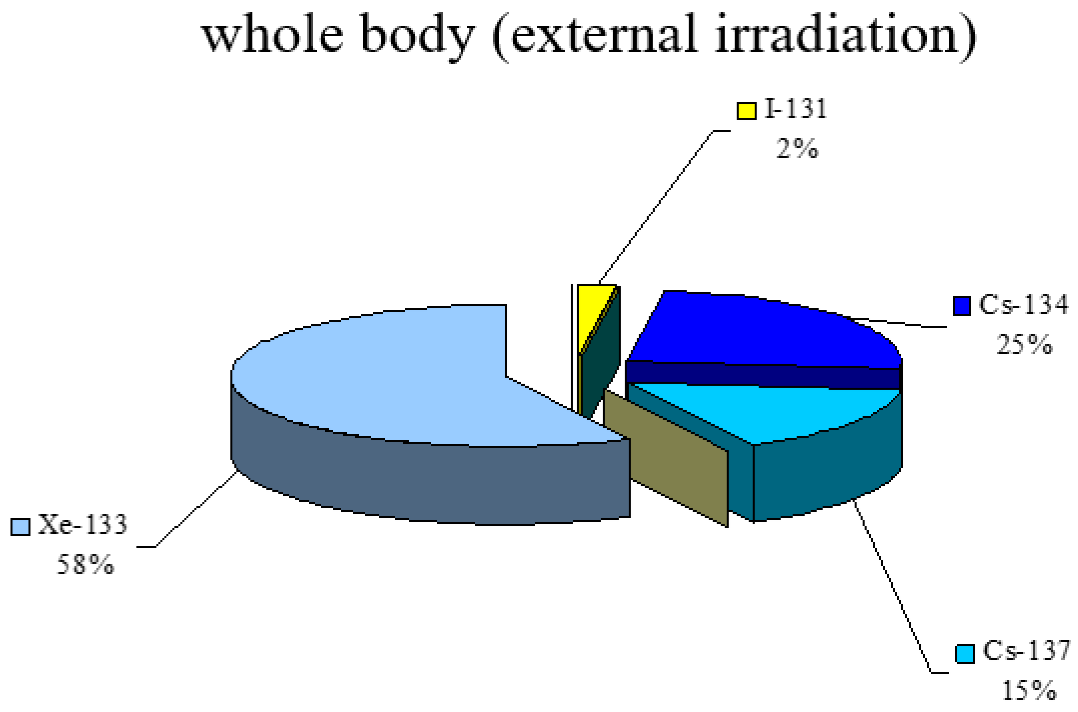


Figure 11.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



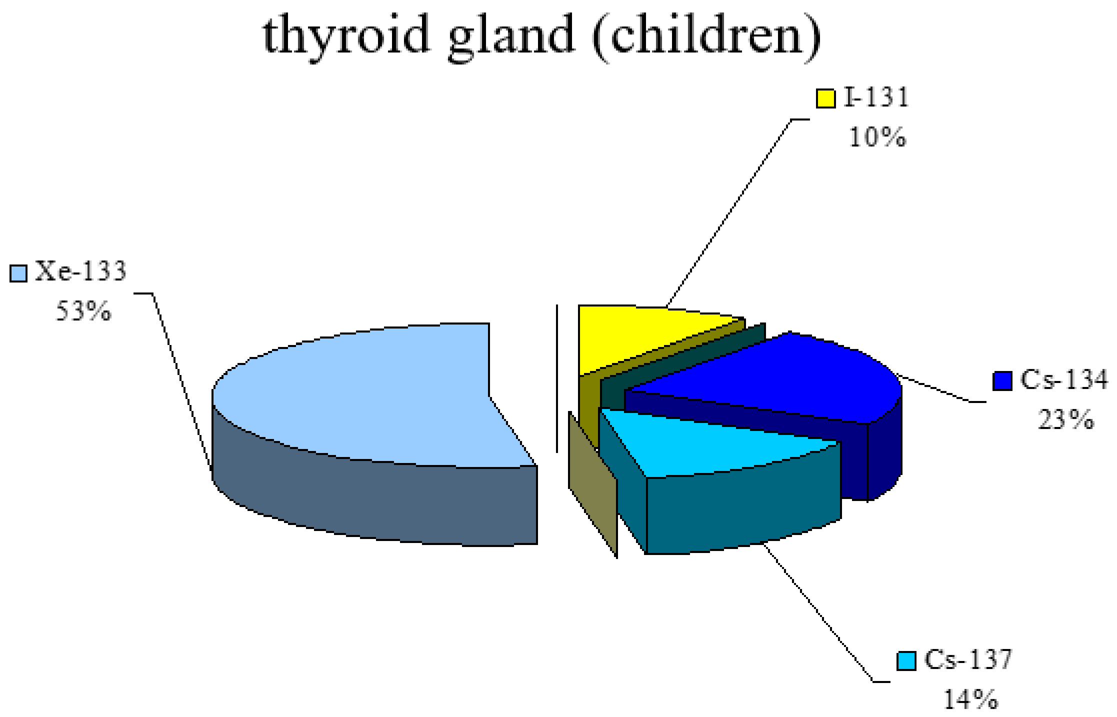


Figure 11.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

11.3.1 Radiation impact estimates for PCDLR as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 11.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 11.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	PCDLR estimates, Gy
Entire body (bone marrow)[1]	1	2.49E-09 (1.80E-09)
Lungs	6	2.42E-09
Skin	3	4.84E-10
Thyroid gland	5	2.92E-09
Eye lens	2	3.34E-09
Gonad	2	1.56E-09
Fetus	0.1	1.79E-09

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 11.13), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by activity of radionuclides deposited on the ground surface.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 11.14, while calculation results for standardized values for PCDLR are given in Table 11.15.

Table 11.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 11.15 - Dose estimates over the first 2 weeks following the PCDLR

For the entire body, mSv	For thyroid gland, mGy	For skin, mGy
2.63E-06	3.23E-06	1.95E-06

Based on the calculation results given in Table 11.15, the lower justifiability limit for basic urgent countermeasures is not exceeded during the PCDLR upon any criterion. Therefore, there is no need to plan basic urgent countermeasures.

Calculation results suggest that support countermeasures at such radiation dose level are not feasible.

11.3.2 Radiation impact estimates for PCDLR as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
  - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
  - 0,1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during PCDLR shall be 5.41E-09 Sv/year, and for the entire body due to external radiation - 4.28E-09 Sv/year. As can be seen, calculated values are well below the limit values as per SP AS-88.

12 ENVIRONMENTAL AND POPULATION IMPACT OF RADIOACTIVE RELEASES IN CASE OF A BEYOND DESIGN BASIS ACCIDENT (BDBA)

12.1 Input data for calculating radiation exposure during BDBA

Effective values of the total environmental radioactive release are shown in Table 12.1.

Table 12.1 - Radioactive release during BDBA

Radionuclide	Environmental release, Bq
Kr-85m	5.51E+16
Kr-87	1.10E+17
Kr-88	1.40E+17
Sr-89	6.00E+13
Sr-90	5.00E+12
Ru-103	3.00E+12
I-131	1.00E+15
I-132	1.50E+15
I-133	2.10E+15
I-134	2.30E+15
I-135	2.00E+15
Cs-134	6.00E+13
Cs-137	3.00E+13
La-140	5.00E+12
Ce-141	4.00E+12
Ce-144	3.00E+12
Xe-133	4.27E+17
Xe-135	1.87E+17
Xe-138	3.20E+17
Ba-140	1.00E+14
Total	**1.25E+18**

12.2 Calculation results for BDBA at the border of the SPZ (2.5 km)

Table 12.2 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the SPZ (2.5 km from the release source) during BDBA.

Table 12.2 — Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during BDBA

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-85m	2.80E+07	0.00E+00
Kr-87	1.82E+07	0.00E+00
Kr-88	5.52E+07	0.00E+00
Sr-89	3.78E+04	1.23E+06
Sr-90	3.15E+03	1.03E+05
Ru-103	1.89E+03	6.15E+04
I-131	5.06E+05	3.33E+07
I-132	3.21E+05	2.12E+07
I-133	9.74E+05	6.43E+07
I-134	1.21E+05	7.96E+06
I-135	7.56E+05	4.98E+07
Cs-134	3.78E+04	1.23E+06
Cs-137	1.89E+04	6.15E+05
La-140	3.00E+03	9.75E+04
Ce-141	2.52E+03	8.20E+04
Ce-144	1.89E+03	6.15E+04
Xe-133	3.33E+08	0.00E+00
Xe-135	1.19E+08	0.00E+00
Xe-138	5.39E+04	0.00E+00
Ba-140	6.28E+04	2.04E+06
Total	5.57E+08	1.82E+08

The maximum radionuclide air activity and surface fallout density values under weather condition parameters used are expected within the SPZ. The maximum air volumetric activity values at the border of the SPZ are expected to make up to 333 MBq/m^3 for ^{133}Xe and up to 119 MBq/m^3 for ^{135}Xe. The maximum ground surface fallout densities at the border of the SPZ for iodine isotopes are expected to make up to 64.3 MBq/m^2 for ^{133}I, up to 49.8 MBq/m^2 for ^{135}I, up to 33.3 MBq/m^2 for ^{131}I and up to 21.2 MBq/m^2 for ^{132}I.

Tables 12.3–12.5 show calculation results of maximum radiation doses for different body organs and tissues at the border of the SPZ (2.5 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 12.1–12.3 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 106 mSv.

Table 12.3 - Human organ and tissue radiation doses during BDBA over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-85m	1.28E-04	1.32E-04	1.50E-04	1.14E-04	1.08E-04	1.50E-04	9.59E-05	0.00E+00	1.50E-04	1.28E-04
Kr-87	4.97E-04	5.05E-04	5.83E-04	4.66E-04	4.27E-04	5.43E-04	4.27E-04	0.00E+00	5.83E-04	4.97E-04
Kr-88	5.64E-03	6.24E-03	5.95E-03	4.93E-03	4.75E-03	5.64E-03	4.45E-03	5.31E-03	6.55E-03	5.36E-03
Sr-89	3.78E-06	1.06E-06	5.48E-07	4.31E-06	2.21E-05	1.86E-09	5.47E-07	4.99E-04	1.63E-06	3.78E-08
Sr-90	2.76E-07	2.18E-07	3.71E-08	3.23E-07	1.55E-06	2.53E-14	3.71E-08	6.40E-05	1.11E-07	0.00E+00
Ru-103	9.84E-07	2.54E-06	7.62E-07	6.60E-07	1.12E-06	7.17E-07	6.27E-07	1.24E-05	7.92E-07	9.64E-07
I-131	5.27E-04	2.93E-04	5.27E-03	2.72E-04	2.47E-04	3.02E-04	2.56E-04	5.69E-02	6.43E-03	4.69E-04
I-132	9.12E-05	8.42E-05	3.17E-04	7.56E-05	6.89E-05	8.40E-05	6.98E-05	2.78E-03	3.42E-04	8.76E-05
I-133	7.35E-04	3.70E-04	8.00E-03	3.38E-04	3.09E-04	3.72E-04	3.19E-04	5.99E-02	1.04E-02	6.25E-04
I-134	2.16E-05	2.12E-05	3.84E-05	1.84E-05	1.72E-05	2.12E-05	1.67E-05	5.96E-04	4.15E-05	2.08E-05
I-135	4.32E-04	3.48E-04	2.36E-03	3.20E-04	2.92E-04	3.54E-04	3.02E-04	1.85E-02	2.64E-03	4.06E-04
Cs-134	4.51E-05	4.49E-05	4.96E-05	4.24E-05	3.91E-05	4.53E-05	4.01E-05	3.80E-04	4.96E-05	4.51E-05
Cs-137	8.73E-06	8.67E-06	9.33E-06	8.01E-06	7.59E-06	8.34E-06	7.62E-06	2.53E-04	9.52E-06	8.64E-06
La-140	3.49E-06	5.60E-06	2.93E-06	2.56E-06	4.99E-06	2.75E-06	2.44E-06	3.43E-05	3.05E-06	3.42E-06
Ce-141	6.76E-07	3.83E-06	1.51E-07	1.31E-07	1.06E-06	1.42E-07	1.26E-07	3.30E-05	1.93E-07	5.81E-07
Ce-144	1.43E-06	6.87E-06	6.09E-08	5.37E-08	5.43E-06	5.73E-08	5.10E-08	1.26E-05	1.21E-07	7.30E-07
Xe-133	3.07E-04	2.99E-04	3.56E-04	2.21E-04	2.21E-04	4.13E-04	1.93E-04	0.00E+00	3.56E-04	3.07E-04
Xe-135	9.09E-04	9.16E-04	1.05E-03	8.42E-04	7.65E-04	1.05E-03	7.12E-04	0.00E+00	1.05E-03	9.09E-04
Xe-138	4.29E-04	4.51E-04	4.45E-04	3.74E-04	3.42E-04	4.26E-04	3.36E-04	1.07E-03	4.63E-04	4.20E-04
Ba-140	1.05E-04	1.01E-04	1.08E-04	9.81E-05	1.71E-04	1.03E-04	8.84E-05	1.17E-03	1.08E-04	1.05E-04
Total	**9.89E-03**	**9.84E-03**	**2.47E-02**	**8.13E-03**	**7.80E-03**	**9.51E-03**	**7.32E-03**	**1.47E-01**	**2.92E-02**	**9.39E-03**

Table 12.4 - Human organ and tissue radiation doses during BDBA over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-85m	1.28E-04	1.32E-04	1.50E-04	1.14E-04	1.08E-04	1.50E-04	9.59E-05	0.00E+00	1.50E-04	1.28E-04
Kr-87	4.97E-04	5.05E-04	5.83E-04	4.66E-04	4.27E-04	5.43E-04	4.27E-04	0.00E+00	5.83E-04	4.97E-04
Kr-88	5.64E-03	6.24E-03	5.95E-03	4.93E-03	4.75E-03	5.64E-03	4.45E-03	5.31E-03	6.55E-03	5.36E-03
Sr-89	9.54E-06	2.54E-06	2.02E-06	2.10E-05	6.12E-05	1.13E-08	2.02E-06	2.83E-03	5.94E-06	2.86E-07
Sr-90	1.07E-06	6.40E-07	2.41E-07	2.80E-06	5.65E-06	4.76E-13	2.41E-07	5.25E-04	7.23E-07	0.00E+00
Ru-103	5.10E-06	1.27E-05	4.56E-06	3.90E-06	4.89E-06	4.29E-06	3.66E-06	6.90E-05	4.65E-06	5.05E-06
I-131	2.37E-03	1.23E-03	2.51E-02	1.16E-03	1.05E-03	1.30E-03	1.09E-03	2.27E-01	3.11E-02	2.09E-03
I-132	9.12E-05	8.42E-05	3.17E-04	7.56E-05	6.89E-05	8.40E-05	6.98E-05	2.78E-03	3.42E-04	8.76E-05
I-133	1.18E-03	4.73E-04	1.51E-02	4.37E-04	3.99E-04	4.79E-04	4.12E-04	7.41E-02	2.08E-02	9.59E-04
I-134	2.16E-05	2.12E-05	3.84E-05	1.84E-05	1.72E-05	2.12E-05	1.67E-05	5.96E-04	4.15E-05	2.08E-05
I-135	4.52E-04	3.54E-04	2.66E-03	3.26E-04	2.98E-04	3.60E-04	3.06E-04	1.86E-02	2.98E-03	4.25E-04
Cs-134	2.84E-04	2.93E-04	3.25E-04	2.78E-04	2.57E-04	2.98E-04	2.65E-04	2.31E-03	3.25E-04	2.84E-04
Cs-137	5.46E-05	5.58E-05	6.15E-05	5.28E-05	5.01E-05	5.52E-05	5.07E-05	1.55E-03	6.15E-05	5.46E-05
La-140	5.90E-06	1.04E-05	4.98E-06	4.35E-06	9.15E-06	4.67E-06	4.12E-06	5.85E-05	5.17E-06	5.78E-06
Ce-141	2.97E-06	1.75E-05	8.92E-07	7.68E-07	3.16E-06	8.44E-07	7.24E-07	1.80E-04	1.05E-06	2.70E-06
Ce-144	6.18E-06	3.93E-05	4.11E-07	3.60E-07	1.47E-05	3.87E-07	3.33E-07	7.62E-05	7.15E-07	3.89E-06
Xe-133	3.07E-04	2.99E-04	3.56E-04	2.21E-04	2.21E-04	4.13E-04	1.93E-04	0.00E+00	3.56E-04	3.07E-04
Xe-135	9.09E-04	9.16E-04	1.05E-03	8.42E-04	7.65E-04	1.05E-03	7.12E-04	0.00E+00	1.05E-03	9.09E-04
Xe-138	4.29E-04	4.51E-04	4.45E-04	3.74E-04	3.42E-04	4.26E-04	3.36E-04	1.07E-03	4.63E-04	4.20E-04
Ba-140	4.93E-04	4.92E-04	5.39E-04	4.84E-04	6.97E-04	5.13E-04	4.38E-04	7.81E-03	5.39E-04	4.93E-04
Total	**1.29E-02**	**1.16E-02**	**5.27E-02**	**9.81E-03**	**9.54E-03**	**1.13E-02**	**8.87E-03**	**3.45E-01**	**6.54E-02**	**1.20E-02**

Table 12.5 - Human organ and tissue radiation doses during BDBA over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-85m	1.28E-04	1.32E-04	1.50E-04	1.14E-04	1.08E-04	1.50E-04	9.59E-05	0.00E+00	1.50E-04	1.28E-04
Kr-87	4.97E-04	5.05E-04	5.83E-04	4.66E-04	4.27E-04	5.43E-04	4.27E-04	0.00E+00	5.83E-04	4.97E-04
Kr-88	5.64E-03	6.24E-03	5.95E-03	4.93E-03	4.75E-03	5.64E-03	4.45E-03	5.31E-03	6.55E-03	5.36E-03
Sr-89	2.01E-05	4.10E-06	3.59E-06	8.58E-05	6.96E-05	6.24E-08	3.58E-06	7.02E-03	1.03E-05	1.41E-06
Sr-90	8.35E-06	1.08E-06	6.45E-07	5.35E-05	7.80E-06	1.46E-11	6.45E-07	2.10E-03	1.94E-06	0.00E+00
Ru-103	1.92E-05	3.93E-05	1.90E-05	1.63E-05	1.61E-05	1.80E-05	1.52E-05	1.59E-04	1.94E-05	1.90E-05
I-131	3.62E-03	1.74E-03	4.12E-02	1.64E-03	1.48E-03	1.83E-03	1.54E-03	2.89E-01	5.27E-02	3.11E-03
I-132	9.12E-05	8.42E-05	3.17E-04	7.56E-05	6.89E-05	8.40E-05	6.98E-05	2.78E-03	3.42E-04	8.76E-05
I-133	1.19E-03	4.79E-04	1.51E-02	4.41E-04	4.03E-04	4.85E-04	4.16E-04	7.41E-02	2.09E-02	9.63E-04
I-134	2.16E-05	2.12E-05	3.84E-05	1.84E-05	1.72E-05	2.12E-05	1.67E-05	5.96E-04	4.15E-05	2.08E-05
I-135	4.52E-04	3.54E-04	2.66E-03	3.26E-04	2.98E-04	3.60E-04	3.06E-04	1.86E-02	2.98E-03	4.25E-04
Cs-134	4.75E-03	4.94E-03	5.48E-03	4.69E-03	4.28E-03	5.13E-03	4.45E-03	8.10E-03	5.48E-03	4.75E-03
Cs-137	1.02E-03	1.06E-03	1.17E-03	1.01E-03	9.27E-04	1.08E-03	9.54E-04	5.58E-03	1.17E-03	1.02E-03
La-140	5.90E-06	1.06E-05	4.99E-06	4.37E-06	9.15E-06	4.68E-06	4.14E-06	5.90E-05	5.19E-06	5.78E-06
Ce-141	7.92E-06	4.28E-05	3.39E-06	2.91E-06	5.28E-06	3.21E-06	2.72E-06	3.88E-04	3.79E-06	7.44E-06
Ce-144	4.62E-05	3.30E-04	6.84E-06	6.21E-06	2.30E-05	6.48E-06	5.49E-06	2.54E-04	9.03E-06	3.74E-05
Xe-133	3.07E-04	2.99E-04	3.56E-04	2.21E-04	2.21E-04	4.13E-04	1.93E-04	0.00E+00	3.56E-04	3.07E-04
Xe-135	9.09E-04	9.16E-04	1.05E-03	8.42E-04	7.65E-04	1.05E-03	7.12E-04	0.00E+00	1.05E-03	9.09E-04
Xe-138	4.29E-04	4.51E-04	4.45E-04	3.74E-04	3.42E-04	4.26E-04	3.36E-04	1.07E-03	4.63E-04	4.20E-04
Ba-140	8.79E-04	8.92E-04	9.82E-04	8.81E-04	1.05E-03	9.35E-04	7.95E-04	1.25E-02	9.82E-04	8.79E-04
Total	**2.00E-02**	**1.85E-02**	**7.55E-02**	**1.62E-02**	**1.53E-02**	**1.82E-02**	**1.48E-02**	**4.28E-01**	**9.38E-02**	**1.89E-02**

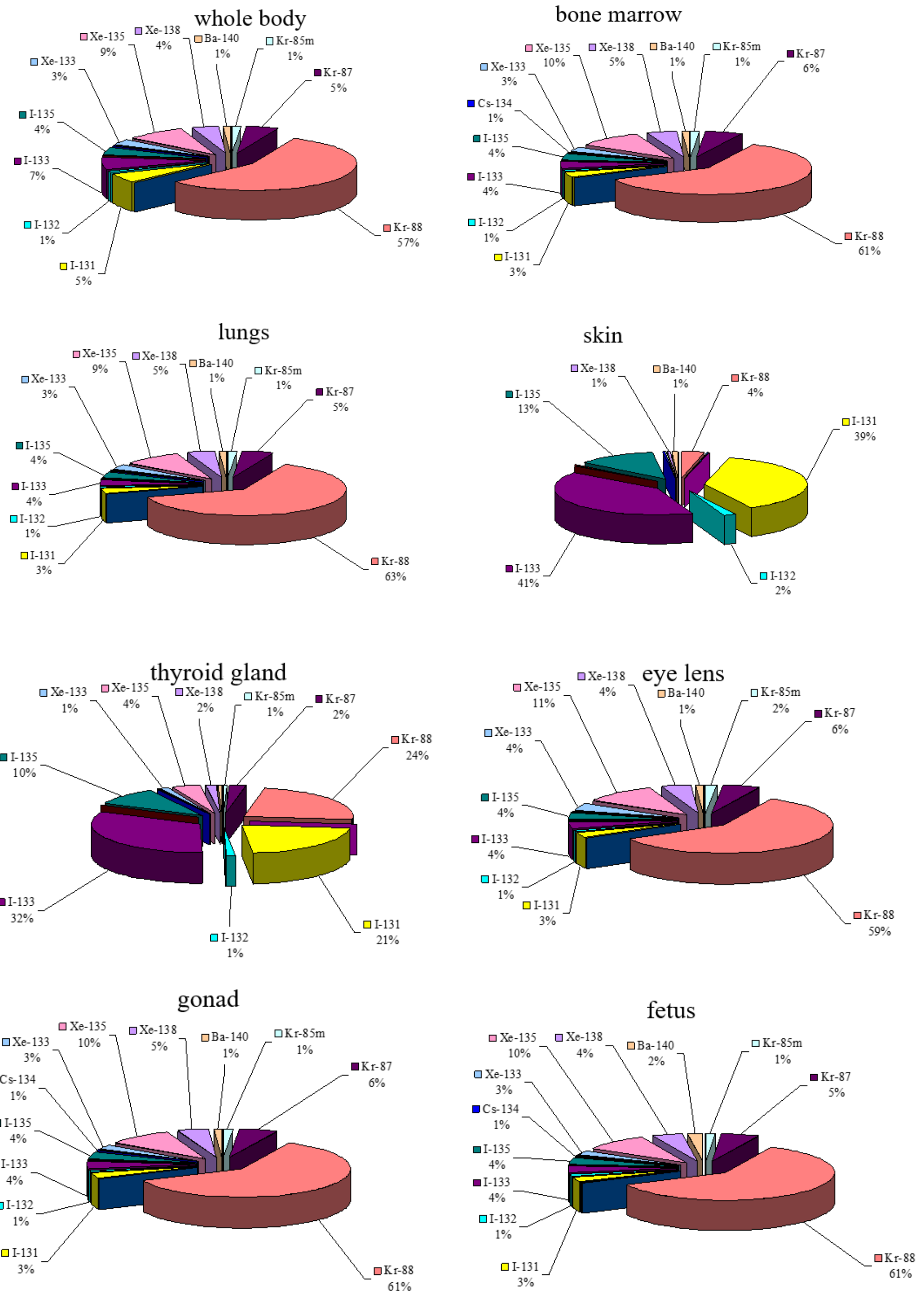
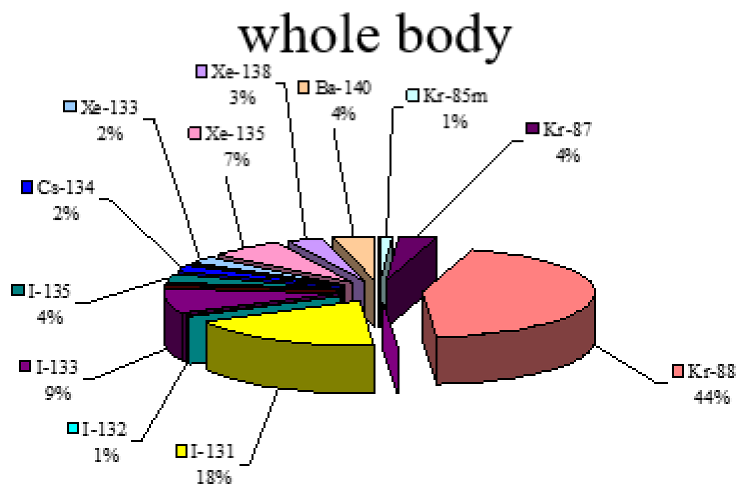
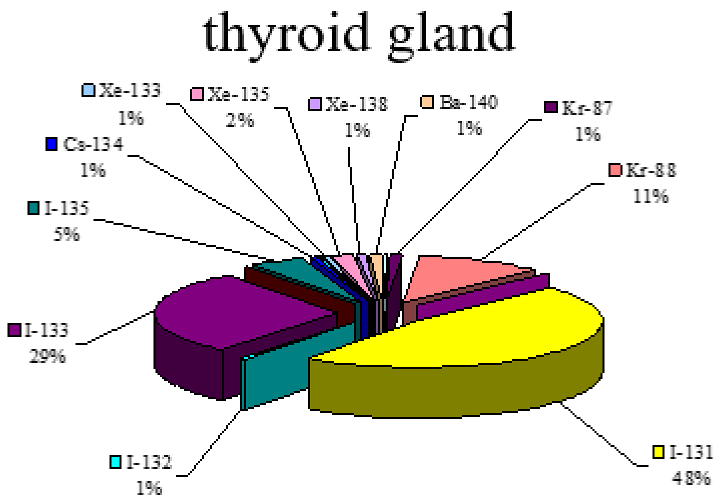


Figure 12.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period





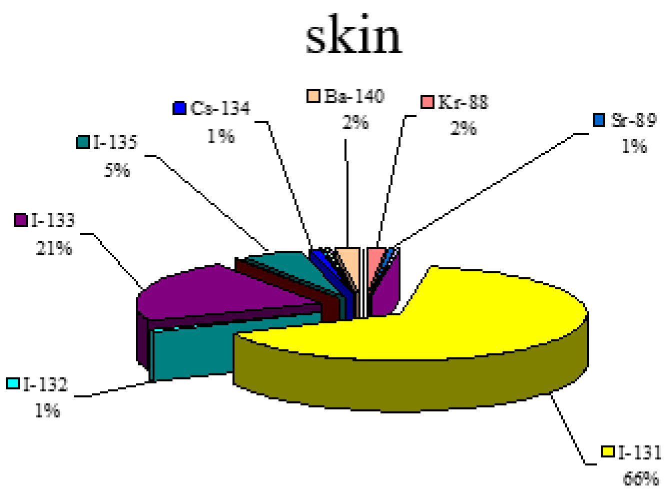
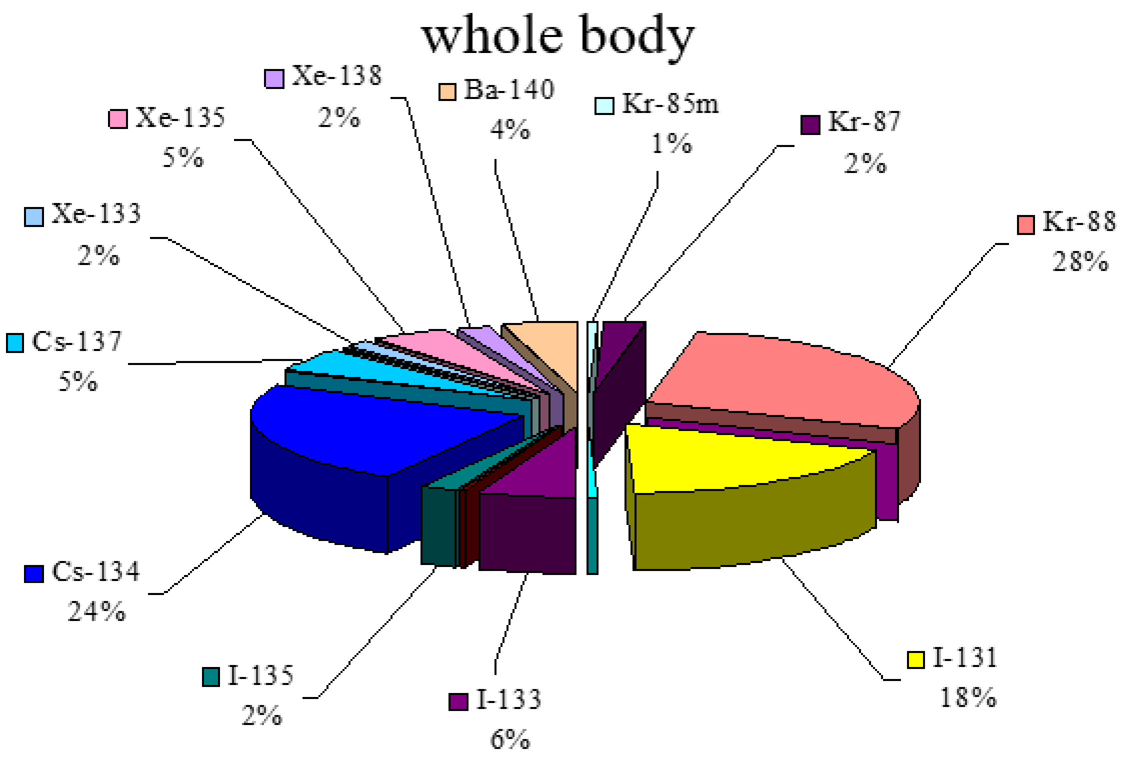


Figure 12.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



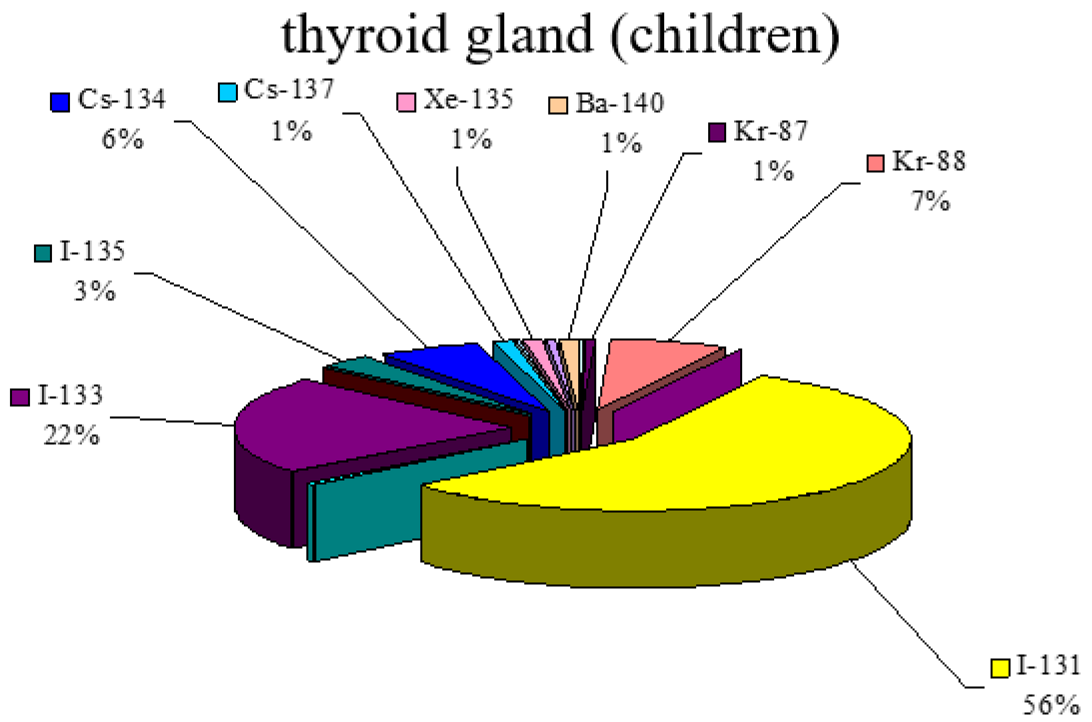


Figure 12.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

12.2.1 Radiation impact estimates for BDBA as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 12.6) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens , gonad and fetus.

Table 12.6 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	BDBA estimates, Gy
Entire body (bone marrow)[1]	1	0.0094 (0.0081)
Lungs	6	0.0098
Skin	3	0.15
Thyroid gland	5	0.025
Eye lens	2	0.0095
Gonad	2	0.0073
Fetus	0.1	0.0078

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 12.6), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by a release cloud.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 12.7, while calculation results for standardized values for BDBA are given in Table 12.8.

Table 12.7 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Table 12.8 - Dose estimates over the first 2 weeks following the BDBA

For the entire body, mSv	For thyroid gland in adults (children), mGy	For skin, mGy
12.9	52.7 (65.4)	345

Based on the calculation results given in Table 12.8, lower justifiability limits are exceeded in case of BDBA at the border of the SPZ, and shelter, iodine prophylaxis in children and limited stay outside for everyone shall be needed.

12.2.2 Radiation impact estimates for BDBA as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:

- 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
- 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during BDBA shall be 0.094 Sv/year, and for the entire body due to external radiation - 0.019 Sv/year. As can be seen, calculated values do not exceed the limit values as per SP AS-88.

12.3 Calculation results for BDBA at the border of the OZ (30 km)

Table 12.9 contains calculation results for surface air volumetric activity of radionuclides and fallout density at the border of the OZ (30 km from the release source) during BDBA.

Table 12.9 - Calculation results for surface air volumetric activity of radionuclides and fallout density on the ground surface during BDBA

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Kr-85m	1.62E+07	0.00E+00
Kr-87	1.52E+07	0.00E+00
Kr-88	3.46E+07	0.00E+00
Sr-89	6.77E+02	6.78E+05
Sr-90	5.65E+01	5.65E+04
Ru-103	3.38E+01	3.39E+04
I-131	6.58E+04	2.85E+07
I-132	5.54E+04	2.40E+07
I-133	1.31E+05	5.65E+07
I-134	3.29E+04	1.43E+07
I-135	1.08E+05	4.68E+07
Cs-134	6.78E+02	6.78E+05
Cs-137	3.39E+02	3.39E+05
La-140	5.46E+01	5.45E+04

Radionuclide	Maximum air volumetric activity, Bq/m^3	Maximum fallout density on the ground surface, Bq/m^2
Ce-141	4.51E+01	4.52E+04
Ce-144	3.39E+01	3.39E+04
Xe-133	1.67E+08	0.00E+00
Xe-135	6.39E+07	0.00E+00
Xe-138	4.25E+05	0.00E+00
Ba-140	1.13E+03	1.12E+06
Total	**2.98E+08**	**1.73E+08**

The maximum air volumetric activity values at the border of the OZ are expected to make up to 167 MBq/m^3 for ^{133}Xe and up to 63.9 MBq/m^3 for ^{135}Xe. The maximum ground surface fallout densities at the border of the OZ for iodine isotopes are expected to make up to 56.5 MBq/m^2 for ^{133}I, up to 46.8 MBq/m^2 for ^{135}I, up to 28.5 MBq/m^2 for ^{131}I and up to 24.0 MBq/m^2 for ^{132}I.

Tables 12.10–12.12 show calculation results of maximum radiation doses for different body organs and tissues at the border of the OZ (30 km from the release source) for radiation periods of 2 days, 2 weeks and 1 year. Fig. 12.4–12.6 show relative shares of radionuclides in doses as per NRBU-97 and SP AS-88.

The effective dose over a 50-year period is 68.5 mSv.

Table 12.10 - Human organ and tissue radiation doses during BDBA over a 2-day period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-85m	7.44E-05	7.60E-05	8.65E-05	6.56E-05	6.23E-05	8.65E-05	5.51E-05	0.00E+00	8.65E-05	7.44E-05
Kr-87	4.15E-04	4.21E-04	4.86E-04	3.88E-04	3.56E-04	4.53E-04	3.56E-04	0.00E+00	4.86E-04	4.15E-04
Kr-88	3.82E-03	4.07E-03	4.26E-03	3.57E-03	3.37E-03	4.09E-03	3.26E-03	1.26E-03	4.68E-03	3.63E-03
Sr-89	6.84E-08	1.99E-08	1.08E-08	7.80E-08	3.97E-07	9.60E-10	1.06E-08	8.94E-06	3.22E-08	6.84E-10
Sr-90	4.75E-09	3.06E-09	6.65E-10	5.80E-09	2.69E-08	1.20E-14	6.65E-10	1.14E-06	2.00E-09	0.00E+00
Ru-103	3.45E-07	3.90E-07	3.96E-07	3.36E-07	3.15E-07	3.78E-07	3.18E-07	2.22E-07	4.12E-07	3.38E-07
I-131	2.62E-04	2.40E-04	9.11E-04	2.26E-04	2.05E-04	2.53E-04	2.13E-04	7.41E-03	1.11E-03	2.33E-04
I-132	6.54E-05	6.63E-05	1.12E-04	6.21E-05	5.63E-05	6.95E-05	5.84E-05	4.77E-04	1.21E-04	6.28E-05
I-133	3.34E-04	2.96E-04	1.35E-03	2.79E-04	2.52E-04	3.11E-04	2.63E-04	8.02E-03	1.75E-03	2.84E-04
I-134	1.87E-05	1.91E-05	2.53E-05	1.76E-05	1.61E-05	1.99E-05	1.65E-05	1.63E-04	2.73E-05	1.79E-05
I-135	2.84E-04	2.82E-04	5.96E-04	2.66E-04	2.40E-04	2.96E-04	2.50E-04	2.66E-03	6.68E-04	2.67E-04
Cs-134	2.15E-05	2.24E-05	2.49E-05	2.12E-05	1.92E-05	2.38E-05	2.00E-05	6.78E-06	2.49E-05	2.15E-05
Cs-137	3.96E-06	4.14E-06	4.59E-06	3.90E-06	3.54E-06	4.38E-06	3.69E-06	4.53E-06	4.68E-06	3.92E-06
La-140	1.27E-06	1.37E-06	1.46E-06	1.24E-06	1.18E-06	1.39E-06	1.17E-06	6.25E-07	1.51E-06	1.24E-06
Ce-141	7.72E-08	1.37E-07	7.84E-08	6.68E-08	7.76E-08	7.48E-08	6.32E-08	5.92E-07	1.00E-07	6.64E-08
Ce-144	5.25E-08	1.51E-07	3.21E-08	2.75E-08	1.22E-07	3.09E-08	2.59E-08	2.26E-07	6.36E-08	2.68E-08
Xe-133	1.55E-04	1.50E-04	1.79E-04	1.11E-04	1.11E-04	2.08E-04	9.65E-05	0.00E+00	1.79E-04	1.55E-04
Xe-135	4.88E-04	4.92E-04	5.61E-04	4.51E-04	4.10E-04	5.61E-04	3.83E-04	0.00E+00	5.61E-04	4.88E-04
Xe-138	2.76E-04	2.88E-04	3.14E-04	2.67E-04	2.43E-04	3.00E-04	2.49E-04	1.13E-04	3.26E-04	2.70E-04
Ba-140	5.05E-05	5.25E-05	5.83E-05	4.98E-05	4.66E-05	5.57E-05	4.69E-05	2.07E-05	5.83E-05	5.05E-05
Total	**6.27E-03**	**6.49E-03**	**8.96E-03**	**5.78E-03**	**5.40E-03**	**6.73E-03**	**5.27E-03**	**2.02E-02**	**1.01E-02**	**5.97E-03**

Table 12.11 - Human organ and tissue radiation doses during BDBA over a 2-week period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-85m	7.44E-05	7.60E-05	8.65E-05	6.56E-05	6.23E-05	8.65E-05	5.51E-05	0.00E+00	8.65E-05	7.44E-05
Kr-87	4.15E-04	4.21E-04	4.86E-04	3.88E-04	3.56E-04	4.53E-04	3.56E-04	0.00E+00	4.86E-04	4.15E-04
Kr-88	3.82E-03	4.07E-03	4.26E-03	3.57E-03	3.37E-03	4.09E-03	3.26E-03	1.26E-03	4.68E-03	3.63E-03
Sr-89	1.79E-07	5.17E-08	4.30E-08	3.86E-07	1.12E-06	6.18E-09	4.17E-08	5.06E-05	1.26E-07	5.36E-09
Sr-90	1.90E-08	9.45E-09	4.38E-09	5.10E-08	1.01E-07	2.59E-13	4.38E-09	9.40E-06	1.31E-08	0.00E+00
Ru-103	2.14E-06	2.37E-06	2.46E-06	2.09E-06	1.92E-06	2.35E-06	1.98E-06	1.24E-06	2.51E-06	2.12E-06
I-131	1.15E-03	1.04E-03	4.26E-03	9.86E-04	8.94E-04	1.11E-03	9.31E-04	2.96E-02	5.28E-03	1.01E-03
I-132	6.54E-05	6.63E-05	1.12E-04	6.21E-05	5.63E-05	6.95E-05	5.84E-05	4.77E-04	1.21E-04	6.28E-05
I-133	4.68E-04	3.86E-04	2.37E-03	3.63E-04	3.30E-04	4.07E-04	3.44E-04	9.93E-03	3.27E-03	3.79E-04
I-134	1.87E-05	1.91E-05	2.53E-05	1.76E-05	1.61E-05	1.99E-05	1.65E-05	1.63E-04	2.73E-05	1.79E-05
I-135	2.90E-04	2.86E-04	6.44E-04	2.70E-04	2.44E-04	3.02E-04	2.54E-04	2.66E-03	7.21E-04	2.73E-04
Cs-134	1.47E-04	1.54E-04	1.70E-04	1.45E-04	1.31E-04	1.63E-04	1.37E-04	4.13E-05	1.70E-04	1.47E-04
Cs-137	2.72E-05	2.84E-05	3.15E-05	2.69E-05	2.44E-05	3.00E-05	2.54E-05	2.77E-05	3.15E-05	2.72E-05
La-140	2.25E-06	2.43E-06	2.58E-06	2.20E-06	2.09E-06	2.46E-06	2.07E-06	1.07E-06	2.68E-06	2.20E-06
Ce-141	4.56E-07	7.36E-07	4.84E-07	4.12E-07	4.16E-07	4.60E-07	3.88E-07	3.22E-06	5.71E-07	4.15E-07
Ce-144	2.98E-07	9.09E-07	2.23E-07	1.90E-07	4.35E-07	2.12E-07	1.79E-07	1.37E-06	3.87E-07	1.87E-07
Xe-133	1.55E-04	1.50E-04	1.79E-04	1.11E-04	1.11E-04	2.08E-04	9.65E-05	0.00E+00	1.79E-04	1.55E-04
Xe-135	4.88E-04	4.92E-04	5.61E-04	4.51E-04	4.10E-04	5.61E-04	3.83E-04	0.00E+00	5.61E-04	4.88E-04
Xe-138	2.76E-04	2.88E-04	3.14E-04	2.67E-04	2.43E-04	3.00E-04	2.49E-04	1.13E-04	3.26E-04	2.70E-04
Ba-140	2.54E-04	2.65E-04	2.94E-04	2.51E-04	2.32E-04	2.81E-04	2.37E-04	1.40E-04	2.94E-04	2.54E-04
Total	**7.66E-03**	**7.75E-03**	**1.38E-02**	**6.98E-03**	**6.49E-03**	**8.08E-03**	**6.41E-03**	**4.45E-02**	**1.62E-02**	**7.21E-03**

Table 12.12 - Human organ and tissue radiation doses during BDBA over one year period

Nuclide	Effective dose, Sv	Lungs, Gy	Thyroid gland (adults), Gy	Bone marrow, Gy	Fetus, Gy	Eye lens, Gy	Gonad, Gy	Skin, Gy	Thyroid gland (children), Gy	Entire body (external), Gy
Kr-85m	7.44E-05	7.60E-05	8.65E-05	6.56E-05	6.23E-05	8.65E-05	5.51E-05	0.00E+00	8.65E-05	7.44E-05
Kr-87	4.15E-04	4.21E-04	4.86E-04	3.88E-04	3.56E-04	4.53E-04	3.56E-04	0.00E+00	4.86E-04	4.15E-04
Kr-88	3.82E-03	4.07E-03	4.26E-03	3.57E-03	3.37E-03	4.09E-03	3.26E-03	1.26E-03	4.68E-03	3.63E-03
Sr-89	4.13E-07	1.10E-07	1.03E-07	1.67E-06	1.36E-06	3.43E-08	9.60E-08	1.25E-04	2.95E-07	2.89E-08
Sr-90	1.84E-07	1.99E-08	1.42E-08	1.18E-06	1.69E-07	8.00E-12	1.42E-08	3.76E-05	4.25E-08	0.00E+00
Ru-103	8.94E-06	9.72E-06	1.03E-05	8.79E-06	8.01E-06	9.87E-06	8.31E-06	2.85E-06	1.05E-05	8.85E-06
I-131	1.66E-03	1.47E-03	6.77E-03	1.39E-03	1.26E-03	1.56E-03	1.31E-03	3.77E-02	8.67E-03	1.43E-03
I-132	6.54E-05	6.63E-05	1.12E-04	6.21E-05	5.63E-05	6.95E-05	5.84E-05	4.77E-04	1.21E-04	6.28E-05
I-133	4.73E-04	3.91E-04	2.39E-03	3.68E-04	3.34E-04	4.12E-04	3.49E-04	9.93E-03	3.30E-03	3.83E-04
I-134	1.87E-05	1.91E-05	2.53E-05	1.76E-05	1.61E-05	1.99E-05	1.65E-05	1.63E-04	2.73E-05	1.79E-05
I-135	2.90E-04	2.86E-04	6.44E-04	2.70E-04	2.44E-04	3.02E-04	2.54E-04	2.66E-03	7.21E-04	2.73E-04
Cs-134	2.54E-03	2.65E-03	2.95E-03	2.51E-03	2.28E-03	2.81E-03	2.37E-03	1.45E-04	2.95E-03	2.54E-03
Cs-137	5.37E-04	5.61E-04	6.24E-04	5.31E-04	4.83E-04	5.94E-04	5.01E-04	1.00E-04	6.24E-04	5.37E-04
La-140	2.26E-06	2.44E-06	2.58E-06	2.20E-06	2.09E-06	2.47E-06	2.08E-06	1.07E-06	2.68E-06	2.21E-06
Ce-141	1.68E-06	2.41E-06	1.84E-06	1.57E-06	1.47E-06	1.76E-06	1.48E-06	6.96E-06	2.07E-06	1.58E-06
Ce-144	4.05E-06	1.01E-05	3.72E-06	3.18E-06	3.24E-06	3.54E-06	2.99E-06	4.53E-06	4.91E-06	3.28E-06
Xe-133	1.55E-04	1.50E-04	1.79E-04	1.11E-04	1.11E-04	2.08E-04	9.65E-05	0.00E+00	1.79E-04	1.55E-04
Xe-135	4.88E-04	4.92E-04	5.61E-04	4.51E-04	4.10E-04	5.61E-04	3.83E-04	0.00E+00	5.61E-04	4.88E-04
Xe-138	2.76E-04	2.88E-04	3.14E-04	2.67E-04	2.43E-04	3.00E-04	2.49E-04	1.13E-04	3.26E-04	2.70E-04
Ba-140	4.64E-04	4.84E-04	5.37E-04	4.58E-04	4.20E-04	5.14E-04	4.32E-04	2.24E-04	5.37E-04	4.64E-04
Total	**1.13E-02**	**1.15E-02**	**2.00E-02**	**1.05E-02**	**9.67E-03**	**1.20E-02**	**9.71E-03**	**5.30E-02**	**2.33E-02**	**1.08E-02**

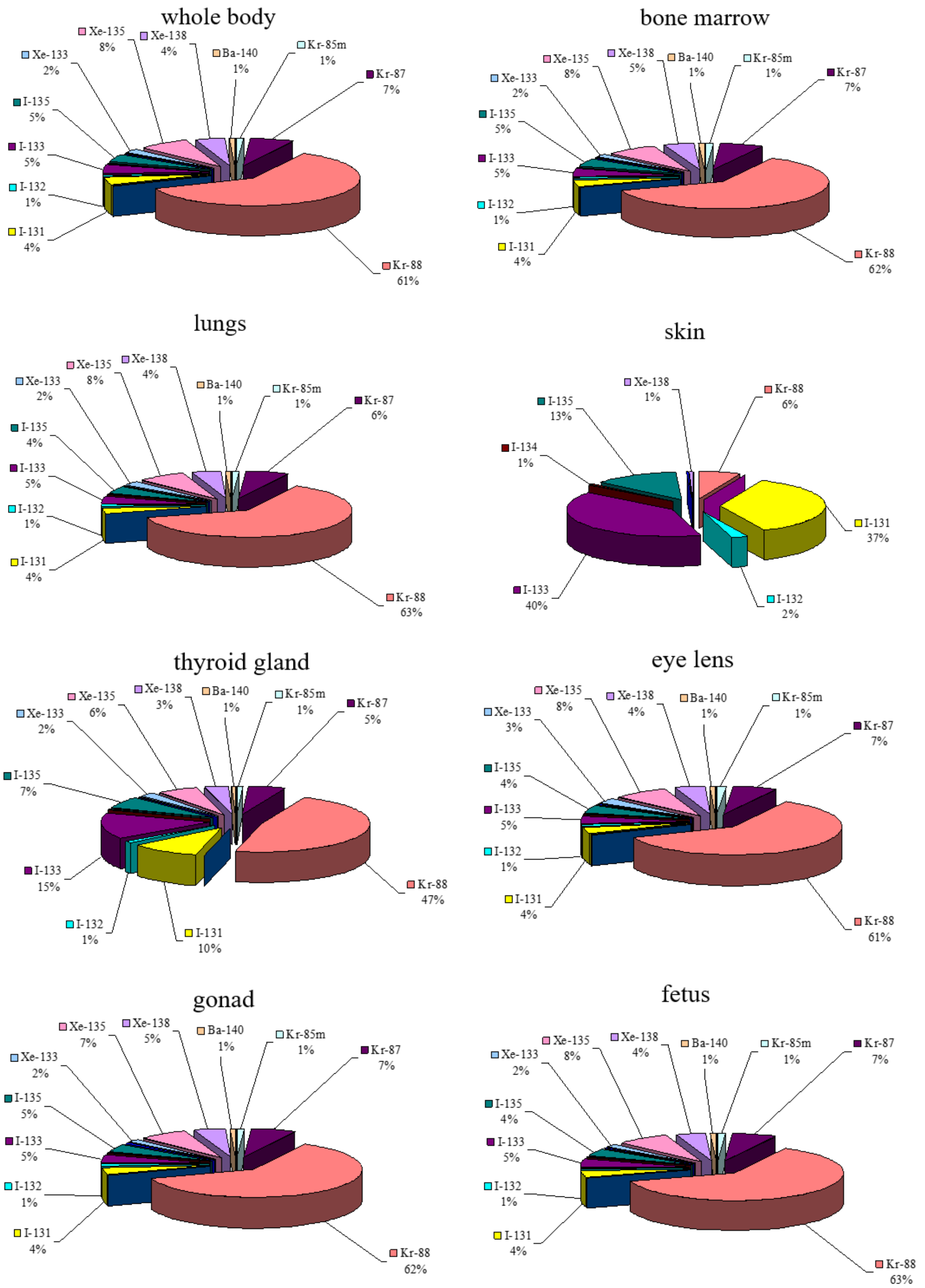
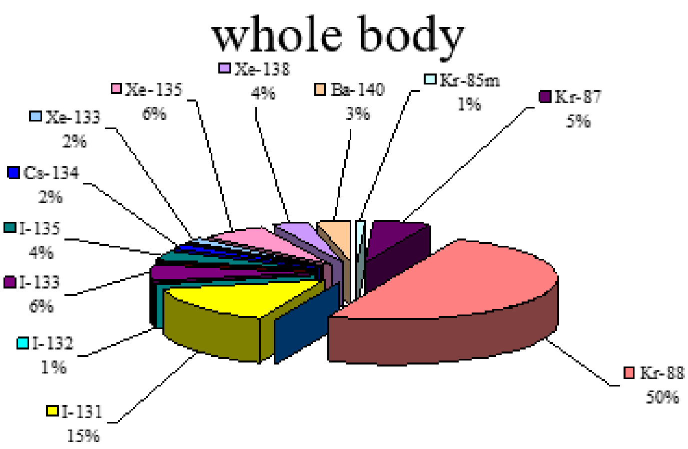
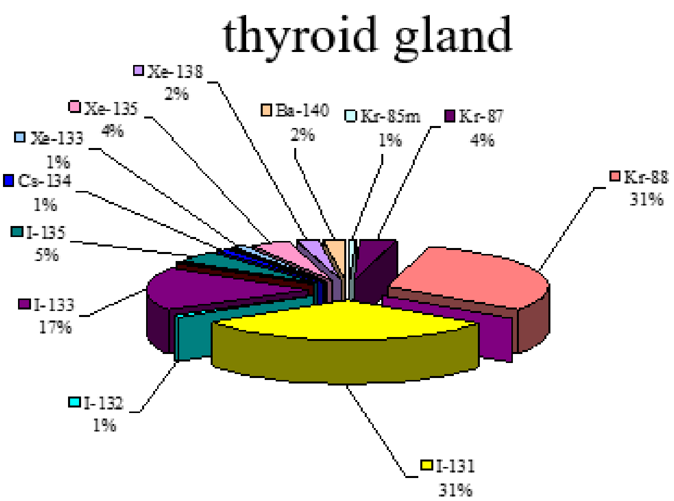


Figure 12.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period





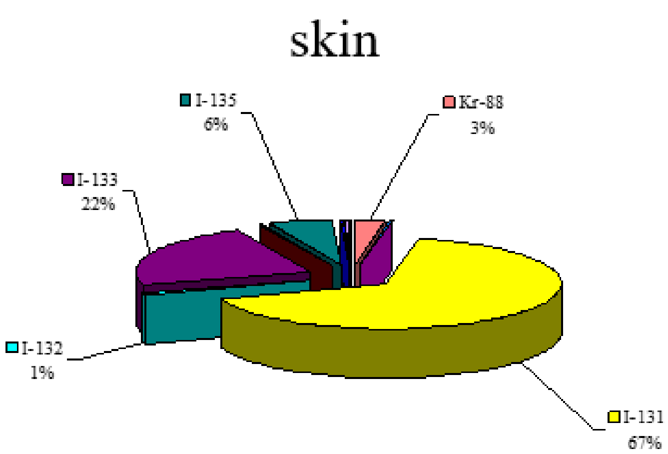
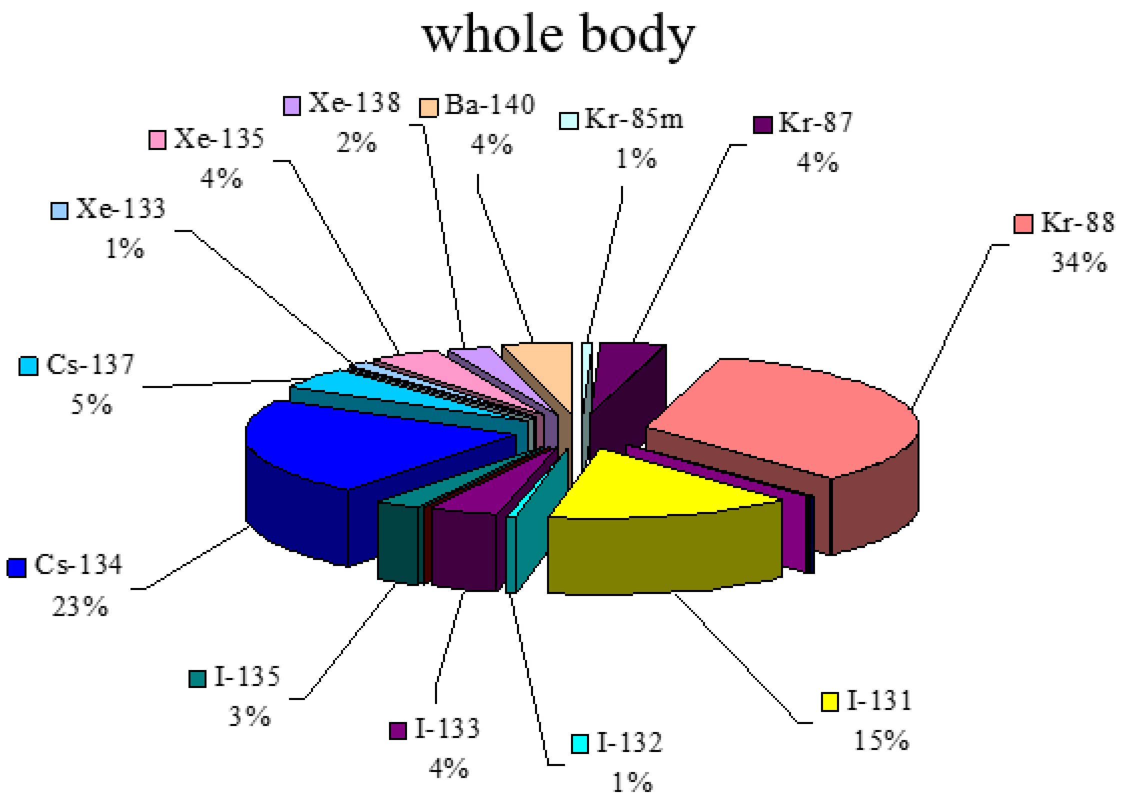


Figure 12.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



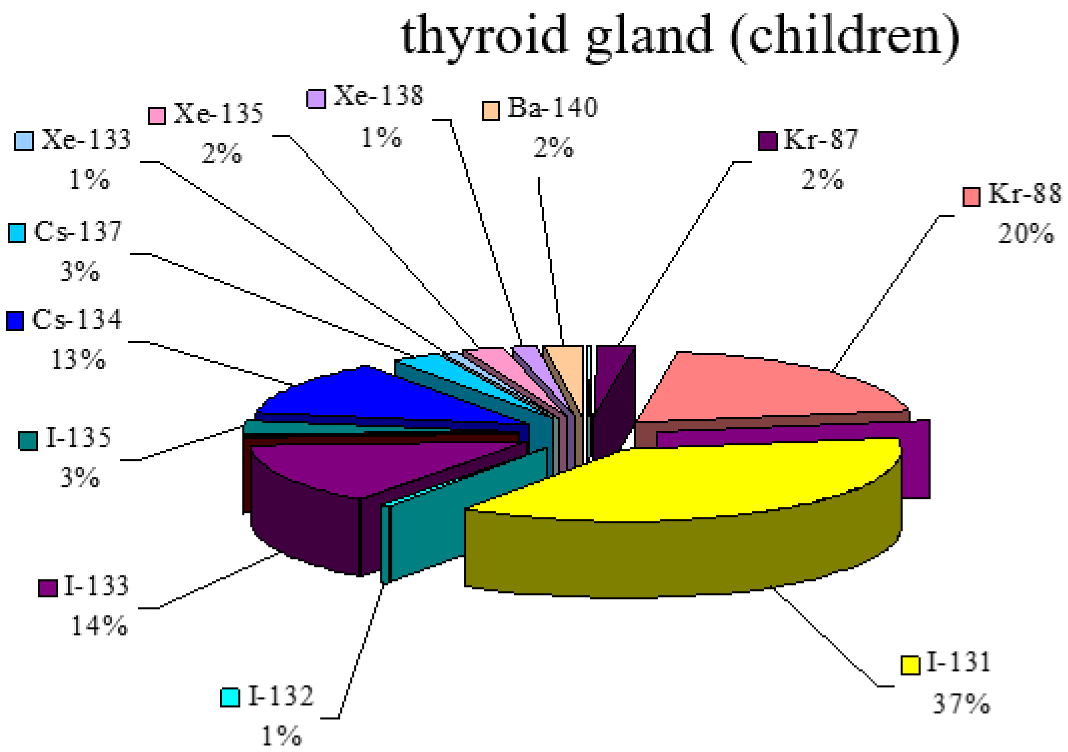


Figure 12.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

12.3.1 Radiation impact estimates for BDBA as per NRBU-97 requirements

Emergency countermeasures

Emergency intervention levels (see column 2 of Table 12.13) are based on the absorbed dose amount over a 2-day period. Absorbed doses are specified for the entire body, lungs, skin, thyroid gland, eye lens, gonad and fetus.

Table 12.13 - Unconditionally justified emergency intervention levels (acute exposure)

Organ or tissue	Intervention levels for dose absorbed over a 2-day period, Gy	BDBA estimates, Gy
Entire body (bone marrow)[1]	1	0.0060 (0.0058)
Lungs	6	0.0065
Skin	3	0.020
Thyroid gland	5	0.0090
Eye lens	2	0.0067
Gonad	2	0.0053
Fetus	0.1	0.0054

[1] As a rule, applies in case of external radiation

Based on the above calculation results (see column 3 of Table 12.3), neither of the above criteria requires urgent countermeasures. The dose is mainly formed by a release cloud.

Urgent countermeasures

Radiation doses standardized in NRBU-97 for urgent countermeasures are given in Table 12.14, while calculation results for standardized values for BDBA are given in Table 12.15.

Table 12.14 - Lower justifiability limits and unconditional justifiability levels for urgent countermeasures

Countermeasure	Dose over the first 2 weeks following accident					
	Lower justifiability limits			Unconditional justifiability levels		
	mSv	mGy		mSv	mGy	
	For the entire body	For thyroid gland	For skin	For the entire body	For thyroid gland	For skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylaxis						
Children	-	50[1]	-	-	200[1]	-
Adults	-	200[1]	-	-	500[1]	-
Limited stay outdoors						
Children	1	20	50	10	100	300
Adults	2	100	200	20	300	1000

[1] Expected dose following internal radiation with radioiodine isotopes taken in over the first two weeks after the accident.

Based on the calculation results given in Table 12.15, lower justifiability limits are exceeded in case of BDBA, and shelter and limited stay outside for both children and adults shall be needed.

Table 12.15 - Dose estimates over the first 2 weeks following the BDBA

For the entire body, mSv	For thyroid gland in adults (children), mGy	For skin, mGy
7.66	13.8 (16.2)	44.5

Based on the calculation results given in Table 12.15, lower justifiability limits are exceeded in case of BDBA, and shelter and limited stay outside for both children and adults shall be needed.

12.3.2 Radiation impact estimates for BDBA as per SP AS-88 requirements

According to para. 3.14 of Sanitary Rules for Design and Operation of Nuclear Power Plants (SP AS-88):

- ✓ values of equivalent individual doses under the least favourable conditions at the border and outside the sanitary protection zone must not exceed:
  - 0.3 Sv/year (30 rem/year) for thyroid gland in children, due to inhalation;
  - 0.1 Sv/year (10 rem/year) for the entire body, due to external radiation.

According to the calculation results, radiation doses for thyroid gland in children during BDBA shall be 0.023 Sv/year, and for the entire body due to external radiation - 0.011 Sv/year. As can be seen, calculated values do not exceed the limit values as per SP AS-88.

CONCLUSIONS

This report contains calculations and justification of radiation impact of radioactive releases from SS Rivne NPP on the environment and the population during normal operation and in emergency cases.

Calculations have been performed using PC COSYMA software suite developed for emergency cases by the National Radiological Protection Board (UK). Modelling of atmospheric propagation of radioactive substances and formation of doses dependent on radionuclide releases from SS Rivne NPP during normal operation was carried out using software suites PC CREAM by National Radiological Protection Board (UK) and CAP-88 by Environmental Protection Agency (USA).

All calculations have been performed for conservative conditions of impurity propagation and radiation dose formation (at maximum doses).

It has been shown that maximum permissible values of radiation criteria for equivalent and absorbed doses in body organs and the entire body at the border and outside the sanitary protection zone, as defined by documents СП АС 88 and НРБУ 97 (SP AS-88 and NRBU-97), are met during normal operation of power units or in case of design basis accidents.

Of all design basis accidents, “Steam generator header cover lift-up — Emergency spike” is the most hazardous DBA for human within 2 days and 2 weeks, with radiation doses of 86.7 μSv and 155 μSv, respectively, at the border of the SPZ. The maximum DBA with the dose of 316 μSv is the most hazardous DBA for human within 1 year period. DBA “Fuel assembly drop on the reactor core in the rector” with the dose of 3.18 mSv is the most hazardous DBA for human within 50 year period.

Based on the above-mentioned calculation data, within 2 weeks of a BDBA at the border of the SPZ (2.5 km) lower justifiability limits are exceeded, and shelter, iodine prophylaxis in children and limited stay outside for both children and adults shall be needed, while at the border of the OZ (30 km), shelter and limited stay outside are required.

LIST OF REFERENCES

1. *Министерство* здравоохранения Украины. Нормы радиационной безопасности Украины (НРБУ-97). – К., 1998. – 134 с.
2. *Санитарные* правила проектирования и эксплуатации атомных станций (СП АС-88), 1988.
3. *PC-CREAM* 97. Installing and Using the PC System for Assessing the Radiological Impact of Routine Releases / A. Mayall, T. Cabianca, C. Attwood et al. – NRPB, 1997. – 172 p.
4. *Simmonds J.R., Lawson G., Mayall A.* Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment. Radiation Protection. – NRPB, 1995. – 353 p.
5. *Крышев И.И., Рязанцев Е.П.* Экологическая безопасность ядерно-энергетического комплекса России. – М.: ИздАТ, 2000. – 384 с.
6. Річний звіт з оцінки радіаційного впливу ВП «Рівненська АЕС» на навколишнє середовище та населення в 2017 році. 132-12-ЗВ-18-ЦРБ. – Вараш. – 2018. – 72 с.
7. Річний звіт з оцінки радіаційного впливу ВП «Рівненська АЕС» на навколишнє середовище та населення в 2016 році. 132-10-ЗВ-17-ЦРБ. – Вараш. – 2017. – 117 с.
8. Годовой отчет по оценке радиационного воздействия ОП «Ривненская АЭС» на окружающую среду и население в 2015 году. 132-10-ОЧ-16-ЦРБ. − Кузнецовск. − 2016. − 120 с.
9. Годовой отчет по оценке радиационного воздействия ОП «Ривненская АЭС» на окружающую среду и население в 2014 году. 132-08-НР-15-ЦРБ. − Кузнецовск. − 2015. − 122 с.
10. Годовой отчет по оценке радиационного воздействия ОП «Ривненская АЭС» на окружающую среду и население в 2013 году. 132-06-НР-14-ЦРБ. − Кузнецовск. − 2014. − 115 с.
11. *Radiation* Protection. ICRP Publication 60. 1990 Recommendations of the International Commission on Radiological Protection (ICRP). – N.Y.: Pergamon Press, 1991. – 197 pp.
12. *ICRP72* International Commission on Radiological Protection, “Age Dependent Doses to Members of the Public from Intake of Radionuclides, Part 5. Compilation of Ingestion and Inhalation Dose Coefficients” ICRP Publication 72, Pergamon Press, Oxford, 1996.
13. *Гусев Н.Г.*, Беляев В.А. Радиоактивные выбросы в биосфере: Справочник. – М.: Энергоатомиздат, 1991. – 256 с.
14. *Barry S. Parks*. User's Guide for CAP88-PC, Version 1.0. – USA: Environmental Protection Agency. – 1992. – 30 p.

15. *Рекомендации* по установлению предельно допустимого и контрольного уровня выбросов углерода-14 (для Запорожской АЭС) / Институт биофизики. – М., 1992.

16. *Коваленко Г.Д.* Радиоэкология Украины: Монография. − 3-е изд., перераб. и доп. – Х: ИД «Инжэк», 2013. – 344 с.

17. *Берковський В. Б.*, Ліхтарьов І. А., Бончук Ю. В., Ратіа Г. Г., Л. В. Близнюкова. Порядок встановлення допустимих рівнів скидів і викидів АЕС України (радіаційно-гігієнічні регламенти I групи). Методичні вказівки/ Комісія з питань гігієнічного регламентування радіоактивних речовин і радіаційних факторів, Комітет з питань гігієнічного регламентування, міністерство охорони здоров'я України. Київ – 2002 р. –57 с.

18. *J. A. Jones*, P. A. Mansfield, S. M. Haywood et al. PC COSYMA (Version 2): An accident consequence assessment package for use on a PC. − Luxemborg: Office for Official Publications of the European Communities, 1996. – 59 pp.

19. *МЕТОДИКА* оценки источника выбросов радионуклидов при возникновении аварии в реакторной установке ВВЭР-1000. 00.РБ.ХY.МТ.07-14.

APPENDIX A.

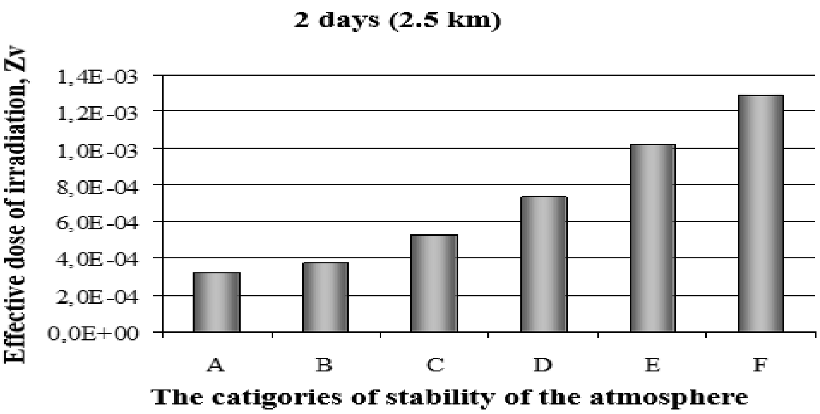
STUDY OF ACCIDENT IMPACT UNDER VARIOUS WEATHER CONDITIONS

This appendix contains the results of studies aimed at establishing the least favourable weather conditions to cause the maximum hazardous impact of radioactive release from SS RNPP on the environment and the population in case of an accident.

Studies were based on the maximum design basis accident since its radionuclide content is typical of most accidents, and it is the most hazardous one. No design basis accident involves destruction of power unit main structures, therefore release through air vents to a height of 100 m is postulated (in case of an accident with a header cover lift-up, the bulk of radioactive substances are released to a height of 100 m). The release based on the scenario lasts 60 min. All human exposure pathways are considered during calculations.

Fig. A.1 shows the calculation results for the maximum expected effective radiation doses over a 2-day and 50-year periods within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on an atmospheric stability class. Maximum expected doses were used for each atmospheric stability class. As can be seen from the figures, the most stable class F is predominant.

Study results for the conditions within class F, which have the greatest impact on the expected radiation doses, are shown in Fig. A.2–A.7. The wide range of the results shows the importance of accounting for low weather conditions. The results are shown for distances of 2.5 km (SPZ), 30 km (OZ) and 60 km (minimum distance to the neighbouring state, Republic of Belarus).



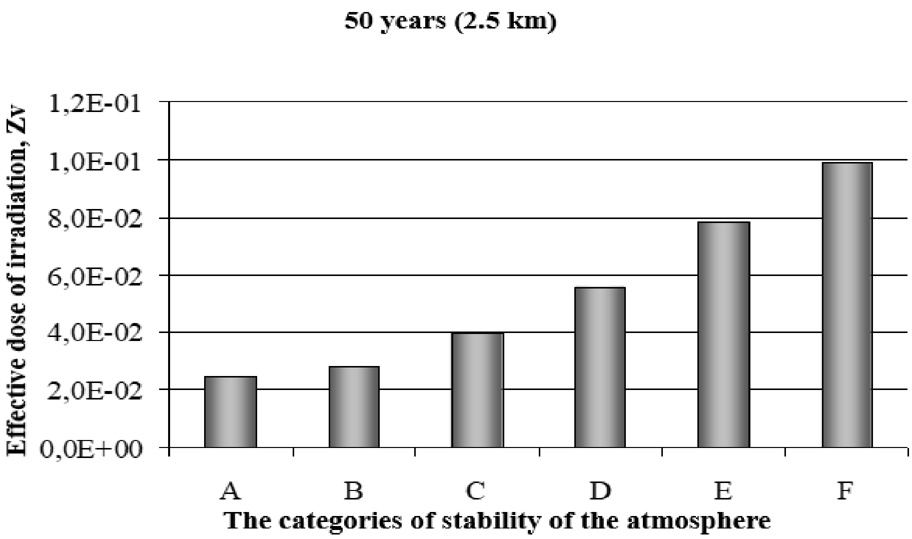


Fig. A.1. Maximum population radiation doses for various stability classes over a 2-day and 50-year periods within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor

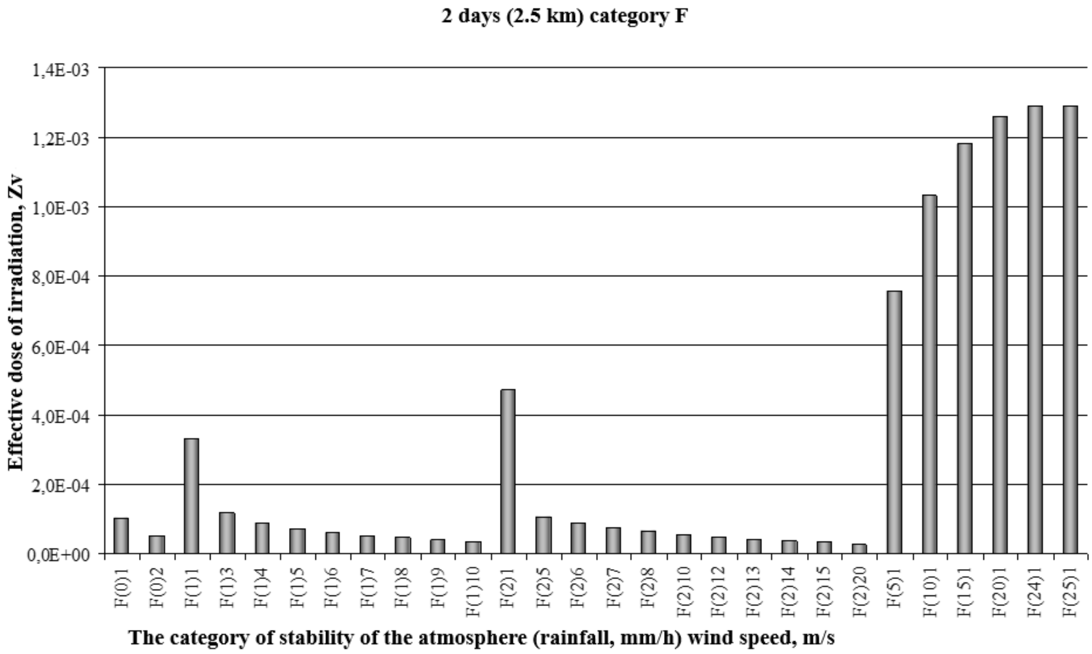


Fig. A.2. Maximum population radiation doses over a 2-day period within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

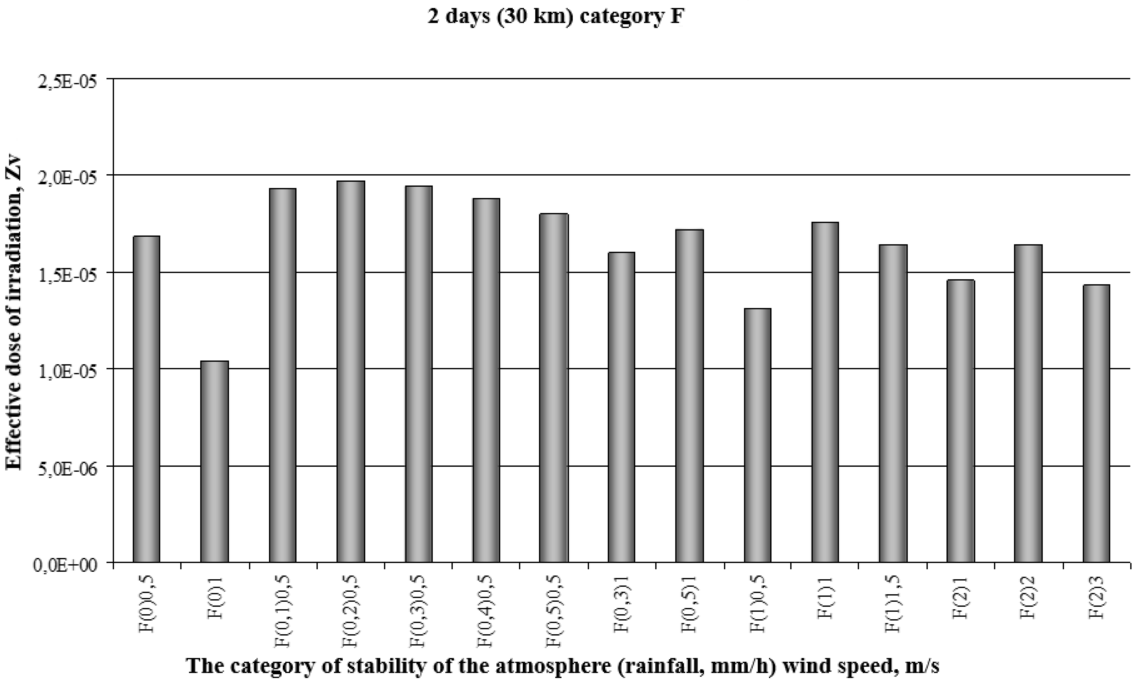


Fig. A.3. Maximum population radiation doses over a 2-day period within 30 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

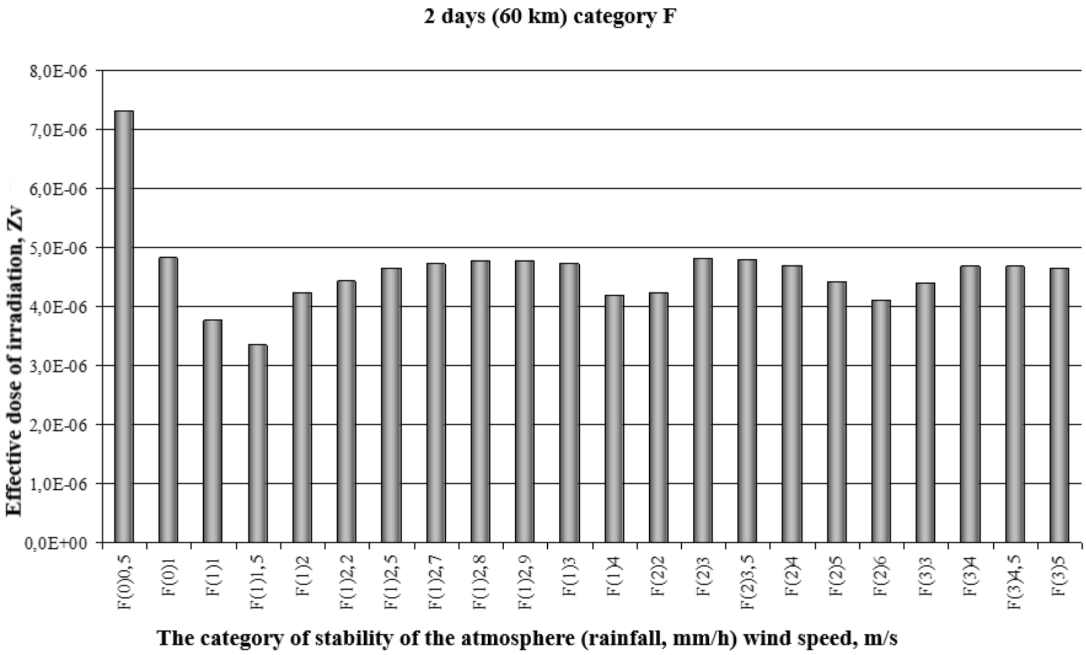


Fig. A.4. Maximum population radiation doses over a 2-day period within 60 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

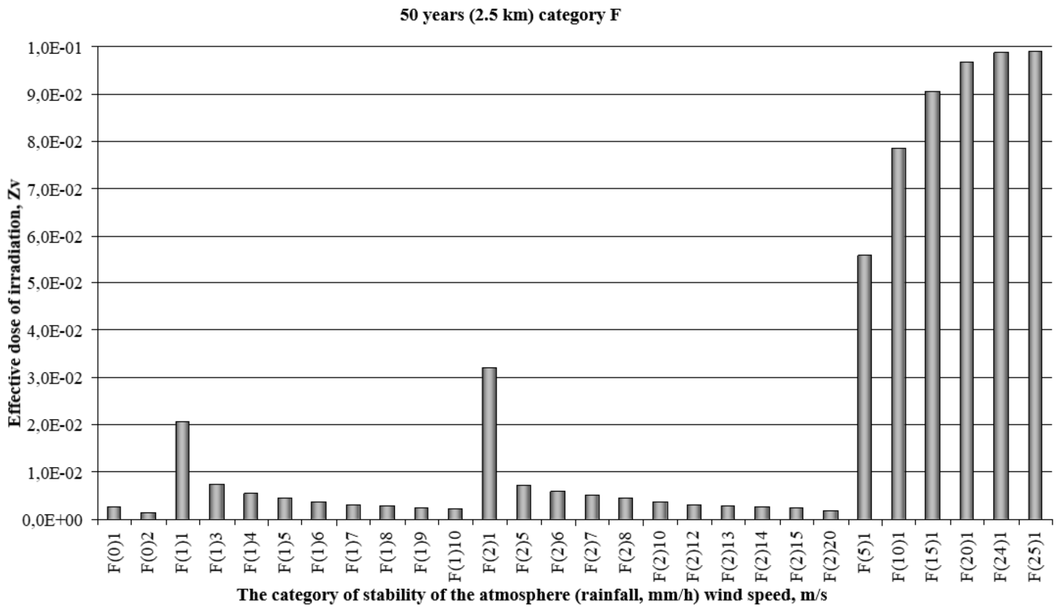


Fig. A.5. Maximum population radiation doses over a 50-year period within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

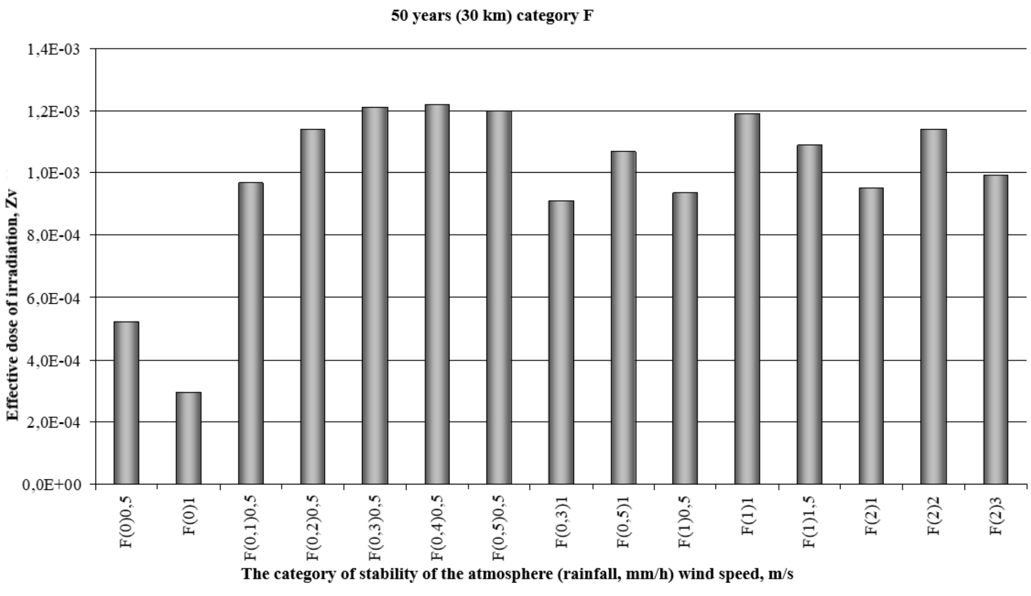


Fig. A.6. Maximum population radiation doses over a 50-year period within 30 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

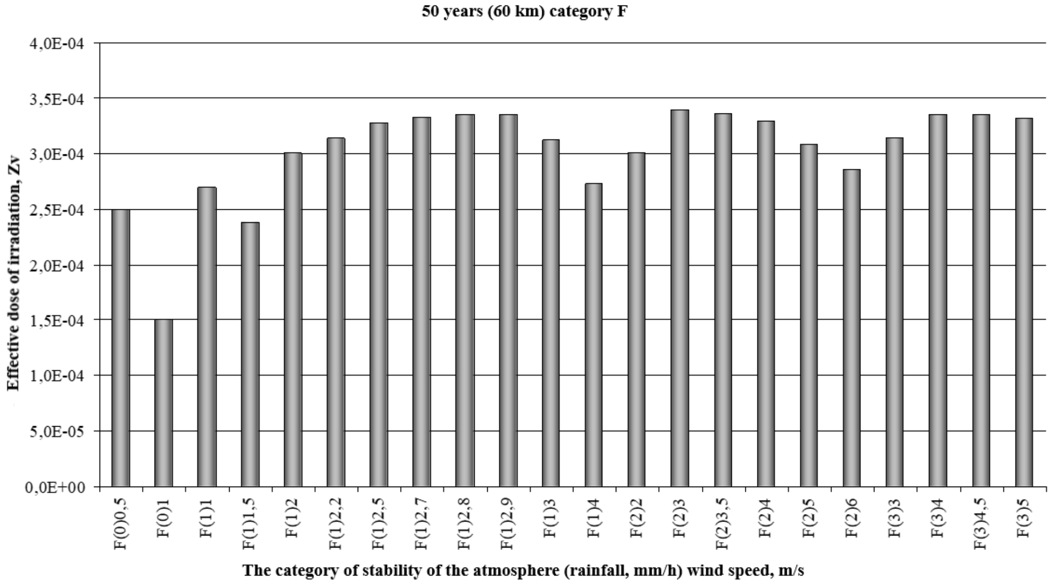


Fig. A.7. Maximum population radiation doses over a 50-year period within 60 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

Based on the study results, the maximum expected radiation doses within 2.5 km in case of the MDBA shall be observed for stability class F, heavy precipitation (25 mm/hour) and low wind (1 m/s), for all exposure periods (2 days to 50 years), i. e. these conditions may be used for compliance assessment at the border of the SPZ.

Within 30 km, the maximum expected doses for all exposure periods shall be observed for stability class F, low wind (0.5 m/s) and moderate precipitation (0.3 mm/hour), i. e. these conditions may be used for compliance assessment at the border of the OZ.

The studies of the MDBA impact within 60 km (distance from Rivne NPP to the Republic of Belarus) have shown that the maximum expected doses within exposure periods from 2 days to 1 year for stability class F, low wind (0.5 m/s), and no precipitations, however doses for 50-year exposure in this case will be reduced by 36 %. The maximum expected doses for 50 years shall be observed for moderate precipitation (2 mm/hour) and moderate wind speed (3 m/s).

Appendix A conclusions

The studies of impact of weather conditions on human radiation levels in case of design basis accidents have shown that weather conditions of stability class F, heavy precipitation (25 mm/hour) and wind speed of 1 m/s are recommended to be used for calculation of the maximum expected population radiation doses in the immediate vicinity of the NPP at the border of the sanitary protection zone (2.5 km) for any exposure period (2 days, 2 weeks, year, 50 years).

Weather conditions of stability class F, moderate precipitation (0.3 mm/hour) and wind speed of 0.5 m/s are recommended to be used for calculation of the maximum expected population radiation doses at the border of the observation zone (30 km) for any exposure period (2 days, 2 weeks, year, 50 years).

Weather conditions of stability class F, no precipitation and wind speed of 0.5 m/s are feasible to calculate the maximum expected population radiation doses in a transboundary context.

APPROVED
Director of NT Engineering
______________R. V. Maraikin
"05" December 2018

REPORT
ON
SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 3 Volume 3

Geologic Environment

Version 2

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2018

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ABSTRACT

Book 3 Part 3 of this Report contains 98 pages, 4 figures, 17 tables. The object of consideration are the operating power units integrated into thechnological complex of SS Rivne NPP site of SE "NNEGC "Energoatom" and their impact on the environment in the vicinity of SS «Rivne NPP".

The object of consideration is the operating enterprise SS Rivne NPP which includes operating power units, auxiliary production facilities and structures, and the environment at SS Rivne NPP location.

The purpose of development of these EIA sections is the assessment of SS Rivne NPP impact on the "Geological Environment" during operation of power units VVER-440 (2 units) and VVER-1000 (2 units) upon the results of implementation of environmental actions, long-term environment monitoring, and comparison of geologic environment state around NPP before and during power units operation.

Volume 3 of Book 3 consideres the characteristic of main geological environment indicators of SS "Rivne NPP" location area and provides the analysis of change dynamics using the observation data. The assessment of underground water at SS Rivne NPP location has been carried out before and durng the NPP operation and for the period of plant perspective development.

The report is made in compliance with the requiremnts to the structure and content of environmental impact assessment materials.

The result of this report is the environmental justification of the acceptability of SS Rivne NPP operating facilities economic activity and identification of environmental safety conditions under further operation.

KEY WORDS: SS Rivne NPP, gological environment, karst, chalk, water-bearing horizon, impact, natural environment, contaminants, environment.

Conditions of report dissemination: in compliance with the agreement.

CONTENT

REPORT STRUCTURE

"SS Rivne NPP Environmental Impact Assessment"

Book No.	Part No.	Title	Note
1		Basis for EIA. Physical and geographical characteristic of SS Rivne NPP location area.	
2		General characteristic of SS Rivne NPP .	
3		Assessment of SS Rivne NPP impacts on the environmental	
	1	Climate and microclimate. Air environment. Chemical air pollution.	
	2	Air environment. Influence of the radiation factor on the atmospheric air	
	3	Geological environment	
	4	Water environment	
	5	Soils. Flora and fauna, reserve areas.	
4		Assessment of impacts on the social and man-made environment	
5		Comprehensive measures to ensure the regulatory state of the environment and its safety	
6		Non-technical summary of SS Rivne NPP site environmental impact assessment	
7		Transboundary impact of production activities on the environment	

LIST OF SYMBOLS, UNITS, ABBREVIATIONS AND TERMS

Abbreviations	Description
ALI	Absolute level indication
ATEP	Lviv “AtomTeploElectroProject”
E	East
EIA	Environmental Impact Assessment
EGP	Exogenous geological processes
CSP	Crosshole seismic profiling
DBE	Design-basis earthquake
EGE	Engineering geological elements
ENF	External natural factors
GWL	Groundwater level
MDA	Minimum detectable activity
MSK-64	Macroseismic intensity scale
N	North
NASU	National Academy of Science of Ukraine
NPP	Nuclear Power Plant
NT-Engineering	Limited liability company “NT-Engineering”
OA	Observation area
OSG	Open switchgear
PEZ	Possible earthquake zone
RNPP	Rivne nuclear power plant
S	South
SB	Special building
SE “NNEGC “Energoatom”	State Enterprise “National Nuclear Energy Generating Company “Energoatom”
SRWS	Solid radioactive waste storage
SS Rivne NPP	Separate Subdivision “Rivne NPP”
SSE	Safe shutdown earthquake
SWP	Special water purification
TEP	Lviv “TeploElectroProject”
W	West

INTRODUCTION

The service: “SS Rivne NPP Environmental Impact Assessment” has been rendered in accordance with the contract No. 347, dated March 27, 2018, concluded between the State Enterprise “National Nuclear Energy Generating Company “Energoatom” (SE “NNEGC “Energoatom”), its Separate Subdivision “Rivne Nuclear Power Plant” and NT-Engineering LLC.

The purpose of Environmental Impact Assessment (EIA) development is the assessment of SS Rivne NPP impact on the environment during operation upon the results of implementation of environmental actions, long-term environmental monitoring, and comparison of environmental state around NPP before and during power units operation.

The result of EIA is the environmental justification of acceptability of SS Rivne NPP operating facilities activity and identification of environmental safety conditions under further plant operation.

Information data used when providing the service include baseline materials, monitoring results, power unit operating experience, implemented and planned environmental actions etc., based on which the calculation and research of SS Rivne NPP impact on the environment and public including that in a transboundary context has been carried out. This document is elaborated after the collected information has been analyzed, systematized and unified.

Specifics of the types of power units and SS Rivne NPP site impacts, taking into account their ranging by scale and consequence significance, within EIA scope the following environmental components are admitted for consideration:

- Geological environment;
- Air environment and microclimate;
- Surface and ground water;
- Soils;
- Flora and fauna;
- Assessment of impacts on social and man-made environment;
- Comprehensive measures to assure the regulatory state of the environment and its safety
- Transboundary impact of production activity on the environment.

EIA has been carried out in compliance with the law of Ukraine “On Environmental Impact Assessment” [1], which establishes legal and organizational framework of environmental impact assessment aimed at preventing damage to the environment, ensuring environmental safety, environmental protection, rational use and reproduction of natural resources, in the process of decision making on the implementation of economic activities that can sinificanly effect the environment, taking into account state, public and private interests, ДБН А.2.2-1-2003 “Structure and Content of Materials on Environmental Impact Assessment” [2] and Manual for the development of Environmental Impact Assessment Materials (for ДБН А.2.2-1-2003) [3].

When developing Book 3 Part 3 “General Characteristic of SS Rivne NPP. Geological Environment” archival materials of the Kyiv Institute of Engineering Survey and Research “Enrgoproekt” (now Joint Stock Company Kyiv Research and Design Institute “Energoproekt”), subcontractors, fund materials of Geoinform of Ukraine and State Regional Geological Enterprise “Pivnichgeologiia” were used.

“Environmental Safety Assessment of SS Rivne NPP site” is presented in 7 books.

Book 3 Volume 3 shows the impact of SS Rivne NPP on the environment in terms of SS Rivne NPP operation and the plant site impact on the Geological environment.

1 GENERAL CHARACTERISTIC OF GEOMORPHOLOGICAL FEATURES, GEOLOGICAL AND STRUCTURAL AND TECTONIC PATTERN

Geomorphological features, geological and structural and tectonic pattern are characterized by certain differences within this or that part of SS Rivne NPP 30-kilometer zone. In particular, geological environment of different areas of 30-kilometer zone are characterized by a different structure, therefore, the characteristics of both 30-kilometer zone as a whole and its main components are proided below to assess the impact of SS Rivne NPP power units on geological environment, SS Rivne NPP site, town of Varash and other infrastructure facilities and areas between them.

1.1 Geomorphological conditions and relief of SS Rivne NPP 30-kilometer zone

Surveillance zone (30-kilometer zone) of SS Rivne NPP in Geomorphological terms includes a rather heterogeneous area. Geomorphological zoning of Rivne NPP area and location of 30-kilometer zone is shown in Figure 1.1 [4].

Geomorphological zoning of 30-kilometer zone includes the selection of different taxonomic units (regions, subregions, districts), information about it is given in Table 1.1.

Table 1.1. Geomorphological zoning of SS ‘Rivne NPP” location area

Country	Region	Subregion	District	Relief forming sediments
Russian polygenic plain	III South – Polissia layered accumulative lowland plain	A Volyn Polissia (moraine – outwash and terrace plains)	14 Upper Prypiat alluvial – outwash plain 16 Volyn (Kovel Stolinsky) moraine ridge 17 Turiya denudation plain 18 Kostopil denudation plain	Upper Quarternary alluvial sands, sandy loam, loam, peat (baQ_3). Mid-Quarternary water-glacial sands with gravel and pebbles, sandy loam, loam (f, lgQ_2), glacial boulder sandy loam and loam (gQ_2). Upper Cretaceous marl, chalk, chalk-like limestone with sandstone and silicon sandstone layers (K_2).

30-kilometer zone is located within one region (Ш) of South Polissia layered accumulative lowland plain. All the territory is located within the subregion Ш-А – Volyn Polissia (moraine – outwash and terrace plains).

Main part of 30-kilometer zone is occupied by three regions:

First region. 16 – Volyn (Kovel-Stolinsky) moraine range (northern part),

Second region.17 - Turiya denudation plain (south-western part), Third region.18 - Kostopil denudation plain (south-eastern part), is not large in area territory in the northern part of 30-kilometer zone of SS Rivne NPP , is a part of region 14 - Upper Prypiat alluvial – outwash plain.

Figure 1.1 shows geomorphological zoning of SS Rivne NPP area. This map was prepared by the Institute of Geography National Academy of Science of Ukraine and finalized by the specialist of NT-Engineering.

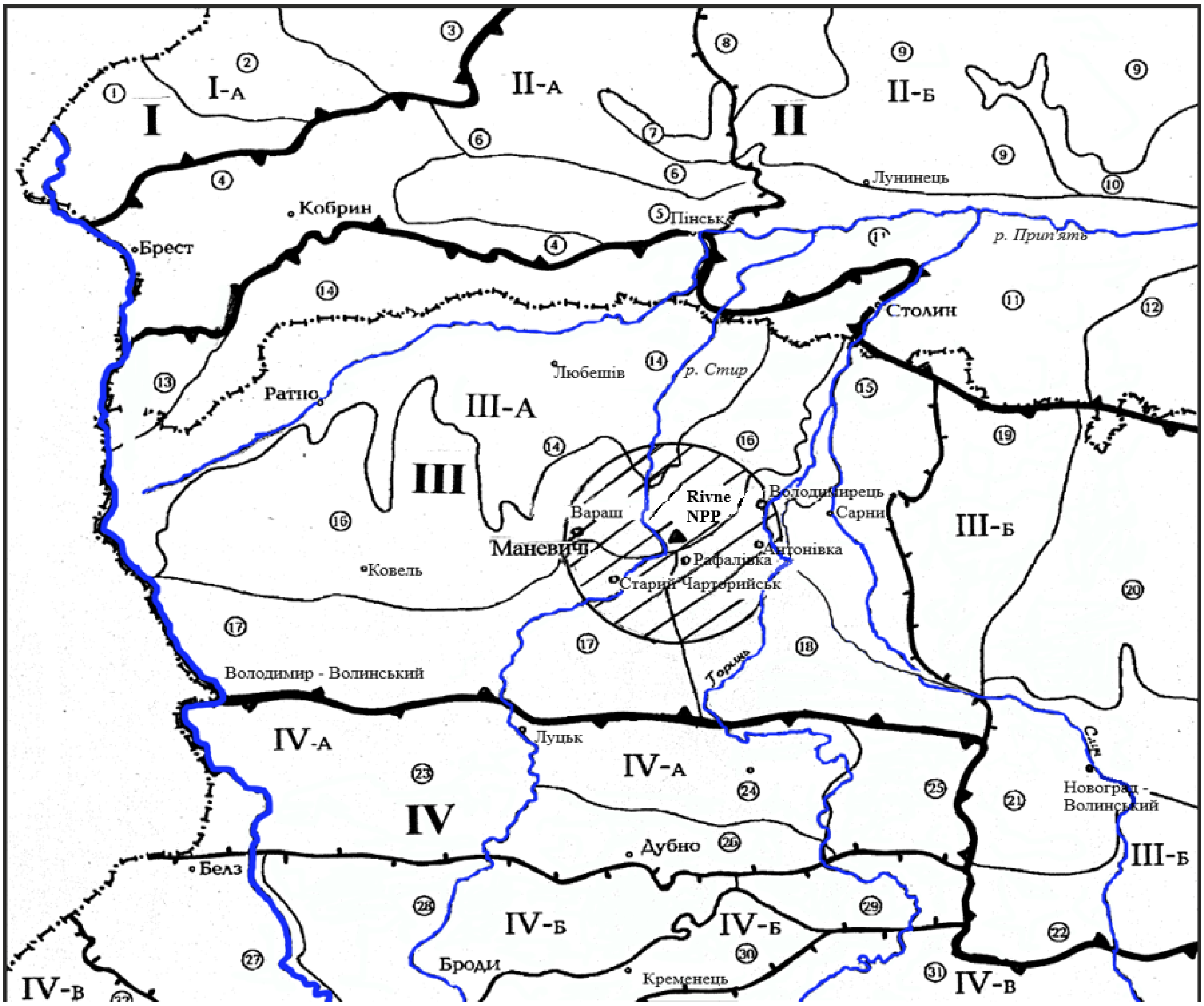


Figure 1.1 Geomorphological zoning of SS Rivne NPP region.

Orographic plan of SS Rivne NPP 30-kilometer zone is characterized by not high relief differentiation in regard of absolute heights. The main relief type is accumulative and denudation.

The main factor defining the relief structure of studied territory is Dnieper Glacier. Glacigenous relief of Volyn Polissia is characterized by the complex structure and high genetic diversity.

Peculiarly moraine plain occupies approximately 20% of the territory. Its largest part extends along the line of Varash – settlement of Rafalivka in the north-east direction. The other parts are found to the west of the Styr river at the distance of 2-4 km, and to the west of Manevychi. Smaller moraine islands are found in the northern part of the territory.

Moraine plain is characterized by average elevations up to 180.00 m, and flat-wagging morphology. It is comprised of main moraine primarily of loamy-sand-boulder composition with thickness of 5.00-7.00 m.

Modern relief distinguishes the forms associated with the marginal zone of the Dnieper Glacier. Volyn finite-moraine ridge is composed of separate hills and ramparts with flattened tops and gentle slopes. Absolute elevations in the number of places reach 200.00 meters and more.

The largest finite-moraine ridges are located in town of Manevychi, near Varash, settlement of Rafalivka, to the south of town of Volodymyrets. Rafalivska ridge is comprised of two parts: the first one is situated on the right bank of the Styr river within the town of Varash. It is assymetrical (steeper slope facing the valley), absolute height is up to 211.00 m. A higher part is situated to the south of Rafalifka, maximum height is 215.50 m, the north-eastern slope is steeper.

Genetically among finite-moraine forms within SS Rivne NPP 30-kilometer zone the dominant are bulk type characterized by the interbedded moraine and flufioglacial deposits.

The most common relief type (over 60% of SS Rivne NPP 30-kilometer zone) is water-glacial plain which looks differently depending on glacier edge location. In the northern part of the territory it is genetically related to inter-ridge outwash. Here the absolute plain elevations vary from 160.00 to 180.00 meters. In the periglacial zone, the water-glacial plain is mostly flat, mostly marshy, genetically represents a valley outwash.

In the northern part of the territory the hilly-depression kame relief is widely developed against the background of a gently undulating water-glacial plain. Kames look like isometric or oval dome-shaped or cone-shaped hills with size from 200.00 - 500.00 m to 1.50 - 2.00 m and height from 1.00 - 2.00 m to 10.00 – 15.00 m, seldom up to 20.00 meters. At some places they form linearly elongated rolling ridges.

To the east of the town of Manevychi the lake-glacial plain is located. It is characterized by a flat marshy relief.

The relief forms associated with the erosive activity of the glacier include glacier depressions and erosion. They are located in the north-western part of SS Rivne NPP 30-kilometer zone. These depressions are partially inherited by modern valleys.

In the postglacial relief forming period the surface of the territory was significantly transformed by fluvioglacial, aeolian, karst and other processes.

Fluvial (accumulative) relief is created by the activity of the Styr river and its tributaries, as well as left tributaries of the Horyn river.

Within SS Rivne NPP 30-kilometer zone the valley of the Styr river to the village of Stary Chortoryisk has the north-eastern direction, from the village of Stary Chortoryisk to the town of Varash – the north-western direction (Volyn ridge penetration area), and downstream the submeridional direction of the valley is maintained. Its width varies in a significant range: near the village of Stary Chortoryisk the Styr river valley is wide (up to 8.00 km and more), and downstream the abrupt narrowing of the valley up to 4.00 – 5.00 km is observed. Down from the village of Stary Chortoryisk there are relative narrowings (to 2.00 km), for example near the town of Varash (Figure 1.2).

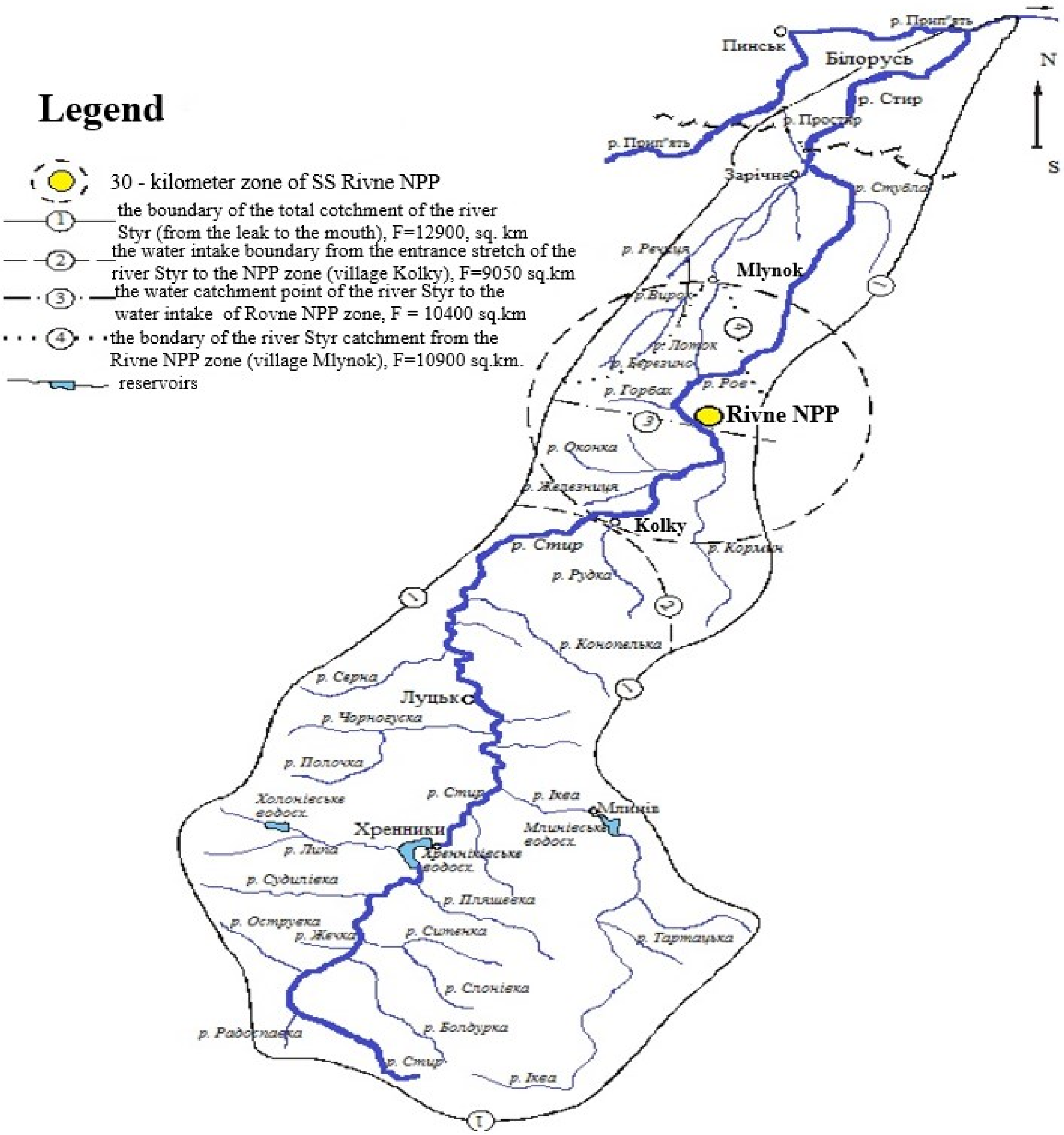


Figure 1.2. Hydrogeographic water intake network of the Styr river and its separate parts

The course of the Styr river has a good fit into the floodplain terrace along almost its entire length (up to 1.00 – 3.00 m). The total length of the river is 494 km, the total intake area is 12 900 km^2. The Styr river enters the 30-kilometer zone at 268 km from the headwater (226 km from estuary) near the settlement of Kolky, and exits the zone at 400 km from the headwater (113 km from estuary) at the village of Mlynok. It means the river flows 113 km across the SS Rivne NPP territory.

The water intake area of the Styr river within the zone is 1850 km^2; the area of the upper water intake (from the headwater to entrance range in the settlement of Kolky) is 9 050 km^2, and the total area from the river headwater to its exit from SS Rivne NPP zone (the village of Mlynok) is 10 900 km^2.

SS Rivne NPP water intake is located at 326.7 km from the Styr river headwater (167.3 km from its estuary) and closes the water intake area of 10 400 km^2 [5].

Within 30-kilometer zone the biggest tributaries of the Styr river are Kormyn, Okonka, Stubla and Zheleznytsa. The rest of the river network is small rivers, first- and second-order tributaries. Water intake areas of the tributaries flowing into the Styr river within SS Rivne NPP zone are almost completely located within the zone.

Morphometric characteristics of the valley, floodplain of the Styr river are changing as moving from the headwater. On the upper course where gully-ravine forms of relief prevail the width of the valley is 1.0 - 1.5 km, on the middle and lower course it increases to 2-4 km. The width of the floodplain increases from 0.3 - 0.7 km in the upper river to 2-3 km in the middle course and up to 4 km in the lower course. The floodplain is meadow, marshy in some areas, in some places crossed by old riverbeds. The marshy areas of the floodplain are in most cases reclaimed. During spring floods the Styr river floodplain is flooded to a depth of 0.20 - 0.50 m. There are cases when the floodplain is flooded by rainfall floods.

The course of the river is winding (at some places very winding) with the depth of 10-20 m in the upper course and 30-60 m in the middle and lower course. In the lower course there are separations which create small islands. Beaches and sand spits are seldom found. Within SS Rivne NPP the width of the Styr river course varies from 30 m at the entrance range to 40-50 km at the river exit from the zone.

The banks of the river are steep, 1-3 m high, composed of sandy-loamy sediments, and are easily destroyed. At some places the banks are overgrown with shrubs.

The depth of the reaches of the river is 1.5-2.0 m (at some places up to 2.8-3.5 m). At the river shoals they reduce to 0.7-1.0 m.

The velocity of current in the course is 0.40-0.50 m/s at medium and low levels; at high levels maximum velocities increase to 2-4 m/s.

River slopes range within 0.15-0.20 ‰.

The surface of the upper water intake area is mostly plowed. Forests occupy small areas on ravine slopes and in the river valleys. Amount of forests increases in the lower basin when river enters the Polissia plain.

The floodplain of the Styr river is 1.00 – 2.00 km wide with narrowings up to 0.10-0.50 km and widenings up to 2.50 km, mostly marshy, with old riverbeds. Down from the town of Varash the low floodplain is peaty. Along the entire length of the floodplain terrace there are uneven erosion remnants of the high floodplain with relative height of 0.50 - 1.50 m. Their surface is undulating with often found Aeolian forms. Floodplain alluvium is represented by fine- and average-grained sands, enriched with gravel and pebble in the lower part; loam prevail in some areas. The thickness of the floodplain alluvium mainly excceeds 10.00 m, reducing on the segment Stary Chortoryisk – Varash to 3.00 – 9.00 m.

The first above floodplain rettace is located on both banks of the Styr river valley, including the left bank to the north from the village of Stary Chortoryisk. Height of the first above floodplain terrace over the water line up to the village of Stary Chortoryisk is 5.00 – 7.00 m, from Stary Chortoryisk to Varash is 7.00 – 9.00 m (SS Rivne NPP is situated here), and downstream it is 3.00 – 5.00 m.

Near SS Rivne NPP site the first above floodplain terrace is located on both banks of the Styr river valley. On the right bank it is represented by the stripes of 0.10 to 1.00 km wide; on the left bank the terrace is wider (up to 0.50 - 1.20 km) and is found in separate areas.

The surface of the terrace is flat, in the rear part it is often swampy, where aeolian and karst forms are often found. The transition from the floodplain is clear. The first terrace was composed of sandy-loamy alluvial deposits.

The structure of the valleys of small rivers, tributaries of the Styr and Horyn rivers, is of a similar type: they are narrow (along the first hundreds meters), trough-shaped with flat marshy bottoms and gentle slopes. Floodplains are poorly expressed in relief, often covered with peat bogs. At some places the floodplains are of 0.50 - 2.50 km wide with thin alluvium (1.50 m). Fragments of the first above floodplain terrace are mapped only in lowlands of some rivers. The cources of the rivers are canalized, an extensive network of drainage channels is laid in the valleys.

The lake type of relief is mainly found in the northern part of the territory of SS Rivne NPP 30-kilometer zone. The lakes are of round or oval shape. They were formed as a result of make-up by the glacier melt water and by filling of thermokarst depressions with water. The largest lake in the area, the Lake Bile, has karst-glacial genesis.

The Lake Bile is the largest lake on the territory of SS Rivne NPP 30-kilometer zone, it is located 18 km to NNW from SS Rivne NPP . It has an oval shape extending in the east-west direction (Figure 1.3). The lake is 1.5-2.0 km wide and 2.5 km long, average depth is 9.6 m, maximum depth is 23 m. The water surface area is 4.11 km^2, the volume of water in the lake is 40 millon m^3, water intake area of the lake is 85 km^2.

The lake is surrounded by forests and swamps from all sides. In the southern and eastern parts of the lake marsh comes almost to the water line, in the northern part the river bank height is 0.3-0.5 m.

It is a flow-through lake. In the eastern and south-eastern parts of the lake a reclamation canal and a small stream flow from the lake and run into the Lotok river, in the southern part a stream flows into the lake. Both streams and a canal flow through the marshy floodplain that is why they are not distinguishly seen. The width of the canals and streams is about 1 m, the depth is from 0.10 to 0.40 m. Due to the outflow of water from the lake to the Lotok river the constant water level in the Lake Bile is maintained.

The bottom of the lake is sandy, in some places peaty. The coastal zone to a depth of 1.0-1.5 m is almost everywhere overgrown with reeds, and at depths of 2-3 m there is a floating type of algae.

Aeolian relief forms play a rather big role in the creation of the morphological structure of the territory. There are dunes, ridges, hillocks, sometimes dunes merge together forming dam-like forms. The relative heights of the eolian relief forms range from 1.00 - 3.00 m to 10.00 - 12.00 m, width 50.00 - 200.00 m, less often 500.00 m.

Bogs and wetlands are extremely widespread in all geomorphological elements, with the exception of the moraine plain. Bogs are mostly of lowland type. The processes of bog formation are developing at the present time, although the territory is largely reclaimed.

Karst relief is widely spread due to the presence in the geological section of the marl-Cretaceous rocks capable of karsting lying shallow from the surface. Creation of karst relief forms is connected with the activity of ground and surface water. Besides, the most important condition of karst occurrence is the neotectonic factor, that is why the underground and surface karst forms are often associated with lines of tectonic deformations active in the Quaternary (including Holocene) time. In the intersection points of these deformations the major amount of karst relief forms are often concentrated.

The surface karst forms are represented by sinkholes with the diameter up to 100.00 m and depressions (size 100.00 - 300.00 m). The bottoms of karst forms are flat or weakly bend, marshy or filled with water. The slopes are smooth so they are not clearly distinguished in relief. There are areas where karst form density is high. Such areas are found in the region of Varash. Some lake basins are of karst origin (the Lake Bile). Most marshlands have karst make-up.

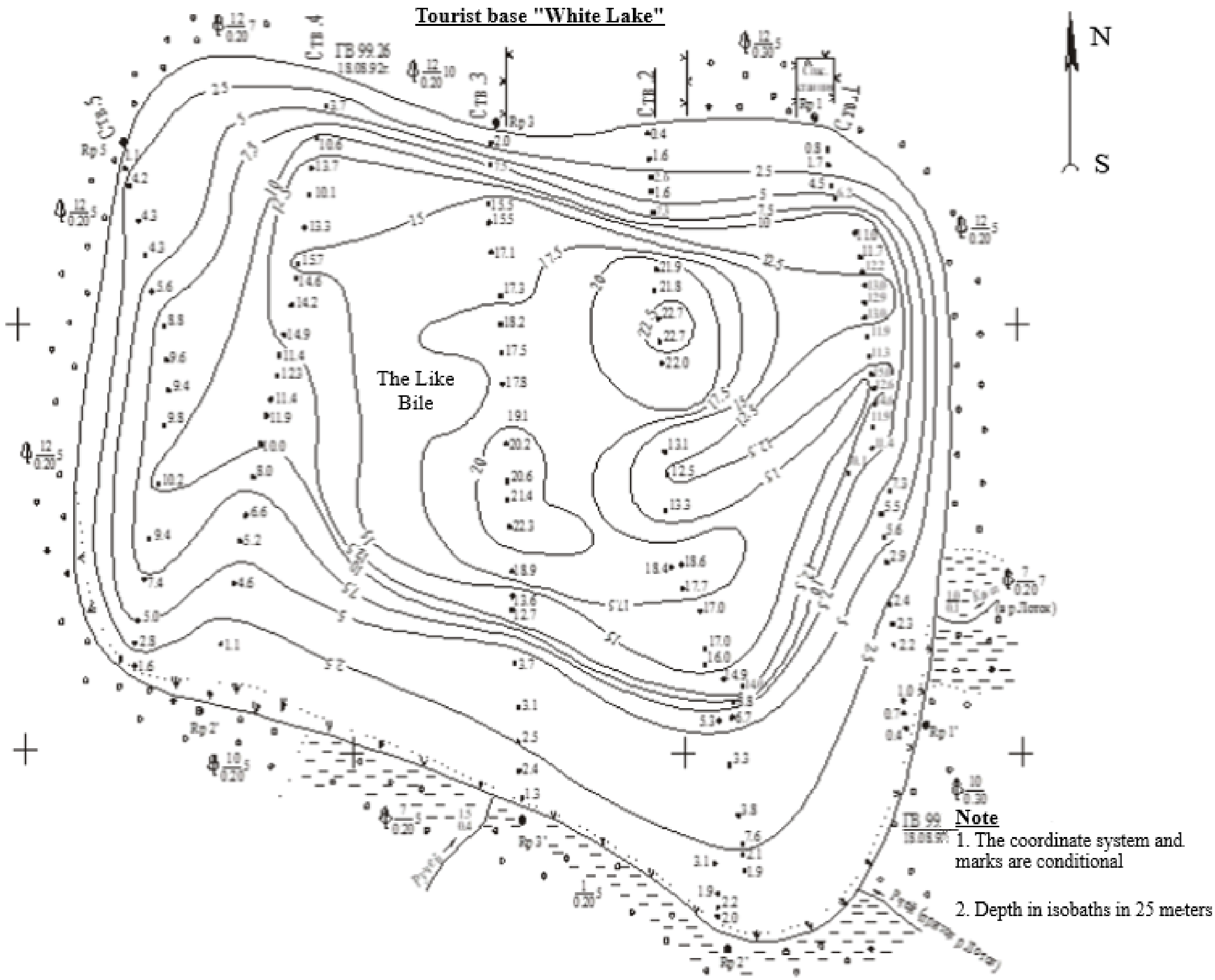


Figure 1.3 The Lake Bile

The antropogenic relief in 30-kilometer zone of SS Rivne NPP is characterized by insignificant development due to:

- absence of large industrial-urban agglomerations (there are four settlements and the town of Varash on the territory);
- presence of one section of large railway (section Antonivka – Manevychi);
- presence of one section of highway (section parallel to the railway);
- limited development of mining and agricultural processes of anthropogenic morphogenesis.

The predominant forms of man-made relief are ditches, canals, artificial reservoirs, dams, ramparts, excavations and embankments, reclamation systems in the basins of the Styr, Horyn rivers and their tributaries are extensively developed.

1.2 Geological structure of SS Rivne NPP 30-kilometer zone

Geological structure of SS Rivne NPP 30-kilometer zone is defined by wide secular range and structure, from loose deposits of Quaternary age to crystalline rocks of the East European Platform foundations of Archaean-Proterozoic age [6-11].

The crystalline base is composed of granites, granodiorite, gabbro-diorites of the Osnytsky intrusive complex ($\gamma\delta PR_{2os}$); gabbro and leptite gneisses, andesitic porphyrites, amphibolites of the Kless series (PR_{2kl}). The depth of the crystalline basement surface within SS Rivne NPP 30-km zone varies from 50.00 m in the north-east to 1200.00 m in the south-west.

The sedimentation formation is represented by middle, upper Proterozoic, and Mesozoic-Cenozoic deposits. The sedimentary cover is composed by three main structural layers:

- Mid-Upper-Riphean (Upper Proterozoic), composed of of sandstones, siltstones and argillites of the Polissia series;
- Upper Proterozoic (Vendian) - Lower Paleozoic, represented by volcanic-sedimentary terrigenous and carbonate formations;
- Meso-Cenozoic, covering all the underlying rocks and composed of terrigenous, carbonate and continental formations.

Below is a description of the geological cross section (bottom-upwards) of sedimentary cover.

Riphean formations of the Polissia series

Riphean formations of the Polissia series (R_{2-3}) of Upper Proterozoic (PR_2) include strata of Romeikian, Pilskian, and Zherbin suites.

Romeikian suite deposits (R_{2rm}) are mainly composed by sandstones, packsand, mainly by bright coloured aleurolite and argillite with lenses and layers of sandstone, gravelite. The thickness of Romeikian suite deposits is 264.00 m.

Pilskian suite (R_{2-3pc}) is represented by packsand, mainly by argillite with lenses and patches of sandstone; its thickness is 60.00-112.00 m.

Zherbin suite ($R_{3\,žb}$), the final section of the Polissia series, is composed by three sub-siuts - lower, middle, upper. All three sub-siuts are composed of packsand, at the base of each are interbedding of argillites and siltstones. The thickess of the Zhebrin suite deposit is 235.00 - 330.00 m.

Vendian Proterozoic system

Vendian Proterozoic system (V, synonym PR_2). Vend deposits are made up (from the bottom up) with the deposits of the Volyn, the Mogilev-Podolsky Kanyliv series.

The Volyn series includes:

- Brodovska suite (V_{1br}) - interlaying of siltstone and argillite with scattered sand and gravel material. The thickness of deposits is 0.00-37.00 m;
- Horbashivska suite (V_{1grb}) – red consertal sandstone, with gravel and pebble material. The thickness is 20.00-66.00 m;
- Berestovetska suite (PR_{2br}), includes basalt streams separated by tuff. According to the last Geochonological scheme instead of Berestovetska suite three following siutes can be distinguished:

- Zabolotivska suite (V_{1zb}) – is represented by one or several basalt streams separated by thin layers of tuffits, fine chipped tuffs. The basalts are of massive or amygdaloidal type. The thickness of the suite is 0.00-16.00 m;

- Babynska suite (V_{1bb}) –differently chipped basalt tuffs. The thickness of the suite is 90.00-120.00 m;

- Ratnenska suite (V_{1rt}) – basalts, lava-breccia and tuff-breccia of basalt composition, tuffs. The main role in the structure of the suite belongs to basalt streams. The thickness of the suite is 159.00 m.

The composition of Mohyliv-Podilsky series includes:

- Chartoryisk suite ($V_{2čr}$), which is divided into two sub-suits: uppwe and lower. The lower sub-suit is structured unevenly, interlayed by volcanomictic aleorulites and sandstone, less often gravelites; the upper sub-suite is composed by argillites, aleorulites and consertal sandstone, interlaying with each other. The thickness of the lower sub-suite is 24.00-47.00 m, the upper sub-suite – 36.00-45.00 m;

- Roznytska suite (V_{2rz}) is represented by rhytmically interlayed aleorulites, argillites, sandstone, gravelites. The thickness of these deposits is 24.00-35.00 m, not widely spread;

- Kolkivska suite (V_{2kl}) is represented by upper- and lower kolkivska sub-suite. The lower sub-suite is composed by sandstone, gravelites with aleorulite layers; thickness is 33.00 m. The upper sub-suite is composed by bright coloured, mica, foliated argillites, the thickness is 40.00 m.

Kanylivska series (V_{2kn}) includes two masses:

- Lower – interlaying of argillites, aleorulites, sandstone. The thickness of the mass is 20.00 m;
- Upper – has the similar structure. The thickness of the mass is 80.00-100.00 m.

Paleozoic Erathem deposits

Paleozoic deposits include the formations of the Cambrian and Silurian systems.

Cambrian system formations are represented by the strata of Baltic and Berezhkovska series. The Baltic series includes Rivnenska ($Є_{1rv}$) and Stokhodska ($Є_{1st}$) suites comprised of argillites, aleorulites and glauconite-quartz sandstones. The thickness of deposits of the Rivnenska suite is 2.00-25.00 m, of the Stokhodska suite is 100.00-110.00 m.

Berezhkovska series is represented by the strata of Dominopol suite ($Є_{1dm}$) – quartz sandstones 1.00-30.00 m thick.

The Silurian deposits are made of the strata of the Yarutska series, including the Furmanivska (S_{1fr}) and Ternovska (S_{1tr}) suites. The Furmanivska suite is represented by marls, limestone argillites, aleurolites approximately 10.00 m thick.

Ternivska is represented by limestones; in the lowlands there are clayed limestones. The thickness is up to 70.00 m.

Mesozoic deposits occur higher

In the north-east and east of SS ‘Rivne NPP” 30-kilometer zone, the rocks of the Polissia series come out under the pre-Mesozoic surface, more rarely, the Osnytsky complex rocks. In the central part within the territory of 5.00 km radius from SS Rivne NPP Vendian formations are mapped at the level of this cross section, in the south-west of the 30-kilometer zone there are Lower Paleozoic carbonate sediments. At the contact points of the Riphean-Vendian formations, numerous intrusive layers of gabbro-dolerite of the Vendian intrusive complex can be traced, deepening to the south-west along the general monoclinal folding of the cover.

Mesozoic Erathem Deposits

Deposits of the Cretaceous system (K), represented by the formations of the Albian low Cretaceous (K1), Cenomanian, Turonian and Coniacian stages of the Upper Cretaceous (K2), lie on the eroded surface of pre-Mesozoic formations with stratigraphic and angular mismatch; they include the Volodymyretsky suite, a layer of Inoceram limestone and the Zdolbunivska suite.

Volodymyretska suite is represented by lower and upper sub-suites.

The lower sub-siuite of the Volodymyretska suite (K_{1vl1}) belongs to Albian stage. It is composed of sand, consertal sandstone, chalcedonoliths, detrital limestone. The thickness varies from 2.00 m (in the east) to 200.00 m (in the west).

The upper sub-suite of the Volodymyretska suite (K_{2vl2}) belongs to Lower-Senomanian substage. It is composed of siliceous sandstone, glauconite-quartz sand with granular phosphorite. At the base of sandstones there are massive conglomerates, consisting of pebbles of different composition, cemented by lime-clay-sand cement. The thickness of these deposits is 31.00 m.

The layer of Inoceram limestone (K_{2i}) belongs to the Upper-Senomanian substage; in composition, these are limestones with inoceram shells, glauconite, phosphate; the thickness ranges from 0.00 to 46.00 m.

Deposits of Turonian and Coniacian stages are integrated into Zdolbunivska suite.

Zdolbunivska suite (K_{2zd}) is represented by the lower and upper sub-suites:

- The lower (Turonian stage) – chalky marls, chalk with rare silica nodules;
- The upper (Coniacian stage) – writing chalk with silica fagments and nodules.

The thickness of the lower sub-suite is up to 173.00 m, the upper sub-suite is from 0.00 to 32.00 m.

Suffosion-karst processes take place in the rocks of the Turonian and Coniacian stages.

Cenozoic erathem deposits

Upward the cross section the deposits of the Paleogene system (P) lie, they are represented by the middle (Eocene) and upper (Oligocene) sections.

Eocene (P2):

- Buchakska series ($P_{2b\check{c}}$) - stratum of dark gray clays with pebbles of quartz, silica, thickness is from 0.00 to 30.00 m;

- Kyiv suite –clays, marls, the thickness is from 0 to 9.00 m;

- Kharkiv series (P_{2hr}, earlier referred to the Oligocene and had index P_{3hr}); includes Obukhivska suite (P_{2ob}) – sands, glauconite-quartz aleorulite; the thickness is from 1.00 to 35.00 m, average is 7.00 – 15.00 m.

Oligocene (P3):

- Poltavska series, which includes Berekska suite (P_{3br}) – clays, lignite, aleorulite, sands; the thickness is from 0.00 to 40.00 m (earlier these deposits belonged to the Neogene).

Quaternary deposits

The deposits described above are overlapped by Quaternary formations (from the lower to the modern Quaternary) of various genesis: alluvial (a), lake-alluvial (la), fluvioglacial (f), glacial (g), lake-marsh (lb), marsh (b), eolian-deluvial ((vd), eolian (v), proluvial (pr).

The lower Quaternary deposits (Q_{1ok}) survived from further erosion only in the ancient river valleys, basins of the glacial plucking. According to the genesis, these are alluvial and lake-alluvial formations, moraine and fluvioglacial (water-glacial) deposits of the oldest in the considered Oka glaciation. According to the lithological composition it consists of sand, gravel-sandy soil, sandy loam and loam, aleorulite, peat lenses, as well as pebbly-gravel-sandy, clayey and carbonate moraine.

The middle Quaternary deposits (Q_{2dn}) are represented by fluvioglacial (glacial-water) and glacial (glacial) deposits of the Dnieper glaciation. Lithologic water-glacial deposits are sands; glacial (moraine) deposits are alternations of sand, clay, sand and pebble material.

The upper Quaternary deposits (Q_3) are represented by alluvial deposits of floodplain terraces of the Styr river and its tributaries - sands of various sizes, sandy loams and loams.

Undifferentiated Upper Quaternary and modern deposits (Q_{3-4}) are aeolian and eolian-diluvial formations on outwash plains, represented by fine and silty sands.

Modern Quaternary deposits (Q_4) are represented by alluvial deposits of floodplain terraces of rivers and modern watercourses - sand, sandy loam and loam, as well as marsh sediments on the swamp massifs in-between rivers, and in river valleys - peat, mud, black muck (lake-marsh muck).

1.3 Structural-tectonic structure of SS Rivne NPP region

Structural-tectonic structure of SS Rivne NPP 30-kilometer zone belongs to Polissia geoblock (Figure 1.4) [12]. The structure of order II is the Manevytsky block, within which the main part of SS Rivne NPP 30-kilometer zone is located.

The territory of SS Rivne NPP 20-kilometer zone is divided by the series of tectonic deformations of the northeastern and sublatitudinal extension.

I range faults include Lutsk (Horyn) through-crust tectonic zone in the south-east of the 30-kilometer zone 20.00 km from SS Rivne NPP site. The zone is about 20.00 km wide, falling from the sub-vertical to 600 south-east direction. Within the zone, a stepwise displacement of crystalline rocks of the basement and the boundaries of the volcanogenic-sedimentary cover along a series of tectonic deformations with an amplitude of 150.00 - 200.00 m is observed.

Other large and extended faults and tectonic zones of the mantle deposit (I rank) within the 30-km zone of SS Rivne NPP were not identified.

Among faults of the II order (inner crust), based on geological and geophysical data, sublatitudinal tectonic zones - Belska and Chortoryisk, as well as Sarny-Varvarivska of the northwestern extension are mapped.

The Belska sublatitudinal fault zone is found in the northern part of the territory at a distance of 17.00 km from NPP spreading over 54.00 km, which means, it crosses the entire 30-km zone from the west to the east. Belska zone is a series of contiguous discharges from 0.50 to 3.50 km wide, along which the southern wing is lowered to 50.00–350.00 m. The fall of the zone is subvertical or southern with angles of 750–800. The depth of zone is 3.00 - 5.00 km. The entire zone is characterized by the presence of landslide deformations.

The Chortoryisk fault zone is found in the central part of the 30-km zone of SS Rivne NPP (5.00 km south of the NPP), from the western border of the territory to the intersection with the Lutsk (Horyn) tectonic zone. The width of the zone is from 2.00 to 0.50 km, the falling of the displacer is close to vertical. The depth is up to 5.00 km.

In geological terms, this fracture zone is characterized by the presence of graben-like structures of sublatitudinal extension; sliding deformations are not specific for this zone.

The Sarny-Varvarovsky fault of the north-west extension is found in the northern and north-eastern part of the territory of SS Rivne NPP 30-km zone. It is an integral part of the deep Central fault zone. The zone is spread to 50.00 km with the width of 8.00 km and is composed of a series of contiguous subparallel tectonic deformations. Sarny-Varvarovska fault zone is a weakly defined stretch zone, serves as the boundary between the blocks of predominant compression and stretching.

All other tectonic deformations identified within 30-kilometer zone are of a smaller order; they are characterized as a rule by insignificant vertical displacement amplitudes, small extent and width, have different directions of extension. This indicates that the deformations are intra-block. Most of the deformations occur in sediments of volcanogenic-sedimentary Vendian strata, which gradually fades away with depth. A part of intrablock deformations is associated with the mass of the crystalline basement, and in the upper layers it occurs slightly - in the form of zones of increased fracturing, flexure bends, facial replacement of some sediments with others within the same age range.

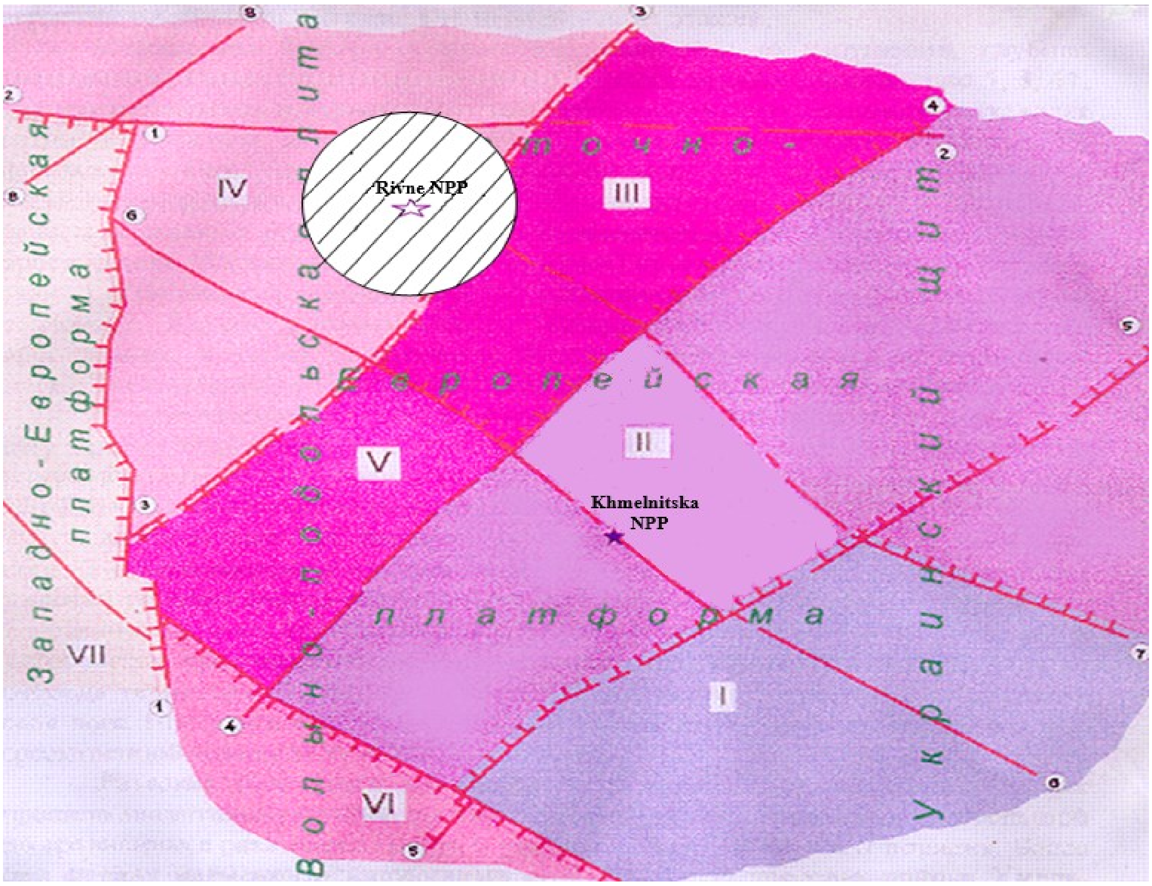
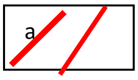


Figure 1.4 Scheme of block structure of SS Rivne NPP region

Scale 1:2 000 000

Legend



Tectonic deformations:

a - tectonic wedges separating structural-formation zones and megablocks;
б – other deep faults.
1 – Radekhivsky, 2 – Pivdenno-Ratnivsky, 3 – Lutsky, 4 – Kremenetsko-Perzhansky, 5 – Teterivsky, 6 – Khmelnytsky, 7 – Tsentralny, 8 – Minsko-Vyzhivsky

I

Megablocks of the earth's crust: I – Podilsky, II – Ternopilsko-Novohrad-Volynsky, III – Osnytsky, IV – Polisky, V – Dubnovsky, VI – Prydnistrovsky, VII – Lvivsky

Note. The drawing is made by the State Regional Geological Enterprise "Pivnichgeologiia"
State Committee on Geology and Subsoil Use of Ukraine

1.3.1 Neo-tectonic conditions

SS Rivne NPP 30-kilometer zone is located in the north-eastern part of regional structure – the Polsko-Podilske elevation; the western border is Rivne saddle (along the Horyn river), which is also a regional structure.

Subregional structure (i.e. structure one rank lower) within the Polsko-Podilske elevation is Volynsko-Poliska homocline; SS Rivne NPP 30-kilometer zone is located in its eastern part. Two stages are distinguished here:

- Verkhnioprypiatska (north-eastern and central part of SS Rivne NPP 30-kilometer zone);
- Kostopilska (south-eastern part of the zone). The border between the stages of north-western – north-eastern extension, nearly parallel to the Styr river course, is at the distance of approximately 10.00 km from the Styr river.

Neotectonic situation is relatively calm. The 30-km zone of SS Rivne NPP is located in the zone of moderate and relatively weak neotectonic uplifts, the indicators of the total amplitudes of which do not exceed 225.00 m.

In the general non-structural plan within the 30-kilometer zone of SS Rivne NPP a number of isometric block structures of different sizes is distinguished, which are characterized by weak differences in the indicators of the total amplitudes of neotectonic movements (Figure 1.5).

The maximum average values of the total amplitudes of the neotectonic movements of the Earth's crust during the Oligocene-Anthropogenic period are traced within the Manevichsky (225.00 m), Prylisnensky (220.00 m), Chartoryisky (220.00 m), Chapelsky (225.00 m), Osnytsky (220.00 m) and Kopylovsky (220.00 m) blocks [4].

The minimum values of the average indicators of the total amplitudes of the earth's crust neotectonic movements over the Oligocene - Anthropogenic period are traced in the northern part of the 30-kilometer area of SS Rivne NPP within Belsky (195.00 m), Bilsko-Volsky (190.00 m), Zelenivsky (185.00 m), Voronkivsky (185.00 m), Sopachivsky (195.00 m) blocks.

The difference in the total amplitudes of neotectonic movements values in adjacent blocks in the vast majority of cases is insignificant.

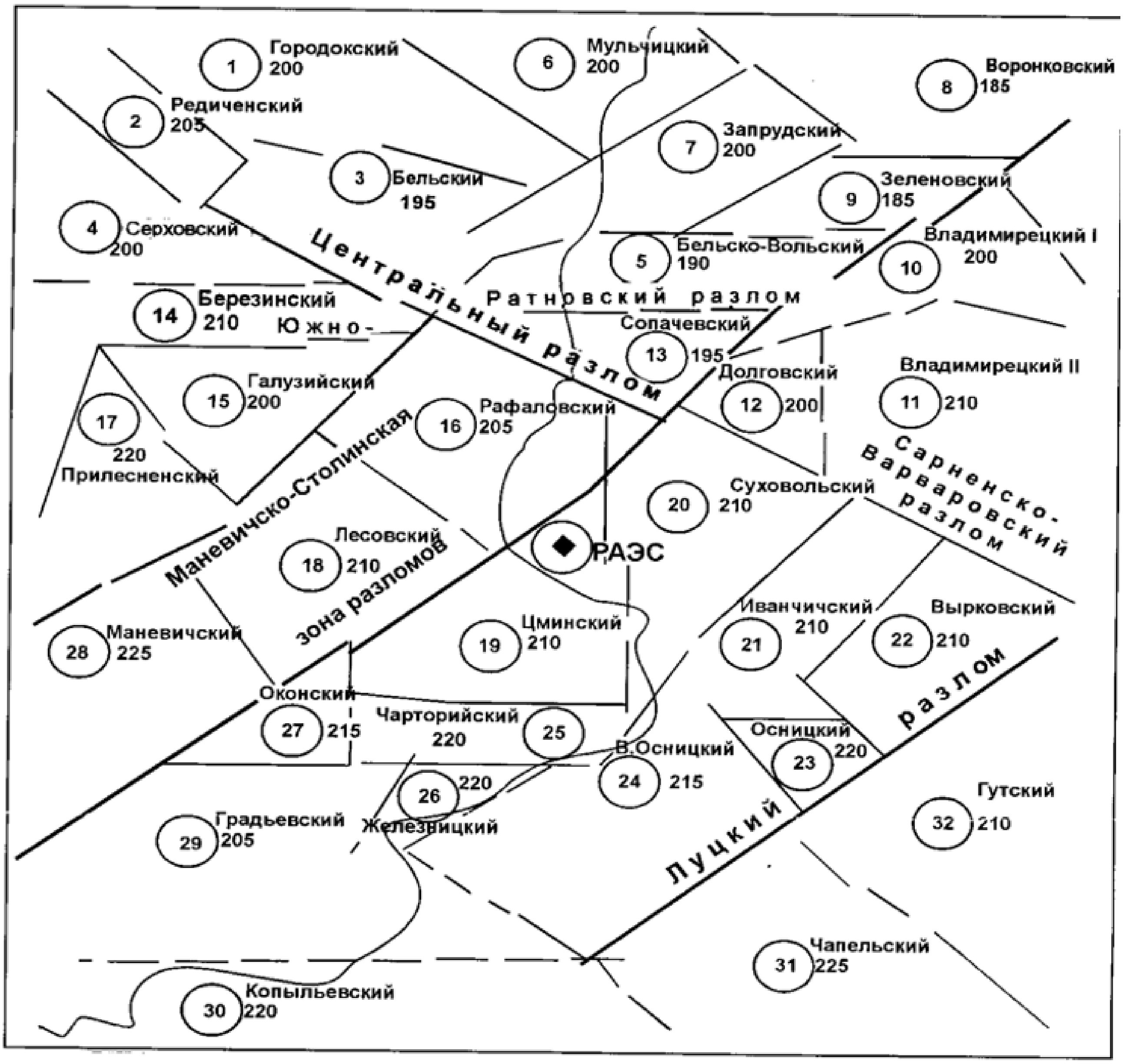


Figure 1.5. Scheme of location of fault-block structures of SS Rivne NPP 30-kilometer zone

1 – block number; 2- average indicator of the total amplitudes of the neotectonic movements of the Earth's crust; 3 – neotectonic active faults

Blocks:
1- Horodoksky, 2 – Redychensky, 3 – Bilsky, 4 – Serkhovsky, 5- Bilsko-Volsky, 6- Mulchytsky; 7- Zaprudsky, 8 – Voronkivsky, 9- Zelenivsky, 10 – Volodymyretsky, 11 – Volodymyretsky II, 12- Dolhivsky, 13 – Sopachivsky, 14 – Berezynsky, 15 – Haluziisky, 16 – Rafalivsky, 17 – Prylisnensky, 18 – Lisovsky, 19 – Tsmynsky, 20 – Sukhovolsky, 21 – Ivanchytsky, 22- Vyrkivsky, 23 – Osnytsky, 24 – V. Osnytsky, 25 – Chartoryisky, 26 – Zheleznytsky, 27 – Okonsky, 28 – Manevytsky, 29 – Hradivsky, 30 – Kopylivsky, 31 – Chapelsky, 32 – Hutsky.

The drawing is made by the Institute of Geography of National Academy of Science of Ukraine

An analysis of the relief formed in the Quaternary period suggests that the movements of the earth's crust taken place on the territory of Volyn Polissia as a whole and in the 30-km zone of SS Rivne NPP in particular were of low amplitude and also were poorly differentiated in space.

Fault deformations of the sub-latitudinal extension within the 30-km zone of the SS Rivne NPP are represented by fragments of the Ratnivska fault zone, the diagonal of Manevytsko-Stolinska zone, the Lutsk and Sarnensko-Varvarivski faults (the north-western end in the Central Fault Zone system).

The following is a description of deformations from the perspective of the possible display of their neotectonic activity.

The Manevytsko-Stolinska zone within the 30-kilometer zone of SS Rivne NPP has a width of up to 10.00 km, expands to 12.00 - 13.00 km in the area of the villages of Stara Rafalivka and Sopachiv and narrows to 5.00 km in the area of villages Zemne, Krasnosillia. The maximum indicators of the neotectonic movements of the earth's crust are observed within the Manevytsky block (225.00 m) and reach a minimum (185.00 m) within the Voronkivsky block.

The zone of the Central Fault is represented on the territory of the 30-kilometer zone of SS Rivne NPP by its south-western branch (Sarnensko-Varvarivsky Fault). The Sarnensko-Varvarivsky Fault separates blocks with neotectonic movement amplitude difference of 5.00 - 10.00 m.

The Ratnivska fault zone within the studied zone is represented by Belsky deformation and a subparallel system of sublatitudinal disturbances, which separate small blocks-stages (Berezynsky, Belsko-Volsky, Volodymyretsky, Zelenivsky) with a difference in indicators of total amplitudes of 5.00 - 10.00 m.

At the intersection of Ratnivska, Manevytsko-Stolinska and Central fault zones (villages Belska Volia, Krasnosillia), there is a higher degree of fragmentation of the structures and the presence of a significant number of minor deformations of various extension.

Among the smaller faults, that can be found within the 30-kilometer zone of SS Rivne NPP , with varying degrees of probability we can talk about the occurrence of weak neotectonic activations by the submeridional fault, along which the Styr river flows, by the sublatitudinal Okonsky and Osnitsky faults.

Faults within the 30-km zone of SS Rivne NPP belong to the amplitude-free and low-amplitude, weakly active category; in this regard, the neotectonic movements during the operation of the SS Rivne NPP shall not be expected.

1.3.2 Geomorphological conditions of SS Rivne NPP site location

SS Rivne NPP power units and site are located on the territory of Volyn Polissia, in its southern part, in the middle course of the Styr river, right tributary of the Prypiat river [13, 14].

The Geomorphological conditions are defined by the character of the Styr river valley and its right bank watershed.

SS Rivne NPP power units and site are located on the right bank of the Styr river which limits the territory from the south and the west. The flow is changed twice here under an anhle of 90°, direction is SW then EW (NPP site is located in this winding bend) and then SN (town of Varash is adjacent to this part of the river course). The river is meandering and has numerous old riverbeds and sleeves.

The banks are low, at many places marshy. In this area, the valley is asymmetric, the left bank part of the floodplain is much wider than the right bank. In the structure of the right bank of the Styr river valley the floodplain and the first above floodplain terrace are distinguished; the watershed is complicated by a finite-moraine ridge.

The right bank floodplain stretches along the river course, the width varies from 50.00 m to 2.00 km. Absolute elevations within the floodplain range from 159.70 to 162.00 m. The surface is uneven, complicated by old riverbeds and depressions filled with water, thickly overgrown with meadow vegetation, at some places with shrubs.

In spring the floodplain is flooded with flood waters. The maximum water level during a flood of 1% occurrence is 163.70 m according to hydrological calculations. The boundary of the floodplain and the floodplain terrace is expressed by a ledge of 2.00 meters or more in height, which is not everywhere visible in relief.

The first above floodplain terraces of the Stir river valley stands out quite clearly in relief, the width is from 300.00 m to 1.00 km. The absolute elevations of the surface within the above floodplain terrace range from 162.00 to 170.00 m. The surface is flat, there is a gradual increase in the surface towards the watershed. The transition from the first above floodplain terrace to the watershed is clearly expressed in the relief within the northern part of the territory of the town of Varash, in some areas the transition is gradual.

The territory of SS Rivne NPP is crossed by the Rafalivska finite-moraine ridge. On the territory of the town of Varash it has a meridional direction (parallel to the Stir river course), its width here is 300.00 - 600.00 m, the maximum elevation is 182.00 m. The ridge is distinguished clearly in the relief; the western slope is steep, the eastern slope is gentle, the relief elevations decrease to the east to 167.50 m. To the north of Varash the northern edge of the ridge is observed, to the south of Varash the ridge turns east and extends further to approximately west-east and passes in the northern part of NPP site (the latitudinal direction). Due to the fact that at present the territory of NPP site is planned, the natural relief can be characterized only on the basis of the analysis of the topographic maps before the start of construction. In addition to the Rafalivska finite-moraine ridge, several other small ridges are found here, mainly of the latitudinal direction.

1.3.3 Geological structure

The geological structure under SS Rivne NPP is composed of a thick strata of sedimentary, metamorphized and volcanogenic rocks lying on a crystalline basement [14-21]. According to the geophysical data, the structure of the basement involves metamorphic and intrusive rocks of an acidic, basic and ultrabasic composition. The surface of the foundation sinks stepwise to the south-west, lying at depths of about 1000.00 m.

The strata of the platform cover consists of Upper Proterozoic, Mesozoic, and Cenozoic deposits. When describing the geological cross section of SS Rivne NPP, we will consider in more detail the rocks that form the active zone of SS Rivne NPP structures and infrastructure, i.e. the Berestovetska suite deposits, and lie above the Mesozoic and Cenozoic deposits, which are studied in detail within SS Rivne NPP location point.

Berestovetska suite (PR_{2br}) - the complex volcanic mass of the traprock formation, including the molded and pyroclastic rocks. The suite consists of several basalt streams separated by tuff packs. Basalt streams consist of massive, adelogenic basalts, and also lava-breccias. Tuff packs consist of tuff of different granulometric composition - from fine-grained to coarse-grained (lapilli) tuffs, tuff-breccia, less often slag-breccia. The thickness of the rocks of the Berestovetska suite is mainly 100.00 - 200.00 m; at the same time, the thickness of individual lithological varieties are dramatically changing. The Upper Proterozoic deposits revealed on the territory of SS Rivne NPP (basalts, tuffs) by age are related to the rocks of the Berestovetska suite. In general, the Berestovetska Suite rocks are characterized by a sharp differentiation of thickness and composition, even in a limited area; the position of its cover determined the nature of the occurrence of the Meso-Cenozoic rocks overlying it. The depth of the cover of these deposits is mainly 40-50 m.

Mesozoic deposits are represented by the upper section of the Cretaceous system and are widespread. They are laying on the Pre-Mesozoic rocks. Lithologically, they are repersented by the basal conglomerate of the Lower Senomanian (K_{2c1}) and the homogeneous Cretaceous stratum of the Turonian stage (K2t) which is karsted; deposits of the Lower Senomanian have an island distribution, thickness is insignificant (less than 1.00 m).

The rocks of the Turonian satge (synonym - Nyzhniozdolbunivska suite) are represented by chalk with thin layers of organogenic detrital limestone and inclusions of siliceous concretions. The thickness of the Upper Cretaceous rocks varies considerably: from a few meters in the valley of the Styr river up to 15.00 - 20.00 m at the watershed. In the immediate proximity to the north from SS Rivne NPP considered deposits are absent. Thickness variations are the result of tectonic factors. The thickness of the Turonian stage was caused by the following intensive block tectonic movements, which resulted in numerous fractured zones. The karsted stratum.

The surface of the Cretaceous rocks is uneven, strongly denudated, hilly, often eroded and karsted. In the relief of the Upper Cretaceous deposits cover, there are oval depressions, perhaps, karst-erosion.

The ruggedness of the Upper Cretaceous rocks relief led to different thickness of Paleogene and Quaternary deposits that overlap them.

The Paleogene deposits are not found throughout the site. They belong to the Kharkivska suite of the Oligocene (P_{3hr}). According to the latest geochronological scale, this is the Obukhivska suite of the Eocene. The deposits of the Kharkivska suite are represented by green quartz-glauconitic sandy loams and sands, sometimes by loams or clays. Their thickness varies from 1.00 to 7.00 m. They are spread in the central and eastern part of the point, and are not found in the rest of the territory.

Quaternary deposits are widespread everywhere, different in age, genetic and lithological terms.

Mid-Quaternary, undifferentiated fluvioglacial and end-moraine deposits (fgQ_{2dn}); Upper Quaternary alluvial deposits of the first above floodplain terrace of the Styr river (aQ_3) valley; modern Quaternary alluvial floodplain deposits ($_aQ_4$); Modern Quaternary bog($bQ4$) and man-made ($tQ4$) deposits are found at the point.

In the geological cross section of fluvioglacial and end-moraine formations in the northern, central and eastern parts of the site the clayey soils predominate (mainly sandy loam), in the western part sands with interlayers of clay soils predominate. Alluvial deposits are represented mainly by sand with thin layers and lenses of clay soils.

The thickness of the Quaternary deposits is different and depends both on the hypsometric position of a particular point and on the nature of the cover of the Upper Cretaceous deposits; the thickness varies from 5.00 to 40.00 m, while at SS Rivne NPP site it is about 15.00 - 20.00 m, at the site of Varash it varies from several meters to 30.00 meters or more; to the north of the site is from 5.00 to 20.00 m.

Different thickness of the cover (Quaternary and Paleogene deposits) is caused by the lowering of the cover of Upper Cretaceous deposits. Due to the relatively high water penetrability of the cover rocks, it is possible for the infiltrating waters to actively enter fractured, previously karsted zones in Cretaceous deposits.

1.3.4 Soils composition, state and properties of soils

Within SS Rivne NPP site a system of tectonic deformations of various order and extension is traced.

In the southern part of the site, the Chartoryisky Fault zone extends approximately in the latitudinal direction.

The rest of the tectonic faults are classified as follows:

- linear tectonically weakened zones of increased fracturing. The most significant is extended to the south-south-east-north, it crosses the central part of the site and runs 1.00 km to the east of SS Rivne NPP; it is established by a complex of geophysical methods and is reflected in the surface relief of the Ratnenska (Berestovetska) suite, confirmed by drilling;
- arc tectonic zones forming subsidence structures. The known structure (i.e., confirmed by a complex of geophysical methods and drilling) is located in the southwestern part of the site;
- minor faults - known and probable only by geophysical data, of different extension, mainly north-west - south-east.

1.4 SS Rivne NPP site

Geomorphological conditions

SS Rivne NPP site [22-24] in geomorphological terms is located within the right bank watershed of the Styr river valley on the planned finite-moraine ridge. The absolute elevations of the natural relief before the construction were 180.00-189.00 m, in the central part of the site they were 185.00-189.00 m, and in some areas they reach 190.00-193.00 m (Attachment A).

The planning elevation at the main structures location is 188.50 m, at the location of 750 kV outdoor switchgear is 179.60 m.

1.4.1 Geological structure

The geological structure at the explored depth of 100.00 m is formed by the Middle Quaternary undifferentiated fluvioglacial and moraine formations underlain by the deposits of the Kharkivska suite of the Upper Paleogene and the Upper Cretaceous; the latter, in their turn, occur on the rocks of the Upper Proterozoic.

The cross section of the site is characterized by relative identity in terms of thickness, the position of the cover and the bottom of even-aged rocks. At the same time, in some areas, deviations from average conditions were detected, especially at the 750 kV outdoor switchgear.

Top-down section of the site has the following form: below the bulk soils lies a mass of Mid-Quaternary undifferentiated fluvioglacial and finite-moraine deposits (fgQ2dn), presented in the upper part (to a depth of 2.00 - 5.00 to 7.00 - 10.00 m) by sands and below by sandy loam. Sands by the granulometric composition are most often small- and medium-grain, occasionally silty and large; by the density of piling they are mainly of medium density.

Sandy loams in the section of Quaternary deposits occupy a dominant position. Their stratum is non-uniform, there are carbonate differences, in many areas numerous layers of sand, often loam, can be traced in sandy loams. The thickness of the sandy layers varies from a few millimeters to several tens of centimeters. The consistency of sandy loams above the groundwater level is solid and plastic, below the groundwater level is plastic and fluid. The density of sandy loam decreases with depth, and the difference in density in the upper and lower parts of the section of the Quaternary deposits in some areas is very significant - the density of dry soil on average decreases from 1.77 to 1.35 t/m^3. Perhaps this is the result of karst-suffusion processes (contact suffusion).

The base of the Quaternary deposits can be traced at a depth of 15.00 -25.00 m on average from the planning elevation which corresponds to the absolute elevations of 162.00 - 170.00 m, mainly 166.00 - 168.00 m. They lie under the Quaternary deposits of the Kharkivska suite of Upper Paleogene (P3hr) and are represented by sandy-sandy loam and loamy-clayey rocks. The sands are glauconitic, of a characteristic green color, in terms of granulometric composition are mainly small and silty, loose and of medium density, sometimes turning into sandy loam; water saturated; include thin layers of clay. The consistency of sandy loam is plastic and fluid. Clays are gray and greenish-gray, the consistency is mostly low-plastic; there are thin layers of sand in the clays. At some places clay alternate with loams, most often green, glauconitic, the consistency is mostly high-plastic. Loamy-clay rocks are extended almost everywhere, although their thickness is small.

The cross section of Kharkiv deposits is not sustained over the area. The thickness ranges from 1.00 to 7.00 m, most often 3.00 - 4.00 m, the base at absolute elevations is 156.00 -164.00 m, mostly 161.00 - 163.00 m. The indicated elevations are elevations of the cove of the Upper Cretaceous rocks of the Turonian stage (K2t), the cover of the latter is uneven. The Upper Cretaceous rocks on the site are represented by deposits of the Turonian stage and only in the lower part of the Upper Cretaceous section by the deposits of the Lower Senomanian (K2c1); the latter are distributed sporadically.

The deposits of the Turonian stage are generally homogeneous in composition, this is chalk, sometimes replaced by limestone downwards. The thickness of the latter is small (several tens of centimeters), and therefore limestone does not play a significant role in assessing the geological section.

Chalk is a karst rock, therefore, under the influence of man-made factors, the process of karst formation can be activated. Hollow intervals and large cracks filled with chalk suspension or fractions of upper rocks, most often in a suspended state, are traced in the chalk; this is the result of karst-suffusion processes. Underground karst hollows are found frequently; in these places, the thickness of the chalk decreases, sometimes even to 1.00 - 3.00 m. In the cover of the Cretaceous, a gentle decline is also observed, which are rather large in area. The rate of development of karst-suffusion processes is largely connected with the state of the Cretaceous layer. The latter is not homogeneous and, as applied to specific conditions, is divided into 4 varieties:

- flow and fluid-plastic chalk, occasionally soft-plastic;
- strongly fissured chalk - chalky crushed stone;
- fissured chalk;

Chalk of massive refractory sometimes soft plastic consistency.

The fissured chalk dominates in the section. In the stratum of the chalk, there are sometimes a few cracks filled with sand, sandy loam, sometimes even clay, most often from the rocks of the Paleogene Kharkiv suite.

Flint inclusions are traced in the Cretaceous. At some places the clusters of flint are found, forming an independent layer of flint with chalky filler; the thickness is usually small - 0.10 - 0.20 m.

The thickness of the limestone occurring in the lower part of the Turonian deposits is 0.10 - 0.20 m; in some places there is no limestone.

The thickness of the Turonian deposit is about 15.00 m; the base at absolute elevations is 135.00 - 156.00 m, mostly 148.00 - 151.00 m. In the underground karst dips, the thickness of the chalk decreases sharply, sometimes to 1.00 - 5.00 m.

They lie under the chalk of the Turonian stage of the Lower Senomanian strata (K2c1) on the site, they are of a very limited distribution and are characterized by small thickness - 0.20 - 0.70 m; only at the 750 kV outdoor switchgear the thickness of the Senomanian stage deposit increases to several meters.

The Senomanian strata are represented by a basal conglomerate on limestone cement; well rounded fragments of various rocks - flint, limestone, quartzite, basalt, and others - are interspersed into the light carbonating light mass. The fragments are generally evenly distributed in the conglomerates. The strata is cracked; occasionally in the upper part occurs as a cluster of rubble.

The described sediments are deposited on the volcanogenic rocks of the Berestovetska suite of the Upper Proterozoic (PR2br), to the explored depth of 100.00 m represented by basalts and tuffs. In the cover of the Berestovetska suite rocks, in places, there is a thin (0.10 - 0.20 m) weathered basalt crust - crushed-stone soil with clay filler. In the areas of Senomanian basalt conglomerate distribution, it covers the basalts, the basalt weathering crust is usually absent.

In general, the Berestovetska suite rocks include several basalt streams consisting of basalts and lava-breccia; basalt streams are separated by tuffs. At the site two basalt streams are opened by wells about 100.00 m deep. The upper basalt stream is represented mainly by massive aphanitic basalts, most often from dark gray to black. In the cover of the lower basalt stream lava-breccia usually occur by fragments of basalts, cemented in a plastic state without foreign cement; the contours of fragments are smoothly curved, not always clearly visible. The basalts and lava-breccia are fissured; cracks, both open and resistive are filled with calcite, chlorite; cracks orientation is chaotic; in separate intervals, the rocks are destroyed to the state of rubble.

The thickness of the upper basalt stream is usually about 10.00 - 16.00 m; the lower one is opened by wells on the site only in the upper part (basically, the thickness traversed up to 16.00 m).

The tuff stratum consists of tuff of different granulometric composition, from fine to coarse-grained (lapillia), brown, reddish brown, sometimes gray or gray-green. Often, the distribution of material according to the particle size is uneven; bombs of basalts are common in tuffs. Layering is often unclear, sometimes banding is observed. The level of fracturing is lower than basalts, but sometimes there are large open fractures. In the lower part of tuffs, tuff-breccia are usually lie and sometimes salg-breccia occur. Tuf-breccia (tuff agglomerates) consist of bombs and lapilles of basalts, cemented with a fine-grained ashes; the size of the bombs is from 3.00 - 5.00 to 10.00 cm, the outlines are curly, winding; cement is of pore structure by filling type. Slag-breccia are baked bubbly basalt-tuff mass; not common everywhere.

Most of the tuff is classified as rocky soil, but there are quite a few intervals of marl soil (strongly weathered).

The total thickness of tuffs is several tens of meters (30.00 - 50.00 m).

The thickness of the soils that make up the geological section of SS Rivne NPP site is divided into 32 engineering and geological elements. Their names, characteristics, indicators of physical and mechanical properties are given in Attachments A and B.

1.5 Town of Varash

Town of Varash is located on the right bank of the Styr river [25-26].

In Geomorphological terms this territory is located within the Styr river valley (the first above floodplain terrace) and its right bank watershed. Within the town of Varash the river flows north to south.

In the structure of the Styr river valley in this area the floodplain terrace is distinguished, mostly narrow (from 75.00 to 400.00 m). The width of the first above floodplain terrace is 300.00 - 800.00 m.

The absolute elevations of the natural relief in the floodplain are 161.00-162.00 m, on the first above floodplain terrace are 163.00 - 170.00 m. Before construction began the transition from the above floodplain terrace to the watershed was found as a very clearly ledge in a natural relief. The watershed is complicated by a finite-moraine ridge extending parallel to the Styr river course, i.e. in the north - south direction. In the southern part of the territory of Varash the ridge turns to the east at an angle of 90°. Absolute elevations within the finite-moraine ridge reach 182.00 m.

Currently, the territory of the town is planned. Most of the urban development is within the watershed.

The geological structure of the site is different within the various geomorphological elements. Therefore the geomorphological elements are composed of Quaternary deposits of different ages and genesis, formed by rocks of the Turonian stage of the Upper Cretaceous (Appendix B).

The modern Quaternary man-made (bulk), marsh and alluvial deposits underlain by Upper Cretaceous rocks are involved in the geological structure of the floodplain.

Man-made (bulk) soils (tQ4) are represented by sands, fine and medium-sized in terms of granulometric composition; thickness is small (up to 0.50-1.00 m), the distribution is limited.

Bog sediments (bQ4) are peat and peaty soils of small thickness, maximum 3.00 m. Distribution is not widespread.

The modern Quaternary alluvial formations (aQ4) are represented by sands of various grain-size composition, mainly small and medium-sized sands. In the sands there are layers and lenses of clay, loam, sandy loam; in some places clay soils have varying degree of peatification or are humified, their thickness varies from 0.40 to 3.00 - 4.00 m.

The total thickness of the modern Quaternary alluvial deposits varies widely from 4.70 to 14.60 m due to the uneven cover of the Upper Cretaceous, the average thickness is 10.00 -12.00 m.

The first above floodplain terrace is composed of Upper Quaternary alluvial deposits (*aQ3*), and the underlying Upper Cretaceous rocks. Their section is characterized by heterogeneity in terms of plan and depth. The Upper Quaternary alluvial deposits are mainly sands with interlayers of clay soils, sometimes humified. Sands are of small and medium size according to granulometric composition, sometimes there are layers of large-grained and silty. Clay soils are of plastic, less often fluid consistency.

The thickness of the Upper Quaternary alluvial deposits varies widely; it is a consequence of the uneven erosion of the cover of the underlying Cretaceous deposits. Most often the thickness of alluvial deposits is 10.00 - 12.00 m, but in some places it reaches 20.00 m.

Right bank watershed of the Styr river valley is composed of Mid-Quaternary undifferentiated fluvioglacial and moraine deposits of the Dnieper glaciation stage (fgQ2dn), characterized by variegated lithological composition. The dominant position in the section is occupied by sands, by the granulometric composition the sands are mainly small and medium size, but in their thickness the lenses and layers of silty, large-grained and gravelly sands are often found. Sands contain inclusions of coarse-grained material as crushed stone, pebbles, gruss, and gravel. Clay soils occur in the form of layers, represented by all lithological differences (from light sandy loams to clay) in some places peaty clay soils and even peat layers are found. The thickness of the Quaternary deposits varies from 15.00 to 20.00 m, and in some places even more; they are spread under upper Cretaceous strata.

The finite-moraine ridge within the right-bank watershed of the Styr river valley is composed of Mid-Quaternary finite-moraine, as well as undifferentiated fluvioglacial and finite-moraine deposits of the Dnieper glaciation stage (*fgQ2dn*). The section within the ridge is characterized by an exceptionally variegated lithologic composition (especially in the upper part), its sharp variability in plan and by depth.

The prevailing position in the section is occupied by sands of various granulometric composition, from silty to gravelly, more often of small and medium size. Clay soils are also represented by various lithological varieties, from light sandy loams to clays, in some places they are peatificated; peat is found in some areas in the section at depths of about 6.00 - 10.00 m. In the section along the whole depth, the inclusions of coarse-grained material are found, from gruss and gravel to boulders. The thickness of the Quaternary deposits is 20.00 - 25.00 meters and more; they are underlied by Upper Cretaceous rocks.

As it has been already noted, the cover of the Upper Cretaceous deposits, which occur under Quaternary formations, is uneven. They are represented by chalk, in the lower part of the layer are changed by marl or limestone. Chalk is a karst rock, therefore, under the influence of man-made factors, the process of karst formation can be activated. Hollow intervals and large cracks filled with chalk suspension or fractions of upper rocks, most often in a suspended state, are traced in the chalk; this is the result of karst-suffusion processes. The underground karst hollows are also frequent; in these places the chalk thickness decreases, sometimes even to 1.00 - 3.00 m. In the Cretaceous layer the gentle declinings rather large in area are found. The rate of development of karst-suffusion processes is largely associated with the state of the Cretaceous layer. The latter is not homogeneous and, as applied to specific conditions, is divided into 4 types:

- flow and fluid-plastic chalk, occasionally soft-plastic;
- strongly fissured chalk - chalky crushed stone;
- fissured chalk;

Chalk of massive refractory sometimes soft plastic consistency.

The total thickness of Uppe Cretaceous deposits varies from 5.00 to 20.00 m, at some places even more.

The basalts and tuffs of the Bereostovetska (Ratnenska) suites with a thickness of 150.00 - 160.00 m occur below.

The thickness of the soil that makes up the territory of Varash is divided into 37 engineering geological elements: 1, 3, 3а, 3б, 4, 4а, 5, 5а, 6, 6а, 6б, 6 г, 6д, 7, 7б, 8, 9, 10, 11, 11а, 12, 12а, 13, 13а, 14, 14а, 14б, 15, 15б, 16, 16а, 16в, 20а, 20б, 20в, 20г, 23. Their names, description and indicators of physical and mechanical properties are given in the attachments.

To eliminate suffusion-karst processes, the Cretaceous layer was cemented under the buildings of the first line of construction, as a result the cracks in the chalk should be cemented. The foundations of the buildings of the second and subsequent lines of construction made on solid slabs guarantee stable and safe operation of buildings, even in the case of karst surface dips. In addition, other anti-karst activities have been implemented.

1.6 Analysis of existing and prognostic negative endogenous and exogenous processes and phenomena

The region of Rivne NPP is located within the Russian platform, which causes a weak occurrence of endogenous processes. Here only the neotectonic processes determining the formation of changes in the relief, modern vertical and horizontal movements of the Earth's crust, as well as modern seismogenic occurrences associated with seismically active faults could be significant. However, an analysis of neotectonic processes allows to state that the neotectonic activity of faults in the considered territory is relatively small. All of them, following the classification of faults by activity, are classified as low active. The gradients of the velocities of neotectonic movements are from 0.001 to 0.005 and higher cm/km/thousand years [27].

Exogenous geological processes (EGP) by the genesis are divided into two groups:

- natural-historical (natural);
- man-made, it means those occurred as a result of enginnering activity.

The group of natural-historical EGP, in its turn, is divided into two subgroups: the first is stabilized EGP; the second is active or temporarily active EGP. Under the influence of man-made factors, the activation of natural EGP can occur, in this case EGP are considered as natural-man-made.

The possibility of EGP occurrence is determined by a number of conditions: geological structure, tectonics, relief, hydrogeological and physiographic features, as well as by the influence of external factors.

The development of EGP is due to the following main factors:

- groundwater impact;
- surface water impact;
- gravity forces impact;
- atmospheric agents impact;
- man-made impact.

EGP occurrence can be local and areal.

The classification and names of the EGP in the 30-kilometer zone of SS Rivne NPP , at the point and on the site of the RNPP are given in Appendix D.

The conditions for the development of EGP within different parts of the 30-km zone are different and differ significantly from the conditions of the site and the Rovno NPP point (the latter includes the site, the controlled area R = 2.5 km and Varash); therefore posible occurrences of EGP (including negative ones) are also different.

The extent of the possible influence of exogenous processes on the stability of SS Rivne NPP structures, including power unit No. 4, and, correspondingly, the influence of RNPP on the intensity of the exogenous processes development are considered below.

1.6.1 30-kilometer zone of SS Rivne NPP

The following exogenous processes develop in the 30-kilometer zone of SS Rivne NPP [28]:

- karst and suffosion - karst, at the same time there are covered, half-open and open karst areas;
- - plane erosion (plane wash), inclined and linear (in river beds, water courses);
- ravine formation;
- bogging of river floodplains and depressions in the relief on low watershed areas;
- Formations of dead river channels due to meandering of river cources;
- aeolian processes (formation of hilly sands);
- talus;
- river bank caving;
- flooding as a result of groundwater recharge during river floods, as well as under the influence of technogenesis in built-up areas.

Part of the exogenous geological processes develops under the influence of natural factors, some - under the influence of natural and man-made factors. Sources of influence on the development and activation of exogenous geological processes are also man-made factors: existing pits, storage ponds and sewage treatment plants for industrial and domestic sewage, as well as livestock farms, wastewater discharge sites. Reclamative land-drainage systems are functioning on large areas.

The most significant of the exogenous processes is suffosion-karst.

According to the karstological zoning performed by the Institute of Mineral Resources of the Ministry of Geology and Mineral Resources of the Ukrainian SSR, the site of RNPP is included in the Central (VI.28) area of the Polissia karst region.

Karsting are the rocks of the Turonian stage of the Upper Cretaceous. In the chalk there are large cracks and hollow intervals filled with chalky suspension, in the soils of the overlapping chalk there are decompaction zones (the result of karst-suffusion processes).

Under the influence of technogenesis, karst formation and suffusion-karst processes can be intensified.

The presence and development of surface karst forms indicates the existence of deep systems of karst cavities that redistribute the underground flow.

The karsts of Upper Cretaceous deposits are of ancient age; evidence of this is the coincidence of the zones of main faults with the hollow forms of the ancient karst relief [29].

Activation of karst processes in the Cretaceous layer took place during periods of elevation of the surface of Cretaceous rocks, beginning from the end of the Upper Cretaceous - the beginning of the Paleogene epoch, in the Pliocene and early Pleistocene.

In the section of karsted rocks the surficial penetrability of the section can be traced, that is the result of the periodicity of movements of various sections in the process of formation of modern morphostructures.

The periodicity of the karst process is due to climatic and tectonic reasons. The levels of increased karst fix the long-standing levels of the karst basis and are evidence of this periodicity.

In Volyn Polissia, karst formation of Cretaceous deposits also occurs in the aeration zone and in the zone of deep groundwater flow; there paleo-karst phenomena have been repeatedly observed.

The development of underground runoff in the direction of natural and artificial karst bases determines the occurrence of irreversible deformations not only in the geological section which is quickly formed to the depth of the intensive water exchange zone, but also on the bottom surface. The fractured and karst rocks are not sustained in the area. The discrepancy in the area of ancient and modern drainless surface forms can serve as an evidence of the shielding effect of the cover on modern karst processes in these areas.

Occurrences of EGP in the territory outside RNPP point cannot affect the stability of RNPP facilities due to their remoteness [30]. Intensification of EGP, the occurrence of natural and man-made exogenous processes in the 30-kilometer zone is possible, but this is in no way connected with the operation of SS Rivne NPP. Analysis of the possibility of EGP intensification can be performed only on the basis of a comprehensive assessment of the man-made impact of all industrial facilities, settlements, infrastructure, etc.

1.6.2 Seismic characteristics

Designing of Rivne NPP started in 1974, the seismic assessment was performed in accordance with the existing regulatotry documents that were in effect at that time.

Based on the conclusion of “Hydroproject” [31], “Main buildings of Rivne NPP are situated at the medium (with magnitude 5) and, in a less degree, worse soils with the magnitude 6 and earthquake repetition once per 10,000 years”.

During engineering investigations in 1986, performed for the feasibility study of the second phase of Rivne NPP construction [20], the site seismic intensity was evaluated as follows: the design-basis earthquake (DBE) was referred to the earthquake with the magnitude 5; the safe shutdown earthquake (SSE) was referred to the earthquake with the magnitude 6 (considering the results of micro-seismic zonation).

According to the “Temporary schematic map of seismic zonation of the European part of former Soviet Union (VSR-87), the Rivne NPP site is located in the zone with magnitude 5 for the soils of the second category.

Since the requirements have increased for the last few years with respect to the completeness and substantiation of documents related to the assessment of NPP sites seismicity, further studies were conducted in 1998 and 2000 regarding seismic hazard of the region and site of Rivne NPP. The complementary seismic hazard studies included: special seismotectonic and seismologic studies [33], seismic micro zonation [33, 34], geomorphologic and neotectonic [4], tectono-magnetic studies [35], additional research of fault-block tectonics [12], surveys of the current Earth’s crust movements [36].

The seismological studies showed that the seismic impact on the site from all seismic active zones within a 750-km radius of the NPP site is of the magnitude less than 5, except for the Vrancea zone. In case of the earthquake in the Vrancea zone (Romania) with the maximum possible magnitude M=7.6, the intensity of seismic impact can achieve approximately a magnitude 6.

The estimated intensity of the seismic impact by the known local earthquakes for the NPP site is significantly lower and is of the magnitude 4.

For the period of seismic instrument surveys conducted by the Geophysics Institute of the National Academy of Science of Ukraine (NASU), there were several hundreds of seismic events recorded. Only four among them were identified as local seismic events and one was related to the local earthquake, the parameters of which are being specified. The results of the seismic instrument studies show that the analyzed region is quiet from the seismic point of view.

The macro-seismic studies, conducted on the basis of collected, analyzed and generalized literature, archive, historical data and results of special expeditionary macro-seismic studies of the consequences from the earthquakes of 1977, 1986, 1990 on the territory of Ukraine, made it possible to compile the Isoseist Atlas for strong earthquakes in the Vrancea zone from 1790 to 1990 (NASU's Geophysics Institute). The Rivne NPP site is situated in the area with the seismicity of a magnitude from 4 to 5 and only during the earthquake of 1802 it was among the isoseists with the magnitude 5 and 6.

As it was mentioned before, the structure of Rivne NPP foundation is characterized with the clearly defined block formations. The following is distinguished here: geo-block of order 1, and accordingly the faults of grade 1 of mantle deposit, internal crust faults of grade 2 and faults of grade 3.

From the structural point of view, Rivne NPP is located within the Dubnivskiy geo-block of order 1, which borders in the south with Novgorod-Volynskiy geo-block, in the south-west and west – with Lvivskiy geo-block, in the north-west – with Polisskiy geo-block, in the north and north-east – with Osnytskiy geo-block. The interim blocking borders are represented by the through-crust zone of grade 1 faults of the mantle deposit and faults zone.

The grade 1 faults of the mantle deposit are:

- zones of north-eastern striking – Minsk-Vizhevska, Mogyliv-Stokhodska, Gorynska (Lutska), Kremenetsko-Perzhanska, Teterivska zones;
- north-western striking – Central (Sarnensko-Varvarivska) zone of faults, Khmelnitskiy and Podilskiy faults;
- latitudinal striking – Kukhitsko-Ratnivska zone of faults, Volodymyr-Volynskiy and Andrushivskiy faults.

According to the geological and geophysical data, the following sublatitudinal tectonic zones are mapped in the grade 2 faults (internal crust) – Bilska and Chartoryyska, as well as Sarnensko-Varvarivska north-eastern striking.

The analysis of neo-tectonic and geological and geophysical studies shows that practically none of the faults along their entire length can be related to the tectonic active faults, i.e. to the faults associated with the relative movements of fault sides in the Quarternary period during (1-2) $x10^6$ years.

Rivne NPP is located in the north-eastern flange of Manevitskiy block, which is the most stable unit of the foundation infrastructure that was minimally affected by the tectonic processes. The borders of the Manevitskiy block are Gorynska (Lutska), Kukhotsko-Ratnivska, Mogyliv-Stokhodska zones of the faults, as well as Volodymyro-Volynskyy fault and its striking - Olexandrivskiy fault. These particular tectonic zones and faults, among all the distinguished ones on the territory of the analyzed region, have the primary importance in the assessment of possible seismicity of the Manevitskiy block. At that it should be noted that only the Gorynska tectonic zone of faults runs across the 30-km area of Rivne NPP, crossing its south-eastern flange.

During a comprehensive geologic and seismotectonic study of the area adjacent to Rivne NPP, seven seismotectonic zones of four levels of potential seismic activity were identified: potential zones of possible earthquakes (source zone) of orders 1 and 2 and seismotectonic zones of orders 1 and 2. The seismotectonic activity of the last two zones is very low. The seismic impact from the local potential source zones was estimated as: DBE – magnitude 5, SSE - magnitude 6.

Thus, the seismic hazard to Rivne NPP site can be posed only from the earthquakes of the Vrancea zone (Romania) and local potential source zone. Assessment of the seismotectonic potential using a formalization method and the earthquake catalogue for the west of Eastern European platform brings to the conclusions that the areas surrounding Rivne NPP site do not have zones with high values of the seismotectonic potential. There are only several zones at the distance of 40 km to the north from the site with the seismotectonic potential of $2.8 < M < 3.9$. Based on the general analysis of seismic and seismotectonic situation the conclusion can be that DBE and SSE are of magnitude 5 and 6 for the average soil conditions.

For clarification of seismicity depending on the engineering and geological conditions, the comprehensive engineering and geological seismic studies were performed for the Rivne NPP site and the territory of 3 km radius from the site. The map of the seismic microzonation was created with the scale of 1:10 000 using a series of methods: engineering and geological analogies, microseists, records of explosions, seismic impedances.

According to the materials of engineering and geological studies, the analyzed territory is distinguished with the areas having the soils of grades 2 and 3 by their seismic properties. Specifically, the territory of Rivne NPP site has a zero increase in terms of earthquake magnitude at the Rivne NPP site, and beyond that territory in a 3 km radius from Rivne NPP site the identified zones have the seismicity intensity increase $\Delta I = +1$ as related to the initial seismicity.

In such a way, based on the results of additional studies of the seismic hazard, the seismic intensity (magnitude) considering the seismic microzonation of the Rivne NPP site is: DBE – magnitude 5, SSE – magnitude 6, which corresponds to the values accepted in the design.

A set of calculated earthquake accelerograms was created, which model the DBE and SSE from the Vrancea Zone and local earthquake source zones to the Rivne NPP site. The calculated accelerograms are given for the reference soil conditions. To recalculate them to other soil conditions within the site area it is necessary to use the empiric transfer characteristics obtained during seismic microzonation.

The external natural geologic and manmade factors (ENF), and their changes caused by the manmade impact of Rivne NPP (within the site and Rivne NPP itself) are provided in Attachment E.

The main factors of Rivne NPP impact on the geological environment (within the site and the town of Varash) are presented in Table 1.2.

Table 1.2. Main factors of Rivne NPP influence on geological environment (within the plant site and the town of Varash)

Factors that define the impact of the RNPP structures on the geologic environment		Possible consequences	Measures that reduce negative consequences, and their assessment
1	Planning of the site territory (design elevation is 188.50 m),	Favorable	The territory is well arranged, the foundation

Factors that define the impact of the RNPP structures on the geologic environment		Possible consequences	Measures that reduce negative consequences, and their assessment
	open switchgear (design elevation is 179.60 m)		slopes secured, the surface runoff organized
2	Territory planning of the town of Varash	Favorable	The territory is well arranged, the surface runoff organized
3	Temporary relief derangement during digging of deep foundation pits on the plant site: with the depth of 14 m – for common pump stations; with the depth of 7 m – for main vessels of power units 1-4 and diesel generating stations	Absent	A complex of protective activities was accomplished during construction: dewatering, securing of slopes of the foundation pit
4	Man-induced underflooding due to drains/leakages of the technical waters from the underground pipelines, their infiltration into the soil on the territory of the plant site and the town of Varash	Increase of the level of underground waters, their temperature and mineralization; activation of the karst-suffosion processes	Control of the underwater mode (level, temperature, chemical composition). Timely control of the water supplying lines, their repairing
5	Activation of the karst-suffosion processes, occurrence of the man-made karst	Loosening of soils, fracturing of cretaceous layer, surface fall-through	Cementing of the cretaceous layer under the structures of power units 1-3 onsite, and under the buildings of the town of Varash. The structures of the main building of power unit 4 are constructed on the piles that cut through the cretaceous layer and thrust against the basalt. The basements of the houses located on the territory of the second and next phases of construction of Varash town are settled on the solid plates. At that, the yearly karst assessment of the territory is required.
6	Changing of the cretaceous layer state by cementing the layer under the structures of power units 1-3 and under the buildings of the town of Varash.	Countermeasures on development of karst and karst-suffosion processes	The measure is anti-karst, it ensures stability of the structures

Factors that define the impact of the RNPP structures on the geologic environment		Possible consequences	Measures that reduce negative consequences, and their assessment
7	Construction of structures of the main building and diesel generating station of power unit 4 on the piles that thrust against the basalt at the depth of 40 m	Improvement of conditions of the geological environment (protection from the karst-suffosion processes)	The measure excludes the possibility of occurring karst-suffosion processes, it ensures stability of the structures
		Possible damming effect (one of the conditions for man induced underflooding)	Control of the level of the underwaters, upper Cretaceous and upper Proterozoic water bearing strata at the site
8	Excavation of the sand quarries at the left bank side of the valley plain of the Styr River (to the north of the Rivne NPP site)	Change of the relief at the valley plain	Measures are not accomplished since the relief change at the valley plain does not impact the functioning of Rivne NPP
9	Commissioning of water intake points for the utility and drinking water supply on the territory northwards from the plant site (Rafalivskyy water intake point -1 in the Ostriv village), to the north (Chudlynskyy water intake point)	Formation of the depression pit in the Proterozoic water bearing strata	The depression pit formation foreseen by the design of water intake points is the inevitable process, which does not pose a negative impact on the geological environment. However, the monitoring observations are needed for the operation of water intake points and development of the depression pits around the water intake points

1.6.3 Substantiation of measures preventing or restraining the impact and assessment of their effectiveness

As it was mentioned in the previous sections, in the accident-free operational mode, the impact of Rivne NPP on the geological environment including the underwaters is not observed in the 30-km area. It can occur only within the plant site and Rivne NPP location point.

In the 30-km area, the impact of Rivne NPP can be imposed only in case of an accident and radionuclide release.

This section describes the activities applied to prevent or constraint the impact from the Rivne NPP site on the geological environment (influence of the manmade factors on the development of exogenic processes except for the radionuclide contamination), as well as measures applied to prevent the negative impact of the geological and naturally occurred manmade exogenic processes on the Rivne NPP site.

The list of measures applied to prevent or constraint the impact and assessment of their efficiency are provided in Table 1.3. The purpose of these measures is the following:

- Improvement of the conditions of the geological environment for levelling the impact of exogenic processes (karst-suffosion processes):
  - anti-karst measures – cementing of the cretaceous layer under the structures of power units 1-3 onsite, and under the buildings of the town of Varash;
  - structures of the main building of power unit 4 constructed on the piles that thrust against the basalt at the depth of 40 m (i.e. the most reliable part of the geological environment is used as the basis of buildings foundation);
- ✓ prevention of soil properties deterioration (reduction of the compression and strength indicators) in the building foundation:
  - monitoring of soils density and humidity using the radio-isotopic logging in the specially equipped well holes along the perimeter of the main buildings of power units 1-3, ventilation stack, diesel generating stations, auxiliary building;
  - similar monitoring along the perimeter of the buildings 4/4, 5/12, 8/2, 10/1, 14/2, 20/2, 34, 140, 364, 374, 387, 396/1 in the town of Varash;
  - building basements of the second and next phases of construction in the town of Varash - on the solid plates, which excludes uneven settlements in case of deteriorated soil properties in the foundation;
- ✓ limitation of impact on the ground waters mode (level, temperature, chemical composition), i.e. minimization of underflooding:
  - monitoring of the ground waters mode (level, temperature, chemical composition);
  - control of the water supply pipelines state and repairing.

The applied measures aimed at prevention and limitation of possible impact of the Rivne NPP site on the geological environment of the site and the town of Varash are efficient; further development of the exogenic geological processes is not forecasted to occur at the location of structures and buildings basement.

Table 1.3. Measures for prevention and limitation of the geological environment impact on the buildings of Rivne NPP and assessment of their efficiency

Processes	SS Rivne NPP (including the town of Varash)			Site of SS Rivne NPP		
	Type of impact	Measures	Efficiency of measures	Type of impact	Measures	Efficiency of measures
Exogenous processes (natural and naturally-technological)	Sheet and linear erosion	Processes that do not affect the operation of the SS Rivne NPP.		Erosion is flat	The planning is done, the area is asphalted and arranged	Equipped with surface runoff; the state of the geological environment has been improved
	Bogging of the River Styr plain					
	Flooding of the territory of the city of Varash (change of regimen factors of groundwater) as a result of leaks from water-borne communications and water infiltration into the soil *	Monitoring of the ground waters mode should be performed on a regular basis	Timely obtaining of the information in order to prevent the negative impact	Flooding (change of regimen factors of groundwater - level, temperature, chemical composition) as a result of leakage from water-borne communications of industrial water and their infiltration into soils *	Monitoring of the ground waters mode (should be performed during the entire period of Rivne NPP operation)	Obtaining of timely information in order to prevent the negative impact
		Control of the state of water supply lines (water pipelines, sewerage) and their repairing	Measures aimed at reduction of water leakages is not accomplished in full scope		Control of the state of water supply lines and their repairing	Measures aimed at reduction of water leakages is not accomplished in full scope
	Suffusion-karst processes, including technogenic karst *	Cementing of the chalk layer that carries under the houses of the first stage of construction of the city of Varash	Effective anti-tartar action, which eliminates the development of the process, and eliminates the development of the process.	Suffusion-karst processes, including technogenic karst *	Cementing of the cretaceous layer under the structures of power units 1-3	Effective anti-karst measures that eliminate development of the process
					Structures of the main building and diesel	Effective measures that completely exclude the

Processes	SS Rivne NPP (including the town of Varash)			Site of SS Rivne NPP		
	Type of impact	Measures	Efficiency of measures	Type of impact	Measures	Efficiency of measures
		Building foundations of the second and next phases of construction in the town of Varash – on the solid plates	Effective measurements that exclude uneven settlements of the foundation even in case of process development		generating station of power unit 4 constructed on the piles that thrust against the basalt at the depth of 40 m, cementing	impact of karst-suffosion process
	Karst-suffosion processes including the manmade karst*	Monitoring of soils density and humidity using the radioactive logging in the specially equipped wells along the perimeter of the main buildings in the town of Varash - № 4/4, 5/12, 8/2, 10/1, 14/2, 20/2, 34, 140, 364, 374, 387, 396/1	Obtaining of modern information in order to exclude negative impact	Karst-suffosion processes including the manmade karst*	Monitoring of soils density and humidity using the radioactive logging in the specially equipped wells along the perimeter of the main buildings of power units 1-3, ventilation stack, diesel generating stations, auxiliary building	Obtaining of timely information in order to prevent the negative impact
*) - naturally occurred manmade exogenic geological processes						

1.7 Comprehensive analysis of the soils condition under the foundation of buildings and structures

The current scientific and technical report provides the results of a series of the engineering and geological surveys and geophysical studies for justification of the lifetime extension of power units 1 and [37].

The engineering and geological surveys of the Rivne NPP site have been conducted for many years by the departments of All-union State Institute “AtomTeploEnergoProject” starting from 1967 at different stages of plant construction. The site selection and surveys were performed by the Leningrad department of the All-union State Institute “AtomTeploEnergoProject” (LDTEP) at the stage of “Engineering design” in 1967-1972.

For justification of power units 1, 2 and 3 at the stage of “Working drawings”, the surveys were performed by the Lviv department of “TeploEnergoProject” (LvivTEP) in 1972-1981; designing - by the Ural department of “TeploEnergoProject”. Although the materials of LDTEP and LvivTEP did not contain the assessment of engineering and geological conditions of the plant site from the point of view of possible karst-suffosion processes.

From 1981, the surveys were performed by the Kyiv department of surveys of “AtomTeploEnergoProject” (the current name is the State Enterprise “Kyiv Institute of Engineering Surveys and Research “Energorpoekt”). In the course of the surveys it was defined that the geological profile of the site contains the cretaceous rocks that can karst (bedding interval □25-40 m), which means that occurrences of the karst-suffosion processes are possible at the site.

To exclude the karst-suffosion processes, the measures were taken to embed the cretaceous layer in the foundation of power units 1, 2, 3 structures, which is its cementing conducted in 1985-1990. In the following years of the plant operation, observations were performed over the settlements of structures, which showed no exceedance of the design values. Thus, soils cementing appeared to be an effective method for improvement of soils reliability in the active zones of building foundations.

Along the perimeter of the main buildings of power units 1 and 2, the steady-state network of well holes was arranged in the 1980s for monitoring of the soils condition and density using the method of radio-isotopic logging. No significant deviations were recorded in the soil density values during the entire observation period.

Besides, for solution of the lifetime extension issue for power units 1 and 2, the assessment of the geotechnical soil properties in the foundation of buildings was performed at the current stage, taking into account the existing regulatory framework. Planning of the lifetime extension of power units 1 and 2 should be based on the results of engineering and geological surveys conducted with consideration of the specific environmental conditions of SE “Rivne NPP” and provided in this report.

The Rivne NPP location point and the site are situated on the territory of Volynskyy Polissya, in its southern part, in the midstream of the river Styr, the right affluent of the River Prypyat.

From the geomorphological point of view, the Rivne NPP site is located at the right bank watershed of the River Styr valley, on the planned terminal moraine range. The absolute elevations of the natural relief before the plant construction were 180.00 – 189.00 m, in the central part of the site - 185.00 – 189.00 m and achieved 190.00 – 193.00 m in some parts.

The planned elevation was 188.50 m in the area of main buildings location, at the site of open switchgear OSG-750 kW – 179.60 m.

Based on the results of activities on the additional research of seismic hazard, the seismic intensity considering the seismic zonation of Rivne NPP site is: for DBE – magnitude of 5, for SSE – magnitude of 6, which corresponds to the accepted design values.

A set of calculated earthquake accelerograms was created, which model the DBE and SSE from the Vrancea Zone and local earthquake source zones to the Rivne NPP site.

In the geological layer, the medium quaternary, poorly defined fluvioglacial and terminal moraine formations are found at the investigated depth of 100.00 m, which are underlaid by the deposits of the kharkiv series of upper paleogene and upper cretaceous; in its turn the last ones are deposited on the upper proterozoic rocks.

The geological profile of the analyzed part of the RNPP site is characterized by the relative homogeneity from the point of view of thickness, position of the top and base of coeval rocks.

The profile of the NPP site from the top to the bottom has the following picture: under the fill-up soils, there is a layer of medium quaternary, poorly defined fluvioglacial and terminal moraine formations (fgQ_2dn), which are represented by the sandy clay and in less amount by the sands. By the granulometric composition the sands are most often fine and silty, occasionally medium-grained; by the density of composition the sands are of medium density and dense with very rare interlayers and lenses of loose sand.

The sandy clay of quaternary deposits take the dominant position. Their thickness is heterogeneous, - the density of sandy clay is changing with the depth, at that the greater difference in density is mainly in the upper layer of the profile. Because of the significant homogeneity in density, the thickness of the sandy clay is split into four engineering geological elements (EGE 12, 12a, 12b, 12c).

The bottom of quaternary deposits is observed at the depth of 18.7 – 28.50 m from the planned elevation (mainly 22-26 m), which corresponds to the absolute elevations 160.00 – 170.00 m, mainly 162.00 – 166.00 m.

Under the quaternary deposits of Kharkiv Stage of Upper Paleogene (P_3hr) there are sandy loam and clayed loam rocks.

The profile of Kharkiv Stage is characterized by the varying thickness – from 1.50 to 7.10 m, most often 3.00-6.00 m, the bottom is at the depths from 24.10 to 33.00 m (at the absolute elevations 155.00 – 164.00 m). The indicated elevations are the marks of the top of upper cretaceous rocks of the Turonian Stage (K_2t).

The upper cretaceous rocks (K_2t) are presented by the deposits of the Turonian Stage. In general, they are homogeneous by composition: it is cretaceous rock that karsts, which is why under the manmade factors the process of karst formation can be activated. The speed of the karst-suffosion processes development is associated in a greater degree with the condition of the cretaceous thickness. The rocks are heterogeneous and they are divided into four types when applied to the Rivne NPP conditions:

- running chalk;
- highly fractured - chalky crushed stone;
- fractured chalk;
- chalk massive of poorly and highly plastic texture.

Thickness of Turonian deposits is 10 – 16 m, mainly 12-15 m; the bottom layer at the depths from 37.2 to 47.4 m, mainly 39-43 m (at the absolute elevations 145.00 – 149.00 m).

The described deposits underlie at the basalts of Berestovetskiy series of Upper Proterozoic.

Within the investigated depth, the following aquifers are found on the territory of the site:

- quaternary paleogene aquifer system (ground waters), which are shortly called "quaternary aquifer" or "ground waters"
- upper cretaceous aquifer.

The groundwater table and piezometric surface of the upper cretaceous aquifer have a dome-like shape.

In September 2008, the maximum elevation in the center of groundwater dome (well hole 225n) was 182.16 km (to the south from the cooling towers №5 and №6). In the area of the main building of power units 1 and 2, the absolute elevations of the level was 175-179 m, in the area of cooling towers №1 and №2 – 176.0-179.5 m.

In September 2008, the mound center of the upper cretaceous aquifer approximately coincided with the mound center of the ground waters. The top absolute elevation of the piezometric level was 181.25 m (well hole 133nm). In the central part of the site, the elevations of the piezometric level were about the same as in 2007 and made: by the main building of power units 1 and 2 – 174.0-179.0 m, by the cooling towers 1 and 2 – 177.0-179.0 m; in the south-western part of the site – 164.2 m.

The degree of aggressive influence of the ground waters on the structures made of concrete and reinforced concrete, on the plaster mortars, metal structures and reinforcement was assessed in accordance with the SNiP 2.03.11-85 "Anticorrosion protection of building structures"

In order to prevent possible development of the karst-suffosion processes, the anti-karst measures were implemented, i.e. cementing of the layer that tends to karst under the buildings of power units 1, 2, 3 at the plant site. During cementing of the cretaceous layer, the soils that cover the chalk were reinforced with the bored piles.

Based on the analysis of the cretaceous layer condition and covering soils, and taking into account the measures on localization and prevention of karst-suffosion processes, and position of the groundwater level, the document "Schematic plan of territory zoning based on the condition and degree of karst processes" was developed, with the drawing's code number 85-9211 as specified in the report.

The buildings included into the safety complex of power units 1 and 2 are located in the subarea "Шб" – which is practically safe (as a results of implemented engineering activities). Along with that, in some points there were intervals detected in the soil profile (of a little soil strength), which should be looked at, - here the density of the soil skeleton is lower than the minimum average statistic one.

As a result of conducted surveys in the area, 23 engineering geologic elements (EGE) were distinguished at the investigated depth of the given geologic profile. The indicators of the physical and mechanical properties of the soils are provided in the table at the drawing (code number 85-14-08, 10-10355). It should be noted, that the recommended values of the indicators of deformation and soil strength are higher than presented in the reports of LvivTEP (and subsequently, LvivATEP).

The comprehensive analysis of the soil condition under the building foundation, which was performed using the data of the current and previous studies, allows us to make the following conclusions:

- physical and mechanical properties of the soils that deposit in the building foundation are stable, and some improvement of the soils is distinguished; there are no contra-indications on the foundation's soil condition with regard to further operation of power units 1 and 2;

- karst-suffosion processes got stabilized and have a slowly developing character. The studies revealed some insignificant zones in terms of strength and indicators with the reduced density of cretaceous and upper deposited layers. Occurrence of the karst processes was not identified on the territory of the plant, but their activation is possible in case of violated hydrodynamic regime;

- settling and cores of the buildings and structures are within the allowable limits;

- a complex of anti-karst measures was implemented – cementing of the soil in the foundation of the main buildings, reduction of the groundwater mound gave a positive effect of stabilizing the geological terrain;

- comprehensive monitoring accomplished at the plant site (i.e. soil condition, groundwaters regime, building cores and settling, territory relief) allowed a timely detection of unreliable processes and take measures on elimination of their causes (including repairing of utility service lines, additional planning of territories).

At the moment of studies, the geological terrain of the site is in balance and the geotechnical properties of the soils in the basis of the building foundation, included to the complex of power units 1 and 2, ensure the reliability of the buildings and structures of the NPP.

However, due to the fact that the site is characterized by the complex engineering and geological conditions, it is necessary to perform continuous comprehensive monitoring of the geological environment and state of the buildings and structures to ensure further safety of operation. The monitoring activities include:

- hydro-geological monitoring – over the groundwaters regime;

- monitoring of the soils condition (density, humidity) using the radio-isotopic logging in the specially equipped well holes along the perimeter of the main buildings;

- monitoring of the settling and cores of buildings and structures;

- karst monitoring of the territory of Rivne NPP site.

The report [29] provides the results of comprehensive engineering and geological and geo—physical studies in distinguishing the soils condition of the building and structures foundation of power unit 3 of Rivne NPP site, aimed at the lifetime extension.

For the construction period and at the beginning of plant operation, occurrences of the karst-suffosion processes were observed in the upper cretaceous deposits, which are not traced now based on the conclusions of the karst monitoring and results of the accomplished surveys within the structures of power unit 3.

With regard to all structures of power unit 3, which define the safety system of its operation, cementing of the cretaceous layer was performed during different years with reinforcement of the rocks that cover this layer by the metal piles. At present, cementing of the cretaceous deposits is performed in the foundation of the ZPSO buildings.

The engineering peculiarities of NPP operation, including power unit 3 structures, according to the research forecast, envisaged a temporary emergency loss from the water supply network and hydro-engineering installations, which would lead to the unbalance of the aquifer level (closely related from the hydraulic point of view) and, in its turn, pose a risk for the cretaceous deposits condition. During the surveys, the registered levels of ground waters indicated absence of emergency losses from water supply lines and hydro-engineering installations.

According to the data of recent studies and taking into account the materials of surveys conducted during different years of RNPP operation, the territory zonation map compiled in 1987 (code 85-14-08-10912) was updated according to the current soil conditions and degree of the karst development for the structures and installations that define the safety system of power unit 3 operation. All structures and installations that define the safety of power unit 3 are related to the subzone, which is safe in terms of possible occurrence of karst-suffosion processes owing to the engineering measures implemented in this area.

To compare the indicators of physical and mechanical properties of the soils that form an engineering and geological profile within the active area of the studied installations, the materials of surveys conducted in the different periods of plant operation were analyzed. Correlation of the intermediated physical and mechanical indicators for soils within the active area of the studied installations, analyzed materials of surveys conducted in the different periods of plant operation and data obtained during current surveys and studies are provided in Table 1.2. The survey results showed that during operation of power unit 3, the deformation indicators of strength for all the engineering and geological elements differentiated in the soil thickness did not undergo significant changes.

The results of laboratory studies on identification of possible developments of the chemical and mechanical suffosion in the cretaceous layer demonstrated that under the existing boundary conditions (insignificant pressure gradients and degree of cretaceous deposits salinity) there are no prerequisites for rapid development of the karst-suffosion processes within the area of the buildings of power unit 3. Thus, the main objective is to preserve the existing boundary conditions for lifetime extension of power unit 3 buildings.

The results of cross-hole acoustic measurements performed by the All-Soviet Union Institute for Geophysics and Geochemistry in 1983 and the data obtained by the State Enterprise “Kyiv Institute of Engineering Surveys and Research “Energorpoekt” in 2014 practically coincide. The velocity characteristics of the cretaceous deposits in 1983 and 2014 are within the same range 1600 m/sec – 2000 m/sec, which demonstrates stability of the soils behavior within the studied area.

According to the data of radio-isotopic studies, it is peculiar for the soils of the geological profile to have variability in the dry soil density indicators, which do not exceed the measurement accuracy (0.05 g/cm^3). Most likely, such changes in the density values are conditioned by the peculiarities of the instrumentation work and in some cases they can be an evidence of quite slow progression of the karst-suffosion processes, which should be monitored on a regular basis.

The obtained results of the density and humidity study demonstrated the stable state of soils in the basis of building foundation. The identified local changes of the soil density do not influence the safe operation of the facility.

The regulatory forecast of the safe plant operation under the conditions of current engineering and geological situation and peculiarities of the manmade load requires the continuous on-line monitoring of hydro-geological situation, state of buildings, density of soils in the buildings foundation, karst monitoring. For this purpose, the following is recommended:

- arrangement of two observation well holes for the soil aquifer observations (well hole is currently arranged at the upper cretaceous aquifer in the area of ZPSO building);
- siting of additional types in the area of south-western area of the special building SK-2, ZPSO building and pump station for monitoring of their settling;
- including of the territory around the pump station and ZPSO building to the routes of karst monitoring;

- observation well-holes on the soil and cretaceous aquifers should be included to the list of selected ones for the purpose of chemical analysis;

- consider the possibility for further performance of cross-hole seismic profiling (CSP) within the Rivne NPP site, owing to which the informative data were obtained during the current studies;

- to accomplish the on-line monitoring on a regular basis (once per 3-5 years), its analysis should be performed.

Having compiled all the relevant factors, the engineering and geological situation within the power unit 3 buildings and installations is acceptable for its lifetime extension, which includes:

- karst monitoring did not identify occurrences of active karst developments within the power unit 3 buildings;

- observation data on settling of the power unit 3 buildings showed no exceedance of the allowed ones;

- hydro-geological situation as per the data of hydro-geological monitoring is characterized as stable and controllable by all relevant indicators;

- soil condition within the active area of the power unit 3 buildings ensure reliability for operation of the buildings.

2 GEOLOGICAL ENVIRONMENT MONITORING SYSTEM

2.1 Ground waters: resources, usage, quality

The territory of Rivne regionis situated within three artesian basins: Volyno-Podilskyy, Prypyatskyy and Ukrainian basins of fissured and edge waters.

The forecasted general resources of the ground waters in the regionconstitute about 1314.913 mln. m^3/year, the proven reserves are 195.798 mln. m^3/year, and proven from forecasted resources are 14.9 %. In the profile of the administrative and territorial regions, the ground water reserves as of 01.01.2017 are provided in Table 2.1 [5].

Table 2.1. Net amount of groundwaters in region

№№	Region	Net of groundwaters		
		Forecasted resources, mln. m^3/year	Proven reserves, mln. m^3/year	% of forecasted resources
1	Volodymyretskyy	97.309	20.502	21.1
2	Bereznivskyy	64.788	6.570	10.1
3	Goschanskyy	129.612	23.361	18.0
4	Dubenskyy	92.637	14.600	15.8
5	Dubrovytskyy	145.124	9.676	6.7
6	Zarichnenskyy	66.905	6.935	10.4
7	Zdolbunivskyy	55.553	13.870	25.0
8	Koretskyy	12.629	3.395	26.9
9	Kostopilskyy	135.488	7.300	5.4
10	Mlynivskyy	101.762	7.180	7.1
11	Demydivskyy			
12	Ostrozskyy	51.867	3.062	5.9
13	Rivnenskyy	165.820	57.907	34.9
14	Rokytnivskyy	21.718	1.862	8.6
15	Sarnenskyy	133.992	14.450	10.8
16	Radyvylivskyy	39.712	5.128	12.9
	In regiontotal	1314.913	195.798	14.9

From the chemical and bacteriological point of view, the ground waters are of good quality with mineralization of up to 1 g/dm^3, calcium hydrocarbonate waters. By the chemical composition, only the ground waters of Gorbashivskyy aquifer on the water intakes of the town Rivne differ, where the aquifer deepens into the significant depth and waters become hydrocarbonate. Although with such composition, they still fully correspond the requirements of the existing DSTU.

At the operating water intakes of the oblast, reduction of operating aquifers levels for the multi-year period did not exceed the allowed limits.

In 2016 the water samples in the Rivne regionwere not taken, new pollution focus was not detected.

Among other resources that may supplement the economic base of Rivne oblast, the significant place belongs to the mineral waters. The balneological water properties and low-cost production is the basis for development of a perspective industry. The most perspective mineral waters are sodium chloride portable waters of the Mirgorod type, which are mostly spread in the area. They are mainly drawn towards the volcanogenic-terrigenous rocks of the Vendian and Paleozoic and they are deposited at the depths from 70-80 to 750 m. reserves of these waters are found in the village Zhobryn and Oleksandriya of Rivnenskyy region, town settlement Stepan of Sarnenskyy region, the town of Ostrog. On these three water springs (Zhobrynskyy, Ostrizskyy and Stepankyy) the mining and industrial pouring of the mineral medicinal table waters into the glass-ware and polyethylene containers for internal use is made.

For the review period, the reserves growth was observed owing to the Vodograyna section of the Zhobrynskyy mineral water spring. This spring has the operating balance reserves in the deposits of Kanylivskyy series of the upper Vendian. Its reserves were proven by the following categories: A – 12.000 m^3/day, B – 68.00 m^3/day. Another spring adding to the reserves growth is the Malomydskyy mineral water spring, the balance reserves of which were proven in the deposits of the Polysh series of the medium and upper Riphean by the category: B – 10.000 m^3/day.

The sodium sulfate drinking waters were found in the Dubenskyy region with mineralization of 3-6 g/dm^3.

The radon mineral waters are met nearby the village Vira of Sarnenskyy region and the village Marynyn of Bereznivskyy region.

The discovered mineral resources in the town of Kortsi constitute 280 m^3/day with the concentration of 20 nCi/dm^3 and are utilized by “Koretska regionhospital of rehabilitation treatment” for musculoskeletal disorders treatment.

The underground water resources of the regionare a matter of further research and utilization.

The main tasks of this area are:

- finalyze the geological surveys at the Moshkivskyy mineral water spring in the Mlynivskyy, Nadsluchanskyy and Bereznivskyy regions;
- increase the mineral water release in PET-bottles for 20-25% at the LLC “Ostrovskyy mineral waters factory”.

The multi-year regular studies of the ground waters are conducted by the Rivnenskyy geological expedition team by means of continuous observations over the regimes of ground water levels and hydro-chemical water indicators in 31 observation settlements situated in different natural and manmade conditions (intense operation of water intakes, dryout, industrial and residential areas). During 2016, the water samples for chemical analysis were not taken, which is due to irregularity of financing of these type of activities.

The main conclusions regarding transformation of ground waters in the regionare the following:

- deep lying (artesian waters), which are used for centralized water supply, do not pose quiality changes and correspond mainly to the sanitary norms to portable water;
- post-Chernobyl pollution with radionuclides was not identified;
- first waters from the surface ground waters are substantially transformed and they experience negative quality changes in the chemical composition.

Regionally, the changes are observed in the chemical composition of ground waters on the territories with low forest coverage, relatively high manmade loading, increased application of fertilizers, which condition the certain problems of ground water self-purification ability.

One of the main sources of groundwater pollution are industrial enterprises, especially their waste waters that accumulate in the sewage ponds, clarifier on the filtration fields, water treatment facilities, from where they reach the groundwaters and then the deepest aquifers.

Significant hazard is posed by the indigested warehouses with toxic chemicals, combustibles and lubricants, as well as waste sites, settlements that do not have sewerage systems.

The potential sources of groundwater pollution are the abandoned well holes and wells that went out of service and require sanitary and technical tamponage, as well as well holes with disarranged zones of sanitary and technical regime, especially when they are located nearby the pollution sources and do not have permanent containment.

Permanent control is conducted at the sources of polluted portable waters within he depression zone that were formed in the area of Gorbakivskyy water intake, which is the biggest water source in the town of Rivne and part of the settlements of Goschanskyy and Rivnenskyy regions. As a results of research activities the map was added with the territory of the biggest influence due to operation of the main aquifer on the Meso-Cenozoic aquifer system.

According to the laboratory data of permanent control performed by the enterprise “RivenOblVodoCanal”, the water from the artesian well holes of the water intakes Goschanskyy (4 well holes) and Rivnenskyy (107 well holes) fully meet the hygienic requirements to the quality of water from the centralized utility and drinking water supply of 2nd class, except for the indicator “turbidity”, which sometimes has cases of exceedance.

In the settlements, where quality of water from the underground sources of the centralized water supply system, does not meet the existing requirements, i.e. to the iron content, it is foreseen to perform water treatment on the water purification facilities (deferrization stations) to make it compliant with the norms and standards, as well as introduce the measures on advanced water treatment and disinfection of portable water.

To measure the volume of the mined groundwaters and to control its supply, the licensees who accomplish business activity regarding the centralized water supply, use the cold water metering devices. Such, in 2016 “RivneOblVodoCanal” have mined the ground water in the amount of 14.71 mln. m^3, supplied to the consumers – 14.14 mln. m^3.

In 2016, the volume of sewerage waters 8.2 mln. m^3 was purified at the water treatment facilitates of “RivneOblVodoCanal”, 14.69 mln. m^3 of water was removed (part of effluents was pumped to “RivenAzot”).

Also, the activities were performed under the regionand local programs “Portable water”, with the total funding amount of 8.86 mln hrivnas provided from all the financing sources in 2016. Particularly these activities included: construction of the iron removal station with capacity of 100 m^3/day in the town of Korets; arrangement of 5.6 km water supply pipelines in the micro-districts of Strakalov, Volytsya, and meat factory in the town of Dubno; reconstruction of unfit and old sections of water supply lines in the town of Rivne; reconstruction of the water supply systems of the 1st uprise in the urban type settlement Rokytne; reconstruction of one of the compact facility (Ku-200) of purification installations in the town of Korets.

2.2 Exogenic-geological processes in region

On the territory of oblast, the following exogenic-geological processes take place: karst, lateral and linear erosion, subsidence of bed surface, underflooding, reprocessing of water reservoir banks.

The Rivne overall geological party of the state enterprise “Ukrainian geological company” fulfills monitoring of the exogenic-geological processes on the territory of oblast.

Because of the very low funding provided in 2016 for observations and study of the exogenic-geological processes, small amount of field works was accomplished in the sections with category 3 lateral and linear erosion development.

In the Rivne oblast, the erosion processes of the denes were studied in the areas called Kunin and Radislavka. The section Kunin is situated in the Zdolbunivskyy region within the Mizotskyy range. Development of the lateral erosion is studied here in the sandy deposits of Sarmatian stage of the Neogene. The dene of the Radislavka’s section is situated in the Rivne region within the Rivne forest plateau, which is composed of the wood-like loam from the lithologic point of view.

Activity of the linear erosion is observed in the eminences. In the section Kunon, development of the new eminences was induced by the human activity. In the section Radyslavka, plowing of the agricultural fields to the entire dene also caused a linear development of the eminences of up to 1.0 m.

Observations of the lateral erosion were conducted in 2016 on the river Goryn in the category 3 sections: Bukhariv (Ostrozkyy region), Orshiv (Rivnenskyy region).

In the section Bukhariv, the width of the edge shift from the cliff was 0.91-3.10 m for the period of 2009-2016.

In the urban settlement Orzhiv, the section is located in the northern village outskirts and territory of LLC “Odek” of Ukraine. The active area on the territory of “Odek” is reinforced, which caused washing-out of the left bank of the river Goryn and adjoining area on the Pidgirna street. The distance from the building to the bank as of 22.09.2016 was 18.20 m.

Over the last years the bank waved back for 9.1 m. At the moment of observations, significant suffosion tubes were detected at the bank.

Extension of the exogenic-geological processes in the regionin 2016 is provided in Table 2.2.

Table 2.2. Extension of exogenic-geological process (EGP) in 2016 [5].

№	Type (EGP)	Extension area, km^2	Number of occurences	% of effected region
1	Karst	4826	747	4.8
2	Underflooding	3379.3	121	21.5
3	Subsidence	3770	-	18.7
4	Bogginess	1750	-	8.7
5	Lateral and linear erosion	1346	370	6.7

2.3 Geological control and approval in the field of geology study and rational use of resources

The state supervision of the geological studies, rational and effective use of the mineral resources is fulfilled by the State Service of Geology and Mineral Resources of Ukraine. According to the Decree of the Ministry of Natural Resources of Ukraine №262 as of 26.07.2011 (with amendments), registered in the Ministry of Justice of Ukraine № 932/19670 as of 29.07.2011 "On approval of Procedure for agreement of resources provision for usage by the Ministry of Natural Resources of Ukraine", the Department of Ecology and Natural Resources of Rivne regionof the State Administration processed 24 packages of documents, submitted from the business entities to the Ministry of Natural Resources of Ukraine and to the Rivnenska RegionCouncil.

3 GROUND WATERS

The territory of Rivne regionis located within three artesian basins: Volyno-Podilskyy, Prypyatskyy and Ukrainian basins of fissured and edge waters.

The general forecasted resources of the ground waters in the regionconstitute about 1314.913 mln. m^3/year, the proven reserves are 195.798 mln. m^3/year, and proven from forecasted resources are 14.9 %. In the profile of the administrative and territorial regions, the ground water reserves as of 01.01.2017 are provided in Table 3.1.

Table 3.1 Situation with groundwaters in the region[5]

№№	Region	Groundwater reserves		
		Forecasted resources, mln. m^3/year	Proven reserves, mln. m^3/year	% of forecasted resources
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From the chemical and bacteriological point of view, the ground waters are of goof quality with mineralization of up to 1 g/dm^3, calcium hydrocarbonate waters. By the chemical composition, only the ground waters of Gorbashivskyy aquifer on the water intakes of the town Rivne differ, where the aquifer deepens into the significant depth and waters become hydrocarbonate. Although with such composition, they still fully correspond the requirements of the existing DSTU.

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3.1 Hydro-geological observations of the groundwater regime

From the geomorphological point of view, the Rivne NPP site is located at the graded ridge with the planned elevation of 188.5 m. The absolute elevations of the natural relief before the plant construction were 180.00 – 189.00 m, and in some parts they achieved 190.00 – 193.00 m. The planning elevation was 188.50 m in the area of main buildings location. The following aquifers and complexes are deposited here, from the top to the bottom:

- filled-up soils (in separate sections) and natural quaternary deposits: sands, then sandy loam underneath, and loam oftentimes. The layer subface is traced at the depth in average of 15.00 ÷ 25.00 m from the planning elevation, the oriented absolute elevations are mainly 166.00 ÷ 168.00 m. The complex is aquiferous, unconfined (ground waters), which is fed by the atmosphere precipitation, partially by overflows from other aquifers. The depth of the groundwater level is 7.00 ÷ 15.00 m, and deeper in some places. The amplitude of seasons fluctuations of ground water level is 1.00 ÷ 2.00 m. The main off-loading of the aquifer complex is in the southern direction from the plant site, specifically in the valley of the river Styr. The horizon is monitored from three well holes of the steady-state observation hydro-geological network for the "perched water" and from 123 well holes for other ground waters;
- aquifer of the upper cretaceous deposits. The dominating position in the section is occupied by the fractured chalk, where the karst-suffosion processes are developed (hollow spacing, big fractures filled up with cretaceous suspension or "healed" with pieces of rocks, which are deposited above – sand, sandy loam, sometimes clay, often in the suspended state). The general depth of the deposits is 15.00 m, the subface of the layer at the absolute elevations is 148.00 ÷ 151.00 m.
- in the upper part of cretaceous marl layer, there is an area with the water-resistant clay mass that include marl pieces. The depth of this confined aquifer of ground water at the site is 25.00 ÷ 40.00 m. The aquifer is monitored from 54 well holes of the steady-state observation hydro-geological network;
- aquifer with the deposits of Berestovetskiy series of Upper Proterozoic is widely spread, sustained in the extend and depth. The water-containing rocks include fractured basalts and various grainy fractured tuff (kunkur). The water-resisting layer is represented by the tuffs that deposit in the upper part of the structure. The separating layer between the upper Proterozoic and upper Cretaceous aquifers is massive chalk, but due to its little spreading, there is a hydraulic connection of the aquifers. That is why the elevations of piezometric level in both aquifers do not differ much. Feeding occurs due to water infiltration from the upper deposited aquifers through the fracture system, partial feeding – from the lower deposited aquifers. The aquifer is confined. The aquifer deposit depth at the site is 40.0-45.00 m. The aquifer is monitored from 13 well holes of the steady-state observation hydro-geological network.

The hydro-geological observations include the following activities:

- measurement of the water level and temperature in the well holes – temperature logging;
- water pumping from the well holes;
- sampling of water from the well holes for identification of the chemical composition of ground waters;
- checkup of the state of hydro-geological observation well holes.

The sanitary protection zones of the first ring of artesian wells of the village of Ostriv are separated and fenced. The area of sludge collector and polygon of the construction and industrial waste from Rivne NPP is monitored by the environmental and chemical laboratory, which performs necessary analysis in this area. Assessment of the reference characteristics show that operation of Rivne NPP does not introduce significant changes into the quality of ground waters.

The systematic hydro-geological observations over the groundwater regime at the Rivne NPP site are performed on a continuous basis starting from 1980. Prior to 1983, the network of steady-state well holes for observations consisted only of 11 check-points (№1-11). From 1983 to 1985, the additional well holes network has been established for the regimes of three aquifers – Quaternary (ground waters), upper Cretaceous, and upper part of the upper Proterozoic. In subsequent years, the network was extended when necessary; the damaged well holes were restored.

Monitoring of water level in the well holes, as well as the temperature and chemical composition of the ground waters is conducted systematically. Observations of the groundwater level and temperature at the site are conducted once per a decade, chemical composition – once or twice a year.

The completeness of hydro-geological materials are evaluated as quite informative, since the materials are compiled with continuous information for a long period (over 20 years).

As of 2003, the amount of well holes used for observations is the following:

- on the ground waters – 140;
- on the upper cretaceous aquifer – 47;
- on the upper part of the upper Proterozoic aquifer – 12.

Locations of the check points at Rivne NPP site as of 2017 are provided in Table 3.2 The network of piezometric well holes consists of 20 well holes located on the territory of RNPP site.

Table 3.2. Location of check points at Rivne NPP site [38, 39].

Location	Numbers of check well-holes
Power unit1	267, 268
Power unit 2	270, 271, 272
Power unit 3	241, 242, 243, 244, 245, 246
Power unit 4	Пс-1, Пс-2, Пс-3а, Пс-4
SB-1	261, 262, 263, 264, 265, 266, 11316н
SB-2	247, 248, 249, 250, 251, 252, 253, 254
Industrial waste storage	273, 274, 275
SRWS	49Н, 50Н

For the analyzed period, a new well hole №11316Н was added in 2009, and the well hole №269 does not exist since 2005.

Samples from the check well holes are combined by the facilitates, samples of the piezometric well holes are combined by the layers – quaternary and cretaceous aquifers. The combined samples go through the gamma-spectrometry analysis.

The radiation condition of the ground waters (Table 3.6 and Table 3.7) is satisfactory, the content of ^{226}Ra, ^{137}Cs and ^{90}Sr is significantly below the values specified in the regulatory documents НРБУ-97 [44] and ДР-2006 [30].

During the planned review of the technical specification for radiation monitoring of Rivne NPP 132-1-Р-ЦРБ [37], the monitoring of piezometric well holes was excluded from the scope of radiation monitoring before the first half of 2014, inclusively.

3.2. Ground water level (GWL)

3.2.1 Ground waters

During the construction and operation of SE "Rivne NPP", the groundwater regime was formed under the influence both of the natural and man-made factors. As it was mentioned before, the groundwater table had a dome-like shape prior to construction, the maximum absolute indicator in the center of the dome was 178.600 m; the center was located in the area of cooling towers 5 and 6. At that, in the central part of the site the absolute elevations were from 172.000 to 175.000 m, and in the area of inlet canal - from 174.000 to 177.000 m.

As a result of production waters infiltration, the level of the ground waters increased. Yet during the construction in 1974, it was recorded in the survey materials of the Institute "LvivTEP" that the level increased for 2-3 meters.

Further on, during the RNPP operation period the dome of ground waters was formed at the plant site with the center in the area of unit pump station and underwater canal; the elevation of the ground waters was 185.200 m in June 1982, i.e. the depth of the level was equal to 3.3 m and the level increase was 10 m. The center of the dome was located in the area of the well hole №3H, between the cooling tower №1 and a canal.

After implementation of activities on reduction of water outflows and water infiltration into the soil, the level of the ground waters decreased, especially in the center of the dome. In the first quarter 1985, the groundwater elevation was 179.600 m; the difference between this and initial level (1969) was 4 m here.

The tendency of level reduction was clearly traced through several years after implementation of the activities on reduction of water outflows.

During 1985-1987, the level at the Rivne NPP site decreased. At that, the center of the dome shifted to the area of cooling towers and underground canal. The values of level reduction for the period 1986-1988 in the different areas of the site were from 1.6 to 5.5 m, in the average of 3-4 m.

Then, in most observation well holes, stabilization of the water level was recorded, and in certain points the tendency of new level increase was observed (insignificant at the beginning).

During 1989-1990, stabilization of the groundwater level was recorded. In the center of the dome (in the area of cooling towers) and near the inlet canal the elevations were 179.000 – 181.000 m.

During 1991 – 1993, the level continued to increase. At that, the micro domes were found on the top of the general dome at the site, which were associated with the places of water outflows and infiltration of production waters. The most significant increase of the level in this period occurred in the area of the well hole №240 (near the underground canal). Here, the level mark was 182.560 m in June 1993, and it achieved 183.650 m in September.

During 1994 – 1995, the level stabilization was observed. At that, the level marks in the well holes №236H -240H (near the unit pump station and outlet canal) reduced to 180.500 – 180.800 m. However, a sharp spike to the elevation of 183.250 m was recorded in the well hole №240H in December 1995.

During 1996-1997, the regime of groundwater level was more stable than in 1994-1995. The maximum level mark (i.e. the dome center), as before, were near the unit pump station and outlet canal; the absolute elevations were 180.200 – 180.500 m (December 1997). In the central part of the site, the absolute elevations (and depths) of the level were:

- under the main building of power units 1 and 2: 174.000 – 178.000 m (14.5-10.0 m);
- under the main building of power unit 3: 178.500 – 180.000 m (10.0 – 8.5 m);
- under the main building of power unit 4: 178.000 – 180.000 (10.5 – 8.5 m).

In the direction of south-western periphery, the absolute level indications (ALI) reduced to 166.000 m, to the southern – up to 168.000 m.

In such a way, the dynamic balance was preserved during several years, and then some ALI increase occurred again, and in the second half of 1988 – rapid increase. The center of the dome shifted somewhat along the outlet canal. At that time, the ALI increase appeared all over the plant site but with different intensity in different places. It was due both to the natural and manmade induced factors.

In 1998, the total amount of yearly precipitation significantly exceeded the amount of precipitation for the previous 15 years and was 994 mm.

Accordingly, the maximum infiltration of the atmospheric precipitation was accompanied by ALI increase everywhere, including the plant site. This is showed in the analysis of ALI fluctuations in the well hole №24H, located on the south-western periphery of the plant site (outside the sources of manmade underflooding), where ALI increase was 1.0 m in 1998, and by the end of 1999 ALI reduced here to 0.5 m; by the end of 2002 – for 0.5 m more, during 2002 the amplitude of ALI fluctuation was up to 0.5 m, and by the end of the year it reduced for about 0.5 m. The influence of manmade factors to ALI was not observed here. Thus, the maximum ALI indications of 1998 demonstrate the general ALI increase during this period of time due to infiltration of the atmospheric precipitations.

However, it was not the only reason for ALI increase: the level increased in the part of the plant site not only due to natural (rapid increase of atmospheric precipitations), but manmade factors as well – infiltration of the production waste due to water outflows from the hydro-engineering installations, primarily, from the inlet canal.

In November 1998, the level increased rapidly for 3.5-4.5 in the area of inlet and outlet canals and the maximum level indicator grew greater than 184 m (well hole №7H). At that, the groundwater dome shifted to the node of connection of the inlet and outlet canals. This dome was preserved during 1998-2003, although some ALI fluctuations were observed over time: by the end of 2000, the maximum level indicator in the dome center was 184.100- 183.300 m, i.e. 4.4 m from the ground surface; in 2001 – 183.100 it was 184.000 m, in 2002 it was 184.000 – 183.300 m.

From 2003, the groundwater dome shifted from the area of open inlet canal of power units 1 and 2 to the territory of power unit 4.

From 2007 to 2010, the groundwater dome was located on the territory of power unit 4 with its top in the area of open inlet canal of power unit 4 (well hole №350H).

In 2011, the groundwater dome was located on the territory of power units 3 and 4 between the outlet canal of power units 1, 2, 3 and cooling tower 6.

During 2012 the groundwater dome was observed to be migrating from well hole №133H to well hole №236H (area of the inlet canal of power unit 3 and cooling tower 6) with absolute elevation of the dome from 182.14 to 182.63 m.

By the end of 2012, the groundwater dome was located between the turbine hall of power unit 3 and cooling tower 6. The top of the dome was found in the area of open outlet canal of power unit 3 and chloride warehouse with the absolute elevation of 182.27 m.

In general, for 2012 a decrease of groundwater level was observed in the average for 0.5 m in the well holes on Rivne NPP site.

For the period from 01.01. to 30.03.17 (1st quarter), the increase of groundwater level was indicated in the average for 0.15 m on the Rivne NPP site and adjacent territory.

As of 31.03.17, the groundwater dome was located on the territory of power units 3, 4 – between the inlet canal of power unit 3, turbine hall of power unit 3, cooling tower 6 and rainwater run-off collector of power unit 4. It had an indistinct shape with feebly-marked “top” near the well hole №350n, located by the open canal of power unit 4, with the absolute elevation – 180.65 m.

For the period from 01.04. to 30.06.17 (2nd quarter), increase of the groundwater level occurred in the average for 0.13 m at Rivne NPP site and adjacent territory.

As of 31.06.17 the groundwater dome was located on the territory of power units 3, 4 – the inlet canal of power unit 3, turbine hall of power unit 3, cooling tower 6 and rainwater run-off collector of power unit 4. It had an indistinct shape with feebly-marked “top” near the well hole №349n, located by the open canal of power unit 4, with the absolute elevation – 180.77 m.

For the period from 01.07. to 30.09.17 (3rd quarter), decrease of the groundwater level occurred in the average for 0.15 m at Rivne NPP site and adjacent territory.

As of 30.09.17 the groundwater dome was located on the territory of power units 3, 4 – between the inlet canal of power unit 3, turbine hall of power unit 3, cooling tower 6 and rainwater run-off collector of power unit 4. It had an indistinct shape with feebly-marked “top” near the well hole №350n, located by the open canal of power unit 4, with the absolute elevation – 180.68 m.

For the period from 01.10. to 30.12.17 (4th quarter), increase of the groundwater level occurred in the average for 0.14 m at Rivne NPP site and adjacent territory.

As of 30.12.17 the groundwater dome was located on the territory of power units 3, 4 – between the inlet canal of power unit 3, turbine hall of power unit 3, cooling tower 6 and rainwater run-off collector of power unit 4. It had an indistinct shape with feebly-marked “top” near the well hole №350n, located by the open canal of power unit 4, with the absolute elevation – 180.64 m.

Compared to the absolute level indication of the groundwater’s dome center during the period from 1969 to 1972 (area of the outlet canal of power unit 4 and cooling towers 5, 6), which is 178.600 m, the groundwater level as of December 30, 2012 in this area was greater than the natural groundwater level for 3.60-4.50 m.

Summarizing the dynamics of the groundwater level behavior at Rivne NPP site, the following should be mentioned:

prior to the plant construction, the on-site groundwater surface had a dome-like shape; the groundwater level indicator was 178.600 m in the center of the dome;

during the process of Rivne NPP construction and operation, the groundwater level tended to increase as a result of the man-made influence. The level increased to 10 m in the dome center. After introduction of a complex of specific measures, a significant level decrease was achieved. However, the level failed to be decreased to the initial indicators (in 1985 the difference between the actual and initial level was 4.0 m);

for the following years, the regime of groundwater level was manly characterized by the dynamic balance, although micro-domes on the groundwater surface were identified in separate areas of the plant site. The level fluctuation is a result of manmade influence occurred during the plant construction and operation, first of all – outflows of production waters from the canal, water transfer lines;

infiltration of industrial waters occurred unequally across the entire territory of the plant site; it is concentrated in the separate areas different in shape and size;

in the second half of 1998, a rapid increase of groundwater level occurred again, the dome center somewhat shifted along the outlet canal. At that time, the ALI increased across the entire territory of the plant site, but with unequal intensity depending on the part of the area. It was associated both with the natural and manmade factors, at present the outflow center is the outlet canal;

in 2000, the maximum level indicator in the dome center (well hole №7N) was 184.100 m (March-June), i.e. 4.4 m from the ground surface; in 2001 it was 184.000 m (December), in 2002 – 184.000 m (March), 183.200 m (December). In different parts of the plant site as opposed to the initial level (1969), the values of level increase tend to be different, the level in the central part of the plant site was 4.0-5.0 m;

from 2003 to 2010, the groundwater dome was located on the territory of power unit 4, and from 2011 – on the territory of power units 3, 4;

during 2012, the absolute dome level indicators from 182.140 to 182.630 m were observed; as for the well holes the groundwater level tended to decrease in the average for 0.5 m;

compared to the absolute level indicators of the groundwater dome center in 1969 – 1972 (area of outlet canal of power unit 4, cooling towers 5, 6) – 178.60 m, the groundwater level in this area as of December 30, 2012 exceeded the natural one for 3.60 – 4.50 m;

manmade influence from RNPP operation reflected on the position of piezometric level of upper cretaceous aquifer below the ALI indicators. The level fluctuation dynamics of the ground waters and upper cretaceous aquifer is mainly synchronic.

3.2.2 Temperature and chemical composition of ground waters

The analyzed materials on RNPP site monitoring of the groundwater regime allow us to ascertain the influence of the plant onto the temperature and chemical composition of the ground waters, both of the ground waters and upper cretaceous aquifer.

3.2.2.1 Temperature of ground waters

The influence of manmade factors on the groundwater temperature is a result of warm water infiltration from the inlet and outlet canals, cooling towers, and other water lines. It can be also due to warming of the soils where the water conduits are laid, through which the hot water is transported (for example, area of well hole №8N).

During the multi-year hydrological surveys of separate areas of the plant site, the temperature increase was practically always recorded in the soils. The so-called "temperature field" was formed, which conditionally can be called "temperature dome". The background temperature of water was 8-12 ^{0}C (depending on the time of the year and outdoor air temperature). The range of the groundwater temperature fluctuations across the area within the plant site was 10-12 ^{0}C during the entire observation period. Only at the beginning of 80s the temperature of 27.5 ^{0}C was recorded in some points, at that the range of temperature fluctuations across the site area achieved the groundwater temperature.

During the entire period of observations within the plant site, the "temperature micro-domes" were recorded and preserved within the general "temperature field" near the main building of power units 1 and 2, near the unit pump station 2, near the main building of power unit 3. The "temperature micro-dome" recorded before in the area of hydraulic structures (well holes №3N and 5N) shifted to the north from the outlet canal, with maximum temperature increase in 2002.

In the process of Rivne NPP operation, the groundwater temperature field was recorded during a significant period of time within the plant site. At that, the background temperature was 9- 10 ^{0}C. The groundwater temperature field was not uniform and included several sections:

- in the western part of power unit 1;
- in the area of outlet canal;
- between cooling towers 1, 4 and inlet canal;
- in the south-eastern part of power unit 3.

The nature of temperature field division was practically preserved during many years, with the increased water temperature of 18-23 0C at the indicated sections. The range of groundwater temperature fluctuation across the site area achieved 16 0C. during a year. The groundwater temperature increase in the indicated sections was a result of manmade influence (and infiltration of the warm water [28,29].

The field of the increased groundwater temperature was steadily preserved and reached 23-28.8 0C at the background temperature not greater than 10 0C. The center of the temperature field was at the eastern edge of the inlet canal, where the water conduits with hot water are laid. Along the inlet canal, the groundwater temperature was not greater than 19-20 0C, although the temperature fluctuations were observed over time in all well holes and were from 3.4 to 9.6 0C. The maximum temperature was observed in November 2002, end of February – beginning of March 2003.

From 01.01.17 to 30.03.17 (1st quarter), the groundwater temperature field was recorded with the background temperature of 12.0-14.0 ^{0}C.

From 01.04.17 to 30.06.17 (2nd quarter II), the groundwater temperature field was recorded with the background temperature of 12.0-14.0 ^{0}C.

From 01.07.17 to 30.09.17 (3rd quarter), the groundwater temperature field was recorded with the background temperature of 12.0-14.0 ^{0}C.

From 01.10.17 to 30.12.17 (4th quarter), the groundwater temperature field was recorded with the background temperature of 12-14 ^{0}C, which corresponds to the season fluctuations of atmospheric air temperature.

In such a way, four "temperature micro-domes" with some water temperature fluctuations in their centers were peculiar for a long period of time for the plant site. However, warming-up of the ground waters had a local character and did not spread over the plant site.

3.2.2.2 Temperature of upper cretaceous aquifer

The manmade influence of Rivne NPP extended to the temperature of the upper cretaceous aquifer, although in a lesser degree than to the groundwater regimes.

Due to hydraulic connection between the ground waters and upper cretaceous aquifer, the character of temperature field distribution of the aquifer is similar in general. However, since the amount of the well holes at the cretaceous aquifer is smaller than at the ground waters, the "temperature domes" have somewhat different shapes on the hydroisotherm diagrams of the cretaceous aquifer. At that, the water temperature of the upper cretaceous aquifer in the center of "temperature micro-domes" was a little bit lower for 1-6 ^{0}C. During the analyzed period, the maximum temperature was 18-19 ^{0}C, the minimum temperature (background) was 8-11 ^{0}C. The maximum range of water temperature changes across the site area was 10 ^{0}C, i.e. lower than the ground water temperature.

In the groundwater dome at the outlet and inlet canals, the character of temperature field distribution in the upper cretaceous aquifer and ground waters in general was similar in the second half of 2002 – first half of 2003. But at that, the water temperature of the upper cretaceous aquifer was less than 6 ^{0}C in the center of "temperature micro-dome" (well hole №3NM) and 18-20 ^{0}C (well hole №5NM).

Temperature increase in the upper cretaceous aquifer is conditioned by the "thermal overflow" from the quaternary to upper cretaceous aquifer, i.e. infiltration of warm water from the quaternary to upper cretaceous aquifer.

The temperature of the upper Proterozoic aquifer is lower than temperature of the upper cretaceous aquifer, and was 10- 14 ^{0}C. During a year the range of water temperature measurements onsite was from 2 to 5 ^{0}C. Changes of the water temperature across the site area were mostly associated with the metrological conditions.

The increases groundwater temperatures can be associated with the constantly high water temperature in the inlet and outlet canals (11-17 ^{0}C in winter and 20-30 ^{0}C during other seasons of the year), as well as man induced losses of heated water from the water lines and warming up of the soil by these lines.

3.2.2.3 Chemical composition of ground waters

Under the conditions of Rivne NPP operation the manmade factors was affected not only the hydrodynamic and temperature regimes of the ground waters (firstly, ground waters), but in some degree their chemical composition as well. Although changes in the chemical composition are not that significant as changes in the hydrodynamic and temperature regimes.

Prior to the plant construction, the dry solid content in the ground waters was up to 100 mg/dm^3. During plant operation, the increase of dry solid content in the ground waters was observed up to 300- 400 mg/dm^3 in separate places, and even greater in some areas.

At that, increased water mineralization is unequal in separate sections. As for example, mineralization of ground waters in the section of inlet canal area is higher than on the site in general, which is a confirmation of the production waters outflow from the canal and, possibly, from other hydraulic facilities.

Table 3.3. Content of dry solid, sulphates, calcium, Ph in the ground waters at Rivne NPP site [29].

Components	Values	Content
The total salt content (dry residue), mg/dm^3	Prevailing values	206 – 588
	Anomalous values	812 – 1718
SO_4^{2-}, mg/dm^3	Prevailing values	56 – 247
	Anomalous values	320 – 1113

Components	Values	Content
Ca2+, mg/dm^3	Prevailing values	20 – 120
	Anomalous values	200 – 320
pH	Prevailing values	6,9 – 8,5
	Anomalous values	4.2 – 5.8; 8.8 – 8.9

Higher groundwater mineralization in the certain underflows can be also associated not only with water enrichment by salts due to infiltration of production waters resulted from outflows from the hydraulic structures, but also with the additional salt dissolution in the soils while water infiltrates through them.

In general, changes in the groundwater chemical composition are relatively small at the Rivne NPP site (except for certain sections), which demonstrates practical absence of the chemical pollution of ground waters, except for the area of special water treatment facility (SWT). Here, the manmade "perched water" was formed and pollution of ground waters occurred. Mineralization of "perched water" is high: dry solid - 25700 mg/dm^3, at that content of HCO_3^- is 4607 mg/dm^3, CO_3^{2-} - 7080 mg/dm^3, Cl^- - 1846 mg/dm^3, SO_4^{2-} - 2525 mg/dm^3, Na+ + K^+ - 8073 mg/dm^3, bicarbonate alkalinity is 8720.

Accordingly, the groundwater mineralization in this section is much higher than on the rest territory of the plant site: dry solid is 1328-5250 mg/dm^3, due to the high content of cations, anions; the bicarbonate alkalinity is 260 – 640. Pollution of the upper cretaceous aquifer did not practically occur.

In general, during the entire period of Rivne NPP 1-4 operation the groundwater dry solid value increased up to 200-400 mg/dm^3 compared to the pre-operational period, when the dry solid value was 50-100 mg/dm^3. The local manmade pollution of the ground waters was observed in the SWP area, where groundwater mineralization was much higher than on the territory of the plant site: dry solid was 1328 mg/dm^3 – 5250 mg/dm^3, bicarbonate alkalinity was 26-64 of German degrees.

3.2.2.4 Chemical composition of upper cretaceous aquifer

In the upper cretaceous aquifer, the periodic and detected increases of the dry solid is lower than in the ground waters (up to 100-300 mg/dm^3). Accordingly, the sulfate content (not mainly greater than 100 mg/dm^3) and calcuim content (up to 50 mg/dm^3) is lower too. This means that the impact of manmade factors on the chemical composition of the upper cretaceous aquifer is lower than on the chemical composition of the ground waters and dry solid increase found in some places is lower than in the ground waters – up to 200-300 mg/dm^3.

3.3 Chemical and radiation monitoring of ground waters

The environmental and chemical laboratory, qualified for performance of measurements of the groundwater (well holes) chemical composition, performed the analysis of ground waters in the area of the sludge collector and polygon of construction and industrial waste of Rivne NPP. The average groundwater indicators for the well holes around waste disposal places is presented in Table 3.4 [29].

Table 3.4. Average groundwater indicators for the well holes around waste disposal places.

2017	Sludge collector's well hole		Polygon-well hole	
	Background 38H	25H	Background 140H	1H
Temperature, ^0C	7.2	7.0	7.0	7.5
pH	7.92	6.08	8.01	8.24
Dry solid, mg/dm	201.50	150.00	1771.50	238.50
Ca mge/dm^3	2.813	1.746	2.425	1.067
Mg mge/dm	10.616	3.593	8.257	8.257
N NH4+ mg/dm^3	0.200	0.600	0.900	2.600
NO2- mg/dm^3	0.091	0.012	0.463	0.019
NO3- mg/dm^3	0.392	0.102	28.095	9.770
Iron, mg/dm^3	0.500	0.475	2.000	0.800
Copper, mg/dm^3	0.000	0.000	0.002	0.000
Zinc	0.544	0.071	0.045	0.003
Chlorides	21.272	11.345	13.472	11.699
Anionic surfactant	0.028	0.019	0.024	0.021
Sulphates	22.350	22.200	32.950	29.867
Oil products	0.055	0.052	0.114	0.041

The department of thermal and underground water lines and the environmental protection service of Rivne NPP performs monitoring of the groundwater state at the water intake point in the village Ostriv according to the schedule. The average indicators of the groundwater state are presented in Table 3.5.

Table 3.5. Average groundwater indicators

Sampling date	Well hole №	pH	Dry solid, mg/dm^3	Hardness gener., mg-equiv./dm^3	Anions, mg/dm^3			Cations, mg/dm^3			
					CL$^-$	SO_4^{2-}	HCO^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
24.10.17	4	7.37	309.60	3.25	60.60	18.50	164.70	61.20	2.43	29.00	8.00
24.10.17	9	9.00	281.00	0.23	46.46	12.20	158.60	3.00	0.91	90.00	1.20
07.11.17	10	8.22	321.00	0.17	85.68	9.60	146.40	1.80	0.97	112.00	0.45
Under repair	11										
18.10.17	12	8.90	292.60	0.35	52.23	10.50	164.70	5.21	1.09	91.00	0.50
18.10.17	13	6.94	304.40	0.12	48.48	10.50	176.90	1.60	0.42	100.00	0.60
24.10.17	14	9.10	306.00	0.20	52.52	19.96	164.70	2.20	1.09	98.00	1.90
18.10.17	15	8.50	610.40	0.50	191.90	11.45	251.93	9.01	0.60	211.00	2.60
18.10.17	16	8.40	304.60	0.30	50.50	13.20	170.80	3.90	1.27	98.00	0.90
18.10.17	2nd path pumps station	8.3	375.40	0.75	80.80	17.50	189.1	12.00	1.82	114.00	2.00

In the area of plant location point and Rivne NPP site, the main aquifer complexes are the following: ground waters (quaternary aquifer), aquifer complex of Palaeogenic deposits, aquifer of upper Cretaceous deposits, and aquifer of upper Proterozoic deposits (Vendian and Riphean).

In the observation area (OA) of SS Rivne NPP two central groundwater intake points are operated in Rivne oblast. At that, groundwater reserves are proven in the six water intakes. The running water intake points used for the purpose of utility and drinking water supply are Rafalivskyy-1 and Chudlynskiy consumer, Rivne NPP and the town of Varash. Besides, there are a lot of water intakes and separate well holes in the OA, which operate different aquifers with unproved groundwater reserves. They are operated by different consumers based on the special use permissions.

The radiation condition of the on-site ground waters is monitored a regular basis starting from 1983.

Water of the first aquifer is monitored from the check well holes located at the depth of 10…14 m from the surface. Water of the deeper layers is monitored from the piezometric well holes.

Samples are taken from the check well holes ones per a quarter, from the piezometric ones – once per 6 months. The type of monitoring is a measurement of ∑β activity.

For monitoring, a sample of one-liter volume is taken and after being evaporated the total β-activity of radionuclides per α/β is measured with MPC-9604 radiometer (USA). The measurement time is 10000 sec. Monitoring of tritium content in the ground waters started in 2008. The volume activity of tritium samples is measured using the liquid scintillator activity meter Tri-Carb 3170 TR/SL, the measurement time is 3600 sec., MDA (minimum detectable activity) ≅5·103 Bq/m^3.

During the observation period a new well hole №11316 was added in 2009, and the well hole №269 does not exist starting from 2005.

The samples of check well holes are combined by the facilitates, samples of the piezometric well holes are combined by the layers – quaternary and cretaceous aquifers. The combined samples go through the gamma-spectrometry analysis.

During the entire observation period except for May-August 1986, the total β-activity was much lower than the reference value of the allowed concentration 3.00E·1011 Ci/l (1.11×10^3 Bq/m^3); in 1986 the condition of the ground waters in the upper layer of lithosphere was affected by "Chernobyl trace". At that, the concentration of ruthenium was 103, cesium – 134, cesium - 137, lantanium – 140, zirconium – 95, niobium – 95 and silver – 110 m, several orders lower than the allowed ones.

The radiation condition of the ground waters is satisfactory, the content of ^{226}Ra, ^{137}Cs and ^{90}Sr is significantly below the values specified in the regulatory documents НРБУ-97 and ДР-2006 .

Tables 3.1 and 3.2 provide average total β-activity of water in the check well holes during the period from 2004 to 2016 and the average total β-activity of water in the check well holes during the period from 2004 to 2014.

During the planned review of the technical specification for radiation monitoring of Rivne NPP 132-1-Р-ЦРБ, the monitoring of piezometric well holes was excluded from the scope of radiation monitoring before the first half of 2014.

Table 3.6. Average total β-activity of water in check well holes, Bq/m^3.

Check points	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
241 RD of Unit 3	1.24E+02	9.33E+01	9.39E+01	8.33E+01	9.87E+01	1.48E+02	1.24E+02	1.40E+02	1.39E+02	1.11E+02	1.42E+02	2.58E+02	8.10E+01
242 RD of Unit 3	1.14E+02	8.54E+01	6.30E+01	7.99E+01	9.54E+01	1.31E+02	8.58E+01	1.20E+02	1.46E+02	1.43E+02	1.39E+02	1.25E+02	8.30E+01
243 RD of Unit 3	1.58E+02	1.19E+02	8.19E+01	1.07E+02	1.31E+02	1.52E+02	1.84E+02	1.61E+02	1.25E+02	1.21E+02	1.67E+02	2.04E+02	1.70E+02
244 RD of Unit 3	1.86E+02	1.10E+02	1.05E+02	1.00E+02	1.32E+02	1.45E+02	1.36E+02	1.78E+02	1.61E+02	1.31E+02	1.46E+02	1.73E+02	1.59E+02
245 RD of Unit 3	1.81E+02	1.12E+02	1.80E+02	1.18E+02	9.21E+01	1.55E+02	1.45E+02	1.26E+02	2.13E+02	1.30E+02	1.40E+02	1.35E+02	1.17E+02
246 RD of Unit 3	1.41E+02	7.60E+01	9.30E+01	1.21E+02	9.81E+01	1.37E+02	1.41E+02	1.33E+02	1.59E+02	1.15E+02	1.36E+02	1.03E+02	8.10E+01
247 AB of Unit 3	1.12E+02	8.26E+01	9.74E+01	1.12E+02	1.13E+02	7.71E+01	1.30E+02	1.14E+02	1.17E+02	1.29E+02	1.30E+02	1.31E+02	8.40E+01
248 AB of Unit 3	1.22E+02	6.47E+01	8.07E+01	1.25E+02	1.05E+02	1.33E+02	1.60E+02	1.86E+02	1.72E+02	1.49E+02	1.54E+02	2.01E+02	1.31E+02
249 AB of Unit 3	1.09E+02	8.37E+01	8.39E+01	8.65E+01	1.29E+02	1.52E+02	1.22E+02	1.52E+02	2.28E+02	1.91E+02	4.05E+02	8.78E+02	4.14E+02
250 AB of Unit 3	7.66E+01	5.93E+01	6.47E+01	8.22E+01	7.23E+01	1.57E+02	1.51E+02	1.98E+02	1.41E+02	1.72E+02	1.72E+02	3.63E+02	1.76E+02
251 AB of Unit 3	8.40E+01	5.06E+01	7.20E+01	7.99E+01	9.41E+01	1.18E+02	9.58E+01	1.43E+02	1.31E+02	1.56E+02	2.21E+02	3.30E+02	1.42E+02
252 AB of Unit 3	1.10E+02	9.60E+01	5.88E+01	7.79E+01	8.93E+01	1.01E+02	8.28E+01	1.26E+02	9.60E+01	7.20E+01	8.70E+01	2.02E+02	1.02E+02
253 AB of Unit 3	9.59E+01	9.68E+01	8.76E+01	1.00E+02	8.50E+01	1.41E+02	1.19E+02	1.11E+02	1.52E+02	1.34E+02	9.10E+01	2.60E+02	1.76E+02
254 AB of Unit 3	8.96E+01	6.05E+01	5.01E+01	1.44E+02	8.19E+01	1.15E+02	9.24E+01	8.90E+01	1.14E+02	1.18E+02	1.14E+02	1.67E+02	1.31E+02
261 AB of Units 1-2	7.47E+01	6.03E+01	6.54E+01	7.31E+01	8.84E+01	1.02E+02	5.19E+01	1.07E+02	1.19E+02	1.08E+02	7.00E+01	1.13E+02	5.40E+01
262 AB of Units 1-2	1.96E+02	1.53E+02	1.90E+02	1.76E+02	2.22E+02	2.96E+02	1.85E+02	1.39E+02	1.45E+02	1.44E+02	1.43E+02	1.99E+02	1.48E+02
263 AB of Units 1-2	2.17E+02	1.34E+02	1.09E+02	1.16E+02	1.34E+02	1.47E+02	1.42E+02	1.14E+02	1.83E+02	1.48E+02	1.21E+02	1.49E+02	1.26E+02
264 AB of Units 1-2	1.84E+02	1.04E+02	9.54E+01	9.04E+01	5.13E+01	7.47E+01	6.91E+01	9.10E+01	9.90E+01	1.25E+02	1.20E+02	1.06E+02	7.40E+01
265 AB of Units 1-2	6.12E+01	6.21E+01	5.06E+01	1.47E+02	1.69E+02	2.96E+02	3.87E+02	3.99E+02	3.87E+02	4.05E+02	3.41E+02	1.91E+02	1.28E+02
266 AB of Units 1-2	8.82E+01	6.88E+01	5.01E+01	8.97E+01	8.89E+01	1.75E+02	6.57E+01	8.00E+01	8.20E+01	8.80E+01	7.60E+01	8.30E+01	1.12E+02
267 RD of Unit 1	1.97E+02	1.90E+02	8.93E+01	1.96E+02	1.27E+02	1.74E+02	1.29E+02	1.86E+02	1.12E+02	1.33E+02	1.24E+02	2.30E+02	3.94E+02
268 RD of Unit 1	1.05E+02	9.60E+01	6.07E+01	6.95E+01	1.04E+02	1.19E+02	1.41E+02	1.53E+02	1.36E+02	1.51E+02	1.13E+02	1.71E+02	1.38E+02
269 AB of Units 1-2	1.14E+02	-	-	-	-	-	-	-	-	-	-	-	-
270 RD of Unit 2	1.51E+02	1.33E+02	1.37E+02	1.82E+02	2.00E+02	1.62E+02	1.37E+02	1.73E+02	1.25E+02	1.54E+02	1.58E+02	2.22E+02	1.62E+02
271 RD of Unit 2	7.72E+01	1.10E+02	7.32E+01	6.50E+01	6.43E+01	6.52E+01	5.77E+01	8.60E+01	8.50E+01	9.90E+01	1.06E+02	1.48E+02	8.00E+01
272 RD of Unit 2	4.64E+01	9.86E+01	8.14E+01	1.57E+02	8.39E+01	7.49E+01	8.12E+01	9.80E+01	6.50E+01	1.00E+02	8.70E+01	1.48E+02	8.60E+01
273 HPO	1.26E+02	1.07E+02	7.12E+01	1.01E+02	1.39E+02	7.72E+01	4.37E+01	5.10E+01	2.60E+01	4.90E+01	9.40E+01	1.77E+02	4.80E+01

Check points	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
274 HPO	2.31E+02	1.71E+02	1.85E+02	1.53E+02	2.20E+02	2.22E+02	1.80E+02	1.80E+02	1.50E+02	2.73E+02	1.79E+02	1.71E+02	1.16E+02
275 HPO	1.29E+02	1.26E+02	1.21E+02	8.96E+01	1.24E+02	1.80E+02	1.00E+02	1.43E+02	9.80E+01	1.38E+02	1.37E+02	1.59E+02	1.44E+02
49-H SRWS	8.53E+01	8.48E+01	1.21E+02	4.98E+01	7.74E+01	7.60E+01	6.41E+01	1.03E+02	7.90E+01	7.20E+01	1.04E+02	2.05E+02	2.08E+02
50-H SRWS	1.01E+02	5.80E+01	8.36E+01	1.53E+02	8.46E+01	1.04E+02	8.50E+01	3.49E+02	5.40E+01	6.40E+01	8.40E+01	2.01E+02	1.35E+02
Ps-1 RD of Unit 4	1.22E+02	1.02E+02	9.79E+01	1.02E+02	9.27E+01	1.11E+02	1.20E+02	8.40E+01	2.24E+02	1.12E+02	9.70E+01	1.09E+02	9.00E+01
Ps -2 RD of Unit 4	1.27E+02	1.21E+02	7.87E+01	9.80E+01	9.83E+01	1.18E+02	2.28E+02	1.39E+02	1.02E+02	9.90E+01	1.67E+02	1.64E+02	1.09E+02
Ps -3 a RD of Unit 4	1.41E+02	9.49E+01	9.58E+01	1.37E+02	6.43E+01	9.57E+01	6.52E+01	6.80E+01	8.40E+01	6.00E+01	4.60E+01	1.41E+02	4.50E+01
Ps-4 RD of Unit 4	8.93E+01	1.03E+02	6.67E+01	1.08E+02	5.91E+01	7.04E+01	6.18E+01	8.60E+01	3.70E+01	5.30E+01	2.50E+01	1.98E+02	4.30E+01
11316n AB of Units 1-2	-	-	-	-	-	7.28E+01	8.45E+01	9.10E+01	1.09E+02	6.20E+01	6.40E+01	2.26E+02	7.50E+01

RD-reactor department, AB-auxiliary building, SRWS – solid radioactive waste storage

Table 3.7. Average total β-activity of water in piezometric well holes, Bq/m^3.

Check points	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
4N	9.28E+01	8.46E+01	1.27E+02	1.37E+02	6.99E+01	8.72E+01	5.25E+01	7.60E+01	7.30E+01	9.40E+01	3.70E+01
8N	2.62E+02	1.68E+02	1.41E+02	9.23E+01	1.07E+02	1.46E+02	4.30E+02	2.90E+02	1.56E+02	1.95E+02	1.77E+02
40N	1.45E+02	1.37E+02	7.65E+01	1.83E+02	1.08E+02	8.73E+01	1.37E+02	6.01E+02	8.00E+01	6.50E+01	5.00E+01
11N	6.80E+01	9.52E+01	2.83E+02	1.47E+02	2.75E+02	2.30E+02	2.43E+02	2.95E+02	1.67E+02	2.10E+02	2.00E+02
9N	1.34E+02	1.56E+02	1.76E+03	1.12E+02	1.15E+02	1.29E+02	1.36E+02	1.40E+02	1.17E+02	1.35E+02	1.01E+02
9N-M	8.00E+01	7.70E+01	8.61E+01	2.44E+02	2.41E+02	2.87E+02	3.19E+02	3.64E+02	1.65E+02	1.37E+02	6.90E+01
7N	1.11E+02	2.33E+02	6.48E+012	1.25E+02	1.34E+02	1.38E+02	1.61E+02	2.00E+02	1.48E+02	1.74E+02	5.90E+01
127N	1.44E+02	1.14E+02	1.60E+03	1.13E+02	1.18E+02	1.50E+02	1.66E+02	1.69E+02	1.67E+02	1.60E+02	1.54E+02
21M	5.98E+01	5.53E+01	1.53E+03	6.64E+01	3.67E+01	4.32E+01	1.09E+02	1.22E+02	5.20E+01	1.01E+02	6.10E+01
130N	7.92E+01	6.70E+01	9.40E+01	1.15E+02	5.66E+01	1.09E+02	1.10E+02	1.58E+02	1.45E+02	1.55E+02	1.15E+02
22N	1.12E+02	7.16E+01	1.25E+02	1.64E+02	6.61E+01	8.99E+01	2.66E+02	9.67E+02	1.25E+02	1.77E+02	8.28E+02

Check points	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
22N-M	1.67E+02	2.47E+02	4.06E+02	7.72E+01	2.28E+02	1.86E+02	4.31E+02	2.18E+02	1.41E+02	4.69E+02	2.23E+02
131M	6.14E+01	5.83E+01	5.51E+01	1.08E+02	7.78E+01	4.31E+01	5.12E+01	8.00E+01	2.55E+02	6.30E+01	6.10E+01
239N	9.61E+01	6.28E+01	1.64E+03	1.41E+02	8.02E+01	7.32E+01	8.06E+01	8.00E+01	6.80E+01	6.80E+01	3.30E+01
240N	9.95E+01	7.74E+01	9.69E+01	7.39E+01	8.05E+01	8.74E+01	4.08E+02	1.03E+02	7.70E+01	5.10E+01	1.23E+02
236N	1.41E+02	1.17E+02	1.13E+02	8.26E+01	1.18E+02	8.68E+01	9.63E+01	3.64E+02	8.50E+01	1.01E+02	1.20E+02
237N	1.17E+02	9.09E+01	1.49E+02	1.30E+02	1.17E+02	1.12E+02	9.36E+01	1.61E+02	1.25E+02	1.35E+02	8.90E+01
131N	5.63E+021	9.74E+01	1.18E+02	2.38E+02	1.23E+02	1.12E+02	3.86E+02	3.66E+02	1.07E+02	1.43E+02	8.50E+01
1N	1.31E+02	1.23E+02	1.41E+02	1.09E+02	1.39E+02	1.39E+02	1.45E+02	3.12E+02	8.50E+01	6.00E+01	9.20E+01
1N-M	<4.4E+01	1.39E+02	1.65E+03	7.24E+01	5.41E+01	5.41E+01	3.75E+02	7.70E+01	4.00E+01	3.00E+01	4.40E+01

CONCLUSIONS

SS Rivne NPP and its 30-km territory is located within one area (Ш) of South-Polyssya bedded-accumulation lowland plain. The entire territory is situated within the sub-region (Ш-А) Volynskyy Polissya (moraine outwash and terrace plains).

The major part of the 3-km area is occupied by three regions:

First region. 16 – Volynskiy (Kovelsko-Stolinskiy) moraine ridge (northern part),

Second region.17 – Turiyskyy denudation valley (south-western part),

Third region.18 - Kostopilskyy denudation valley (south-eastern part), which represents a small by area section in the 30-km zone of Rivne NPP, which is part of region 14 – UpperPrypyat alluvial outwash plain.

The orographic plan of the territory of SE "Rivne NPP" 30-km area is characterized with the low relief differentiation by the absolute elevations. The main relief type is accumulative and sculptured relief.

The main factor that identifies the structure of the studied territory relief is a Dnieper glacier. The glacigenous relief of the Volynskyy Polissya is characterized by a compound structure and great genetic diversity.

The morainic plain occupies about 20% of the territory. Its biggest massif stretched out along the town of Varash and urban type settlement Rafalivka in the north-eastern direction. Other massifs of the morainic plain are traced: to the west from the river Styr at the distance of 2-4 km, as well as to the west from the town of Manevychi. Smaller moraine isles are observed in the northern part of the territory.

The morainic plain is characterized with the medium elevations up to 180.00 m, flat undulating morphology. It is mostly composed of the moraine with mostly loam-sandy dumped composition of up to 5.00-7.00 m depth.

The modern relief has a distinctly shaped form, associated with the marginal zone of the Dnipro glacier. The Volynskyy terminal moraines consist of separate hills and levees with even tops and smooth slopes. The absolute elevations in certain places achieve 200.00 m and more.

The biggest terminal-moraine ridges are located in the town Manevichi, in the area of the town Varash, urban-type settlement Rafalivka, to the south from the town Volodymyrets. The Rafalivskyy ridge consists of two parts: the first one is located at the right bank of the river Styr within the town Varash. It is asymmetric (with a steeper slope facing the valley), the absolute elevation is up to 211.00 m. The highest part is to the south of the urban-type settlement Rafalivka, the maximum height – 215.50 m, the north-eastern slope is the steepest).

Genetically, the fill-up type prevails among the terminal moraine forms in the Rivne NPP 30-km area with typical interbedding of moraine and fluvial-glacia deposits.

The most widely spread relief type (over 60% of the territory of Rivne NPP 30-km area) is the aqueoglacial plain, which can have different shapes depending on the location of the glacier edge. In the northern part of the territory it relates genetically to the inter-ridge sandr. Here, the absolute plain elevations vary from 160.00 to 180.00 m. In the periglacial zone, the aqueoglacial plain is mostly flat, boggy, represents the plain sandr genetically.

In the northern part of the territory, knob and basin kame relief is widely developed on the background of undulating aqueoglacial plain. The kames have the shape of isometric or oval doomlike or conic hills from 200.00-500.00 m to 1.50-2.00 km, height from 1.00-2.00 to 10.00-15.00 m, rarely up to 20.00 m. In some places, they form the linear stretching, gently-sloping ridges.

To the east from the town of Malevichi, the massif of glaciolacustrine plain is located. It is characterized by the flat boggy relief.

The forms of relief associated with the glacier erosion activity include basins of glacial ploughing and washout. They are located in the north-western part of Rivne NPP 30-km area. The indicated basins are partially inherited by the modern plains.

In the postglacial period of relief formation, the surface of the territory was significantly changed by the glacifluvial, eolian, karst and other processes.

Fluvial (accumulative) relief was formed by the activity of the river Styr and its effluents, as well as left effluents of the river Goryn.

Within the 30-km area of Rivne NPP, the valley has a north-eastern direction from the river Styr to the village Old Chortoryysk, from the village Old Chortoryysk to the town of Varash - north-western direction (burst area of the Volynskyy ridge), and a submeridional direction of the valley is preserved down-stream. The width of the valley varies within significant boundaries: approximately by the village Old Chortoryysk the valley of the river Styr is wide (up to 8.00 km and more), lower along the stream a rapid valley narrowing occurs up to 4.00-5.00 km. There is a relative narrowing (up to 2.00 km) below the village Old Chortoryysk, for instance, in the area of the town Varash.

The structural tectonic structure of Rivne NPP 30-km area is conditioned by its association to the Podilskiy geoblock. The order 2 structure refers to the Manevytskyy block, where the major part of the Rivne NPP 30-km area is located.

The 30-km area of Rivne NPP is divided by a series of tectonic faults of north-eastern and east-west trending.

The grade 1 faults include the Luskyy (Gorynskyy) through-crest tectonic zone located on the south-eastern territory of the 30-km area, i.e. 20.00 km from the Rivne NPP site. The width of the zone is about 20.00 km, its inclination is from subvertical to 600 south-eastern direction. A bench-like displacement of foundation crystalline rocks and borders of volcanogenic- sedimentary sheath in the series of tectonic faults with the amplitude of up to 150.00 – 200.00 m are observed within the borders of the area.

Other large and extended faults and tectonic zones of mantle deposit (grade 1) within the 30-km area of Rivne NPP were not recorded.

Among the grade 2 faults (internal crust faults), the following sublatitudinal tectonic zones are mapped here according to the geologic and geophysical data – Belska, Chortoryyska, and Sarnensko-Varvarivska zone of the north-western strike.

The Belska sublatitudinal zone of faults is traced in the northern part of the territory at the distance of 17.00 km from the NPP with 54.00 km length, i.e. it crosses from the west to the east across the entire 30-km area. The Belska zone represents a series of contiguous displacements with the width from 0.50 to 3.50 km, along which the south wall is lowered for 50.00-350.00 m. The inclination of the zone is subvertical or southern with the angles of 750-800. The depth of the zone deposit is 3.00 – 5.00 km. Presence of landslide deformation is peculiar for the entire area.

The Chortoryyska zone of faults is located in the central part of the 30-km area of Rivne NPP (5.00 km to the south from the plant), from the western border of the territory to crossing with the Lutska (Gorynska) tectonic zone. The width of the zone is from 2.00 to 0.50 km, the inclination is close to vertical. The deposit depth is up to 5.00 km.

From the geological point of view, the presence of graben-like structures of east-west trending is peculiar for this zone of faults; sliding deformations are not typical.

The Sarnenskyy-Varvarivskyy fault of the north-western strike is traced in the north and north-eastern part of the territory of the Rivne NPP 30-km area. It is a constituent part of the deep-seated Central zone of faults. The zone stretches for 50.00 km at the width of up to 8.00 km and consists of a series of the contiguous sub-parallel tectonic faults. The Sarnensko-Varvarivska zone of faults is a poor-meshed extension zone, and it serves as a border between the prevailed compression and extension.

All other tectonic faults located within the 30-km area are of smaller order; as a rule, they are characterized with insignificant vertical shift amplitudes, small length and width, different strike directions. This shows that all faults are intrablock. Most faults have extensions in the deposits of volcanogenic-sedimentary mass of the Vendian, which gradually reduces with the depth. A part of intrablock faults is associated with the mass of crystalline basement, and it occurs weakly in the upper layers as zones with increased fracturing, flexure bends, facies substitution of one sediments with another within the coeval mass.

The fracture faults within the Rivne NPP 30-km area relate to the category of no-amplitude and low- amplitude, low-activity faults. Due to this, it is not to be expecting the occurrence of neotectonic movement during operation of Rivne NPP.

Different depth of the cover (quaternary and paleogene deposits) is conditioned with the lows in the cover of upper cretaceous deposits. Due to quite high permeability of the cover rocks, active penetration of the infiltration waters can occur in the fractured zones that were karsted before in the cretaceous deposits.

Sandy loam in the fracture of the quaternary deposits take a dominating position. Its formation is not homogeneous, carbon differences can be met. At many sections of the sandy loam, multiple layers of sand are traced, oftentime loam. The thickness of sand spits varies from several millimeters to several tens of centimeters. The consistence of sandy loam, which is above the groundwater level, is solid and plastic, and below the groundwater level – plastic and flowing. The density of sandy loam reduces with the depth, at that the difference in the density is quite significant: density of the dry soil in the average reduces from 1.77 to 1.35 t/m^3. This may be the results of karst-suffosion processes (contact suffosion).

The thickness of soils that form the territory of the town Varash is broken into 37 engineering and geological elements (EGE): 1, 3, 3а, 3б, 4, 4а, 5, 5а, 6, 6а, 6б, 6 г, 6д, 7, 7б, 8, 9, 10, 11, 11а, 12, 12а, 13, 13а, 14, 14а, 14б, 15, 15б, 16, 16а, 16в, 20а, 20б, 20в, 20г, 23. Their names, characteristics and indicators of physical and mechanical properties are provided in the attachments.

To eliminate the suffosion and karst processes under the buildings of the construction phase 1, the cementation of the cretaceous layer was performed, as a results of which the fractures in the layer should be cemented. The building basements of the construction phase 2 and following phases are built on the solid plates that guarantees stability and safe operation of the buildings even in case of karst caving of the surface. In addition, other anti-karst activities were implemented.

Part of the exogenic geological processes develops under the influence of natural factors, some of them – under the impact of manmade factors. The sources of influence for development and initiation of exogenic-geological processes also include manmade factors: existing quarries, storage ponds and purification facilities for industrial and household sewage, as well as animal complexes, places of wastewater discharge. Also, meliorative drainage systems are operated in the significant areas.

The suffosion-karst process is most essential among exogenic processes.

According to the karst zonation performed by the Institute of Mineral Resources (MinGeo of former USSR), the site of Rivne NPP is a part of the Central (VI.28) region of Polissya karst oblast.

The karsting rocks are the rocks of the Turonian stage of the upper cretaceous. In some places, the cretaceous has large fractures and void intervals, filled with cretaceous suspension. In the soils that superpose the cretaceous, loosening of the zone is found (result of the suffosion-karst processes).

Under the influence of technogenesis, the karst formation and suffosion-karst processes can intensify.

Presence and development of the surface karst forms indicate the existence of deep systems of the caverns, which redistribute the groundwater run-off.

Karstification of upper cretaceous deposits is of old age; it is evidenced by the conjunction of main faults with hollow forms of old age karst relief [29].

Activation of karst processes in the cretaceous formation took place during the surface raise of the cretaceous rocks, starting from the end of Upper Cretaceous – beginning of the Palaeogenic period, during the Pleiocen and beginning of Pleistocene period.

In the profile of karsting rocks, the levelling of profile permeability is traced, which is a consequence of periodicity of movements of different sections during formation of modern morpho-structures.

Periodicity of karst process is conditioned by the climate and tectonic causes. The levels of increased karstification preserve two levels of karst basis, which is an evidence of this periodicity.

On the Volynskiy Polissya, the karstification of cretaceous deposits appears both in the zone of aeration and in the zone of deep groundwater run-off; here the paleokarst phenomena occurred repeatedly.

Development of the groundwater run-off in the direction of natural and artificial basis of karsting leads to occurrence of inconvertible deformations not only in the geological profile, which quickly forms at the depth of the zone of intense water exchange, but also in the daylight surface. By the area, the fracture density of rocks and karstification are not preserved. The area divergence of the old and modern drainless forms can serve as an evidence of masking effect by the cover on the current karst processes in these sections.

The EGE occurrences on the territory outside the RNPP location point can not influence the stability of Rivne NPP structures due to their remoteness. The EGE intensification, occurrence of natural and manmade exogenic processes in the 30-km area are possible, however, it is not associated by any means with RNPP operation. The analysis of a possibility for EGE intensification can be performed only on the basis of assessment of the manmade impact of all industrial facilities, settlements, and infrastructure.

The analysis of neotectonic and geologo-geophysical studies shows that practically none of the faults along its extension can be related to the tectonic active ones, i.e. faults that are associated with the relative relocations of their sides in the quaternary period during (1-2) x10^6 years.

In the course of complex geologic and seismotectonic analysis, seven seismotectonic zones of four levels of potential seismic activity were indicated near Rivne NPP: potential zones of possible earthquakes (PEZ) of orders 1 and 2 and seismo-tectonic zones of orders 1 and 2. The seismotectonic activity of the last two is very low. The seismic activity of the local potential zones PEZ is estimated as: DBE – magnitude of 5, SSE - magnitude of 6.

Thus, the seismic hazard to Rivne NPP site can be posed only from the earthquakes of the Vrancea zone (Romania) and local potential zones PEZ. Assessment of the seismotectonic potential using a formalization method and the earthquake catalogue for the west of Eastern European platform brings to the conclusions that the areas surrounding Rivne NPP site do not have zones with high values of the seismotectonic potential. There are only several zones at the distance of 40 km to the north from the site with the seismotectonic potential of 2.8 <M <3.9. Based on the general analysis of seismic and seismotectonic situation the conclusion can be that DBE and SSE are of magnitude 5 and 6 for the average soil conditions.

In the accident-free operational mode, the impact of Rivne NPP on the geological environment including the grounswaters is not observed in the 30-km area. It can occur only within the plant site and Rivne NPP location point.

In the 30-km area, the impact of Rivne NPP can be imposed only in case of an accident and radionuclide release.

This section describes the activities applied to prevent or constraint the impact from the Rivne NPP site on the geological environment (influence of the manmade factors on the development of exogenic processes except for the radionuclide contamination), as well as measures applied to prevent the negative impact of the geological and naturally occurred manmade exogenic processes on the Rivne NPP site.

The list of measures applied to prevent or constraint the impact and assessment of their efficiency are provided in Table 1.3. The purpose of these measures is the following:

- improvement of the conditions of the geological environment for levelling the impact of exogenic processes (karst-suffosion processes):
  - anti-karst measures – cementing of the cretaceous layer under the structures of power units 1-3 onsite, and under the buildings of the town of Varash;
  - structures of the main building of power unit 4 constructed on the piles that thrust against the basalt at the depth of 40 m (i.e. the most reliable part of the geological environment is used as the basis of buildings foundation);
- ✓ prevention of soil properties deterioration (reduction of the compression and strength indicators) in the building foundation:
  - monitoring of soils density and humidity using the radio-isotopic logging in the specially equipped well holes along the perimeter of the main buildings of power units 1-3, ventilation stack, diesel generating stations, auxiliary building;
  - similar monitoring along the perimeter of the buildings 4/4, 5/12, 8/2, 10/1, 14/2, 20/2, 34, 140, 364, 374, 387, 396/1 in the town of Varash;
  - building basements of the second and next phases of construction in the town of Varash - on the solid plates, which excludes uneven settlements in case of deteriorated soil properties in the foundation;
- ✓ limitation of impact on the ground waters mode (level, temperature, chemical composition), i.e. minimization of underflooding:
  - monitoring of the ground waters regime (level, temperature, chemical composition);
  - control of the water supply lines state and repairing.

The applied measures aimed at prevention and limitation of possible impact of the Rivne NPP site on the geological environment of the site and the town of Varash are efficient; further development of the exogenic geological processes is not forecasted to occur at the location of structures and buildings basement.

The comprehensive analysis of the soil condition under the building foundation, which was performed using the data of the current and previous studies, allows us to make the following conclusions:

- physical and mechanical properties of the soils that deposit in the building foundation are stable, and some improvement of the soils is distinguished; there are no contra-indications on the foundation's soil condition with regard to further operation of power units 1 and 2;
- karst-suffosion processes got stabilized and have a slowly developing character. The studies revealed some insignificant zones in terms of strength and indicators with the reduced density of cretaceous and upper deposited layers. Occurrence of the karst processes was not identified on the territory of the plant, but their activation is possible in case of violated hydrodynamic regime;
- settling and cores of the buildings and structures are within the allowable limits;
- a complex of anti-karst measures was implemented – cementing of the soil in the foundation of the main buildings, reduction of the groundwater mound gave a positive effect of stabilizing the geological terrain;
- comprehensive monitoring accomplished at the plant site (i.e. soil condition, groundwaters regime, building cores and settling, territory relief) allowed a timely detection of unreliable processes and take measures on elimination of their causes (including repairing of utility service lines, additional planning of territories).

At the moment of studies, the geological terrain of the site is in balance and the geotechnical properties of the soils in the basis of the building foundation, included to the complex of power units 1 and 2, ensure the reliability of the buildings and structures of the NPP.

However, due to the fact that the site is characterized by the complex engineering and geological conditions, it is necessary to perform continuous comprehensive monitoring of the geological environment and state of the buildings and structures to ensure further safety of operation. The monitoring activities include:

- hydro-geological monitoring – over the groundwaters regime;
- monitoring of the soils condition (density, humidity) using the radio-isotopic logging in the specially equipped well holes along the perimeter of the main buildings;
- monitoring of the settling and cores of buildings and structures;
- karst monitoring of the territory of Rivne NPP site.

According to the data of recent studies and taking into account the materials of surveys conducted during different years of RNPP operation, the territory zonation map compiled in 1987 (code 85-14-08-10912) was updated according to the current soil conditions and degree of the karst development for the structures and installations that define the safety system of power unit 3 operation. All structures and installations that define the safety of power unit 3 are related to the subzone, which is safe in terms of possible occurrence of karst-suffosion processes owing to the engineering measures implemented in this area.

To compare the indicators of physical and mechanical properties of the soils that form an engineering and geological profile within the active area of the studied installations, the materials of surveys conducted in the different periods of plant operation were analyzed. The study included the following activites: correlation of the intermediated physical and mechanical indicators for soils within the active area of the studied installations, material analyses from the surveys conducted in the different periods of plant operation, and obtaining of data during current surveys and studies. The survey results showed that during operation of power unit 3, the deformation indicators of strength for all the engineering and geological elements differentiated in the soil thickness did not undergo significant changes.

The results of laboratory studies on identification of possible developments of the chemical and mechanical suffosion in the cretaceous layer demonstrated that under the existing boundary conditions (insignificant pressure gradients and degree of cretaceous deposits salinity) there are no prerequisites for rapid development of the karst-suffosion processes within the area of the buildings of power units 1-4. Thus, the main objective is to preserve the existing boundary conditions for lifetime extension of power units 1-4 buildings.

The results of cross-hole acoustic measurements performed by the All-Soviet Union Institute for Geophysics and Geochemistry and the data obtained in 2014 by the State Enterprise "Kyiv Institute of Engineering Surveys and Research "Energorpoekt" practically coincide. The velocity characteristics of the cretaceous deposits in 1983 and 2014 are within the same range of 1600 m/sec – 2000 m/sec, which demonstrates stability of the soils behavior within the studied area.

According to the data of radio-isotopic studies, it is peculiar for the soils of the geological profile to have variability in the dry soil density indicators, which do not exceed the measurement accuracy (0.05 g/cm^3). Most likely, such changes in the density values are conditioned by the peculiarities of the instrumentation work and in some cases they can be an evidence of quite slow progression of the karst-suffosion processes, which should be monitored on a regular basis.

The obtained results of the density and humidity study demonstrated the stable state of soils in the basis of building foundation. The identified local changes of the soil density do not influence the safe operation of the facility.

The regulatory forecast of the safe plant operation under the conditions of current engineering and geological situation and peculiarities of the manmade load requires the continuous on-line monitoring of hydro-geological situation, state of buildings, density of soils in the buildings foundation, karst monitoring. For this purpose, the following is recommended:

- arrangement of two observation well holes for the soil aquifer observations (well hole is currently arranged at the upper cretaceous aquifer in the area of ZPSO building);
- siting of additional types in the area of south-western area of the special building SK-2, ZPSO building and pump station for monitoring of their settling;
- including of the territory around the pump station and ZPSO building to the routes of karst monitoring;
- observation well-holes on the soil and cretaceous aquifers should be included to the list of selected ones for the purpose of chemical analysis;
- consider the possibility for further performance of cross-hole seismic profiling (CSP) within the Rivne NPP site, owing to which the informative data were obtained during the current studies;
- to accomplish the on-line monitoring on a regular basis (once per 3-5 years), its analysis should be performed.

Having compiled all the relevant factors, the engineering and geological situation within the power unit 3 buildings and installations is acceptable for its lifetime extension, which includes:

- karst monitoring did not identify occurrences of active karst developments within the buildings of power units 1-4;

- observation data on settling of the buildings of power units 1-4 showed no exceedance of the allowed values;
- hydro-geological situation as per the data of hydro-geological monitoring is characterized as stable and controllable by all relevant indicators;
- soil condition within the active area of the buildings of power units 1-4 ensure reliability for operation of the buildings.

From the hydro-geoligical point of view, the Rivne NPP site is located at the graded ridge with the planned elevation of 188.5 m. The absolute elevations of the natural relief before the plant construction were 180.00 – 189.00 m, and in some parts they achieved 190.00 – 193.00 m. The planning elevation was 188.50 m in the area of main buildings location. The following aquifers and complexes are deposited here, from the top to the bottom:

- filled-up soils (in separate sections) and natural quaternary deposits: sands, then sandy loam underneath, and loam oftentimes. The layer subface is traced at the depth in average of 15.00 ÷ 25.00 m from the planning elevation, the oriented absolute elevations are mainly 166.00 ÷ 168.00 m. The complex is aquiferous, unconfined (ground waters), which is fed by the atmosphere precipitation, partially by overflows from other aquifers. The depth of the groundwater level is 7.00 ÷ 15.00 m, and deeper in some places. The amplitude of seasons fluctuations of ground water level is 1.00 ÷ 2.00 m. The main off-loading of the aquifer complex is in the southern direction from the plant site, specifically in the valley of the river Styr. The horizon is monitored from three well holes of the steady-state observation hydro-geological network for the “perched water” and from 123 well holes for other ground waters;
- aquifer of the upper cretaceous deposits. The dominating position in the section is occupied by the fractured chalk, where the karst-suffosion processes are developed (hollow spacing, big fractures filled up with cretaceous suspension or “healed” with pieces of rocks, which are deposited above – sand, sandy loam, sometimes clay, often in the suspended state). The general depth of the deposits is 15.00 m, the subface of the layer at the absolute elevations is 148.00 ÷ 151.00 m.
- in the upper part of cretaceous marl layer, there is an area with the water-resistant clay mass that include marl pieces. The depth of this confined aquifer of ground water at the site is 25.00 ÷ 40.00 m. The aquifer is monitored from 54 well holes of the steady-state observation hydro-geological network;
- aquifer with the deposits of Berestovetskiy series of Upper Proterozoic is widely spread, sustained in the extend and depth. The water-containing rocks include fractured basalts and various grainy fractured tuff (kunkur). The water-resisting layer is represented by the tuffs that deposit in the upper part of the structure. The separating layer between the upper Proterozoic and upper Cretaceous aquifers is massive chalk, but due to its little spreading, there is a hydraulic connection of the aquifers. That is why the elevations of piezometric level in both aquifers do not differ much. Feeding occurs due to water infiltration from the upper deposited aquifers through the fracture system, partial feeding – from the lower deposited aquifers. The aquifer is confined. The aquifer deposit depth at the site is 40.0-45.00 m. The aquifer is monitored from 13 well holes of the steady-state observation hydro-geological network.

The hydro-geological observations include the following activities:

- measurement of the water level and temperature in the well holes;
- measurement of the water temperature along the entire shaft of the well hole – temperature logging;

- water pumping from the well holes;
- sampling of water from the well holes for identification of the chemical composition of ground waters;
- checkup of the state of hydro-geological observation well holes.

The sanitary protection zones of the first ring of artesian wells of the village of Ostriv are separated and fenced. The area of sludge collector and polygon of the construction and industrial waste from Rivne NPP is monitored by the environmental and chemical laboratory.

In general, changes in the groundwater chemical composition are relatively small at the Rivne NPP site (except for certain sections), which demonstrates practical absence of the chemical pollution of ground waters, except for the area of special water treatment facility (SWT). Here, the manmade "perched water" was formed and pollution of ground waters occurred. Mineralization of "perched water" is high: dry solid - 25700 mg/dm^3, at that content of HCO_3^- is 4607 mg/dm^3, CO_3^{2-} - 7080 mg/dm^3, Cl^- - 1846 mg/dm^3, SO_4^{2-} - 2525 mg/dm^3, Na+ + K^+ - 8073 mg/dm^3, bicarbonate alkalinity is 8720.

Accordingly, the groundwater mineralization in this section is much higher than on the rest territory of the plant site: dry solid is 1328-5250 mg/dm^3, due to the high content of cations, anions; the bicarbonate alkalinity is 260 – 640. Pollution of the upper cretaceous aquifer did not practically occur.

In general, during the entire period of Rivne NPP 1-4 operation the groundwater dry solid value increased up to 200-400 mg/dm^3 compared to the pre-operational period, when the dry solid value was 50-100 mg/dm^3. The local manmade pollution of the ground waters was observed in the SWP area, where groundwater mineralization was much higher than on the territory of the plant site: dry solid was 1328 mg/dm^3 – 5250 mg/dm^3, bicarbonate alkalinity was 26-64 of German degrees.

Analysis of the reference characteristics demonstrates that operation of Riven NPP does not introduce significant changes into the quality of ground waters. The radiation condition of the ground waters is satisfactory, the content of ^{226}Ra, ^{137}Cs and ^{90}Sr is significantly lower than the values specified in the regulatory documents НРБУ-97.

LIST OF REFERENCES

1. Law of Ukraine “On Environmental Impact Assessment”, Records of the Verkhovna Rada of Ukraine, № 29, 2017, p.315
2. DNB A.2.2-1-2003 “Composition and Content of Materials for Environmental Impact Assessment.” (OVNS)»
3. DNB A.2.2-1-2003 “Guideline for Development of Materials for Environmental Impact Assessment”
4. Rivne NPP. Power Unit 4. Technical Report on Further Research of Seismic Hazard, in 3 volumes. Volume 3 – Justifying Materials for Complex Geologo-Geophysical Works, in 12 books. Books 4 and 5. Geomorphological and Neotectonic Studies. K.: Institute of Geography of the National Academy of Science of Ukraine, 1999.
5. Report on Environmental Condition in Rivne Regionin 2016./Department of Ecology and Natural Resources of Rivne State Obladministration, Rivne, 2017 – 224 p.
6. Vlasov B.I., Volovnyk B.Ya., Gruzman G.G. and others. Geological Map of Prypyat Levee in the scale 1:50 000, pages, M-35-16-Г (Old Rafalivka), M-35-17-В (Vladymyrets), M-35-28-Б (Rafalivka), M-35-29-А (Romeyki). Lviv: Lviv Geological Expedition of the Trest “KyivGeology”, 1972. GRGP Fund “North Geology”, №3504.
7. Volovnyk B.Ya., Matisov M.I. and others. Report on the Topic “Development of Geological Forecast Map of the North-west of Ukraine in the Scale 1:200 000 with large-scale insets”. K.: GRGP Fund “North Geology”, 1981.
8. Gochachko A.A., Stepas N.V., Turuchko I.A., Romanyuk L.V. Report of Hydro-geological and Engineering-geological Survey 1:50 000 Scale for the Purpose of Melioration on the territory of pages M-35-17-Б, В, Г; M-35-29-А, Б. Rivne: 1983. GRGP Fund “North Geology”, №5312.
9. Kharechko V.O. and others. Study of Modern Geological Processes on the Territory of Volynskaya and Rivnenskaya Oblasts of Ukraine. Report of the Rivne Complex Geological Survey Panel for 1991-1997. K.: GRGP Fund “North Geology”, 1997.
10. Garbuz I.S. and others. Further Geological Study of the territory of pages M-35-16-Г, M-35-17-В, M-35-28-В, M-35-29-А in the scale 1:50 000, Report ГСО-2 for 1989 – 1994. GRGP Fund “North Geology”, №6250.
11. Stepas M.V. Hydrogeological and Engineering-geological Survey M 1:50 000 for the Purpose of Industrial Construction on the Territory of Pages M-35-16-Г, M-35-17-В, M-35-28-Б, M-35-29-А (the town of Kuznetsovsk). Report of Rivne Panel on activities conducted in 1989-1998. K.: 1998. GRGP Fund “North Geology”.
12. Rivne NPP. Power Unit 4. Technical Report on the Results of Continued Research of Seismic Hazard, in 3 volumes. Volume 3 – Justifying Materials for Complex Geologic-Geophysical Works, in 12 books. Books 7 and 8. Further Study of fault-block tectonics of the territory of Rivne NPP region and location point. K.: GRGP Fund “North Geology”, 1999.
13. Western Ukrainian NPP (for the Engineering Design). Contents of Engineering Geological Materials Issued for the Engineering Design of Western Ukrainian NPP. Leningrad Department of TeploElectroProject, 1972.

14. Western Ukrainian NPP (for the Engineering Design). Engineering Geological Conditions of the Plant Site and Hydro-Engineering Structures. Leningrad Department of TeploElectroProject, 1972.

15. Western Ukrainian NPP (Rafalivskyy Point). Working Drawings. Report on the Engineering and Geological Surveys. On-site and Cooling Towers with Pump Stations and Circulation Lines. Lviv Department of TeploElectroProject, 1972.

16. Rivne NPP, Feasibility Study. Extension to 3380-4880 MW. Report on the Engineering and Geological Surveys. Lviv Department of TeploElectroProject, 1980.

17. Rivne NPP. Extension (1st phase). Revision of Engineering Design. Part 14, Section 1, Volume 1. Materials on the Engineering Surveys. Lviv Department of TeploElectroProject, 1980.

18. Rivne NPP. Extension (2nd phase). Draft. Part 13. Materials on the Geological Surveys. Section 13.2 - Engineering and Geological Surveys in 6 volumes, 16 books. Kyiv Department of TeploElectroProject, 1983.

19. Rivne NPP. Extension (2nd phase). Draft. Part 13. Materials on the Engineering and Geological Surveys. Section 13.2 - Engineering and Geological Surveys (additional). Report on the Engineering and Geological Conditions for Open Switchgear-750kV. In 2 books. K.: Kyiv Department of TeploElectroProject, 1985.

20. Rivne NPP, Feasibility Study for Extension to 6000 MW. Volume 5. Materials on the Engineering and Geological Surveys, in 2 books. K.: KOATEP, 1986.

21. Rivne NPP. Power Unit 3. Working Drawings. Book 1. Technical Report on the Engineering-geodesic and Engineering-geological Surveys Onsite. Lviv: Lviv Department of AtomTeploElectroProject, 1985.

22. Rivne NPP. Power Unit 4. Working Documentation. Report on the Engineering and Geological Conditions of the Site, in 2 books. K.: Kyiv Department of AtomTeploElectroProject, 1985.

23. Rivne NPP. 2nd Phase (Power Unit 4). Working Documentation. Report on the Engineering and Geological Conditions of Structures Location Onsite. In 2 books. K.: Kyiv Department of AtomTeploElectroProject, 1987.

24. Rivne NPP. Housing and Civil Construction. Stage – design. Report on the Engineering and Geological Conditions of the area of the 2nd Phase Urban Type Settlement Kuznetsovsk. In 2 books. K.: Kyiv Department of AtomTeploElectroProject, 1982.

25. Rivne NPP. Urban Type Settlement Kuznetsovsk. 1st Phase Construction. Report on the Engineering and Geological Survey M 1:5 000. In 2 books. Lviv: AtomTeploElectroProject, 1984.

26. Rivne NPP. Power Unit 4. Technical Report on the Results of Further Research of Seismic Hazard, in 3 volumes. Volume 3 – Justifying Materials for Complex Geologo-Geophysical and Geodesic Works, in 12 books. Books 4 and 5. Geomorphological and Neotectonic Studies. K.: Institute of Geography of the National Academy of Science of Ukraine, 1999.

27. Rivne NPP. Complex Analysis of Soil Condition at the Foundation of Buildings, Structures of Rivne NPP Power Unit 3 for the Purpose of Lifetime Extension. Scientific and Technical Report on Complex Engineering-geological and Geophysical Studies. Book 1. Explanatory Note, Text Attachments./Ministry of Fuel and Coal Industry of Ukraine. State Enterprise "Kyiv Scientific and Research Institute for Engineering Survey and Research EnergoProject", Kyiv, -2014- 97 p.

28. Report on Studying of Modern Exogenic Geological Processes on the Territory of Volynskaya and Rivnenska Oblasts. In 3 volumes. Rivne: Rivne Geological Survey Expedition GSE, 1982

29. Kharchenko V.O. and others. Studying of Modern Exogenic Geological Processes on the Territory of Volynskaya and Rivnenska Oblasts of Ukraine. Report of the Rivne Complex Geological Survey Panel for 1991-1997. K.: GRGP Fund “North Geology”, 1997.

30. Rivne NPP, 1st Phase Construction, Onsite. Power Units 1, 2, 3. Study of the Karst-suffosion Processes. Report on the Engineering and Geological Surveys. In 2 volumes. Lviv: Lviv Department of AtomTeploElectroProject, 1986.

31. Rivne NPP. Power Unit 4. Technical Report on the Results of Further Research of Seismic Hazard, in 3 volumes. Volume 1, Books 1, 2 – Preliminary Conclusion. Simferopol: Seismology Department of the Geophysics Institute of the National Academy of Science of Ukraine, 1999.

32. Rivne NPP. Power Unit 4. Technical Report on the Results of Further Research of Seismic Hazard, in 3 volumes. Volume 3, Book 12. Seismic microzonation. Methods of engineering geological analogies and seismic impedance. K.: Kyiv Scientific and Research Institute for Engineering Survey and Research EnergoProject, 1999.

33. Rivne NPP. Power Unit 4. Technical Report on the Results of Further Research of Seismic Hazard, in 3 volumes. Volume 3, Book 6. Tectonomagnetic studies. K.: Carpathian Department of the S.I. Subbotin Institute of Geophysics of the National Academy of Science of Ukraine, 1999.

34. Rivne NPP. Power Unit 4. Technical Report on the Results of Further Research of Seismic Hazard, in 3 volumes. Volume 3, Book 10. Deep Bench Marks for Geodesic Monitoring. K.: Kyiv Scientific and Research Institute for Engineering Survey and Research EnergoProject, 1999.

35. Rivne NPP. Site. Power Units 1 and 2. Lifetime Extension. Research and Scientific Report on Engineering and Geological Surveys (Complex Analysis of the Soil Condition at Foundation of the Buildings and Structures)/Ministry of Fuel and Energy of Ukraine. State Enterprise “Kyiv Scientific and Research Institute for Engineering Survey and Research EnergoProject”, 2008 – 56 p.

36. Non-technical Resume. Materials on Justification for Lifetime Extension of Rivne NPP Power Unit 3./ Ministry of Fuel and Energy of Ukraine. State Enterprise “Kyiv Scientific and Research Institute for Engineering Survey and Research EnergoProject”, SE “Rivne NPP”, 2018, -58 p.

37. Report on the Environmental Impact of Non-radiation Factors of Rivne NPP of NNEGC “Energoatom” for 2017./ Ministry of Fuel and Energy of Ukraine. State Enterprise “Kyiv Scientific and Research Institute for Engineering Survey and Research EnergoProject”, SE “Rivne NPP”, 2018, -25 p.

38. DGN 6.6.1. – 6.5.061-98 “Norms of Radiation Protection of Ukraine (NRBU-97)”, Ministry of Health Protection of Ukraine, Kyiv, 1998.

39. Allowable Level of ^{123}Cs and ^{90}Sr radionuclides C in the Products and Portable Water (State Health Normatives).

ATTACHMENT A

RNPP Location Point (including the town of Varash). Indicators of physical and mechanical properties of sandy, loamy and cretaceous soils

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, %: Gravel 5-2	Sand Fractions, mm: 2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1	Uniformity coefficient Cv	Natural moisture of soil W	Limits: Liquid limit, W_L	Plastic limit, Wp	Plasticity index Ip	Index of liquidity I_L	Solid particles density ρ_s, g/cm³	Soil density ρ, g/cm³	Soil skeleton density ρ_d, g/cm³	Porosity n, %	Porosity fractions e	Internal friction angle φ, degree	Soil adhesion s, kPa (kgf/cm²)	Deformation module E, MPa (kgf/cm²)
1	Turf	bQ_4								2.11					1.56	1.03	0.33	78.8	3.73	7	10 (0.10)	3 (30)
3	Fine sand, uniform by grain size composition, medium density, water-saturated	aQ_4	0.5	1.5	2.9	32.3	47.8	15.0	2.6	0.20					2.65	1.98	1.65	37.9	0.61	34	3 (0.03)	32 (320)
3a	Sandy silt, non-uniform by grain size composition, high density, water-saturated	aQ_4	1.0	3.3	4.6	30.1	31.2	29.8	4.5	0.16					2.65	2.12	1.83	31.0	0.45	36	8 (0.08)	30 (300)
3б	Fine sand, uniform by grain size composition, low-density sand, water-saturated	aQ_4	0.5	2.6	3.4	37.7	50.5	5.3	2.2	0.22					2.65	1.80	1.48	44.1	0.79	26	0	11 (110)
4	Sandy loam, high-plasticity	aQ_4								0.15	0.19	0.15	0.04	0	2.67	1.91	1.66	37.9	0.61	27	15 (0.15)	19 (190)
4a	Loam, intermediate-plasticity	aQ_4								0.14	0.21	0.13	0.08	0.12	2.69	1.54	1.35	49.7	0.99	16	14 (0.14)	8 (80)
5	Sand, medium-grained, uniform by grain size composition, medium density, water-saturated	aQ_4	0.4	2.5	2.9	63.2	28.6	2.4	2.3	0.21					2.65	2.01	1.66	37.5	0.60	36	1 (0.01)	35 (350)
5a	Medium-grained sand, uniform by grain size composition, low density, water-saturated	aQ_4	0.4	2.5	2.9	63.2	28.6	2.4	2.3	0.25					2.65	1.91	1.53	42.2	0.73	31	0	14 (140)

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, % Gravel	Sand Fractions, mm					Uniformity coefficient Cv	Natural moisture of soil W	Limits		Plasti-city index	Index of liquidity	Solid particles density	Soil density	Soil skeleton density	Poro-sity	Porosity fractions	Internal friction angle	Soil adhesion	Defor mation module
			5-2	2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1			Liquid limit, W_L	Plastic limit, Wp	Ip	I_L	ρ_s, g/cm³	ρ, g/cm³	ρ_d, g/cm³	n, %	e	φ, degree	s.kPa (kgf/cm²)	E.MPa (kgf/cm²)
6	Fine sand, uniform by grain size composition, medium and high-density, from low water-saturated to water-saturated	aQ_3	0.1	0.6	4.0	35.9	45.0	14.4	2.8	0.06 *) ---------- 0.23					2.65	1.70-1.83 *) -- --- ------ - 1.97-2.13	1.60-1.73	34.6-39.8	0.53-0.66	33	2 (0.02)	31 (310)
6б	Fine sand, uniform by grain size composition, low-density, water-saturated	aQ_3		0.3	0.9	16.2	61.3	21.3	2.4	0.27					2.65	1.87	1.47	44.4	0.80	26	0	10 (100)
6а	Sandy silt, uniform by grain size composition, medium and high-density, low water-saturated	aQ_3		0.1	0.3	6.9	64.2	28.5	2.3	0.09					2.65	1.71 -1.92	1.57-1.77	33.3 -40.8	0.50-0.69	31	4 (0.04)	24 (240)
6г	Sandy silt, non-uniform by grain size composition, medium and high-density, water-saturated	aQ_3	1.2	4.5	16.6	6.2	43.5	28.0	3.8	0.23					2.65	1.97 -2.06	1.60-1.68	36.7 -39.8	0.58-0.66	30	4 (0.04)	21 (210)
6д	Sandy silt, uniform by grain size composition, low-density, water-saturated	aQ_3		0.2	0.4	4.2	68.8	26.4	2.2	0.26					2.65	1.78	1.41	46.8	0.88	24	0	8 (80)
7	Medium-grained sand, non-uniform by grain size composition, medium density, from low water-saturated to water-saturated	aQ_3	1.1	6.0	12.6	51.4	19.8	9.1	3.5	0.06 *) ---------- 0.21					2.65	1.80 *) ----------- -2.06	1.70	35.9	0.56	36	1 (0.01)	35 (350)
7б	Medium-grained sand, non-uniform by grain size composition, low-density, water-saturated	aQ_3		1.8	10.8	50.9	25.5	11.0	3.5	0.24					2.65	1.86	1.50	43.5	0.77	29	0	12 (120)

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, % Gravel	Sand Fractions, mm					Uniformity coefficient Cv	Natural moisture of soil W	Limits		Plasti-city index Ip	Index of liquidity I_L	Solid particles density ρ_s. g/cm³	Soil density ρ. g/cm³	Soil skeleton density ρ_d. g/cm³	Poro-sity n. %	Porosity fractions e	Internal friction angle φ. degree	Soil adhesion s.kPa (kgf/cm²)	Deformation module E.MPa (kgf/cm²)
			5-2	2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1			Liquid limit, W_L	Plastic limit, Wp										
8	Loam, high-plasticity	aQ_3								0.20	0.25	0.16	0.09	0.44	2.69	2.10	1.75	35.1	0.54	23	34 (0.34)	25 (250)
9	Sandy loam, low and high-plasticity here and there	aQ_3								0.17-0.22	0.23	0.18	0.05	<0-0.80	2.67	2.02-2.06	1.70-1.73	35.1-36.3	0.54-0.57	26	15 (0.15)	21 (210)
10	Coarse sand, non-uniform by grain size composition, medium density, water-saturated	aQ_3	4.8	25.6	24.0	31.5	9.9	4.2	3.7	0.23					2.65	2.05	1.67	37.1	0.59	39	0	35 (350)
11	Fine sand, uniform by grain size composition, high density, from low water-saturated to water-saturated	fgQ_2dn	0.1	0.9	6.8	36.9	41.4	13.9	2.3	0.09 *) --------- 0.23					2.65	1.83-1.87 *) ------------- 2.07-2.11	1.68-1.72	35.1-36.7	0.54-0.58	35	3 (0.03)	30 (300)
11a	Fine sand, uniform by grain size composition, low-density, water-saturated	fgQ_2dn			1.2	20.2	64.2	14.4	2.4	0.30					2.65	1.86-1.95	1.43-1.50	43.5-45.9	0.77-0.85	26	0	11 (110)
12	Sandy loam, low and high-plasticity	fgQ_2dn								0.12-0.15	0.18	0.13	0.05	<0-0.50	2.67	2.02-2.05	1.76-1.78	33.3-34.2	0.50-0.52	24	30 (0.30)	25 (250)
12a	Sandy loam, high-plasticity	fgQ_2dn								0.22	0.24	0.18	0.06	0.67	2.67	1.93-1.96	1.58-1.61	39.8-40.8	0.66-0.69	22	5 (0.05)	18 (180)
12б	Sandy loam, high-plasticity, fluid consistency here and there	fgQ_2dn								0.21-0.29	0.24	0.19	0.05	0.40-(>1)	2.67	1.90-1.94	1.47-1.50	43.8-44.8	0.78-0.81	18	1 (0.01)	13 (130)
12в	Sandy loam, fluid consistency	fgQ_2dn								0.34	0.24	0.19	0.05	>1	2.67	1.80-1.82	1.34-1.36	49.0-49.7	0.96-0.99	15	0	8 (80)

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, %: Gravel 5-2	Sand Fractions, mm: 2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1	Uniformity coefficient Cv	Natural moisture of soil W	Limits: Liquid limit, W_L	Plastic limit, Wp	Plasti-city index Ip	Index of liquidity I_L	Solid particles density ρ_s, g/cm^3	Soil density ρ, g/cm^3	Soil skeleton density ρ_d, g/cm^3	Poro-sity n, %	Porosity fractions e	Internal friction angle φ, degree	Soil adhesion s, kPa (kgf/cm^2)	Deformation module E, MPa (kgf/cm^2)
13	Medium-grained sand, non-uniform by grain size composition, medium density with high-density sublayers, from low water-saturated to water-saturated	fgQ_2dn	0.2	3.7	16.5	43.5	22.8	13.3	3.1	0.08 *) --------- 0.21					2.65	1.79-1.86 *) ------------- 2.01-2.08	1.66-1.72	35.1-37.5	0.54-0.60	36	1 (0.01)	35 (350)
13a	Medium-grained sand, non-uniform by grain size composition, low-density, water-saturated	fgQ_2dn	0.2	3.7	16.5	43.5	22.8	13.3	3.1	0.28					2.65	1.97	1.54	41.9	0.72	29	0	16 (160)
14	Sandy silt, non-uniform by grain size composition, high-density, low-water and water-saturated	fgQ_2dn	0.1	1.4	4.8	17.9	37.5	38.3	4.2	0.11					2.65	1.89-1.90	1.70-1.71	35.5-35.9	0.55-0.56	32	5 (0.05)	23 (230)
14a	Sandy silt, non-uniform by grain size composition, medium density, water-saturated	fgQ_2dn	0.1	1.4	4.8	17.9	37.5	38.3	4.2	0.27					2.65	1.88-2.04	1.48-1.61	39.4-44.1	0.65-0.79	25	1 (0.01)	11 (110)
14б	Sandy silt, non-uniform by grain size composition, low-density, water-saturated	fgQ_2dn	0.3	0.7	2.1	24.6	39.7	32.6	4.0	0.33					2.65	1.88	1.41	46.8	0.88	24	0	9 (90)
15	Coarse sand, non-uniform by grain size composition, high density, water-saturated	fgQ_2dn	2.0	2.0	47.0	20.0	18.0	11.0	3.4	0.24					2.65	2.13	1.72	35.1	0.54	38	1 (0.01)	39 (390)
15б	Coarse sand, non-uniform by grain size composition, low-density, water-saturated	fgQ_2dn	2.0	2.0	47.0	20.0	18.0	11.0	3.4	0.27					2.65	1.90	1.50	43.5	0.77	28	0	16 (160)
16	Loam, from solid to hard plastic consistency	fgQ_2dn								0.14-0.17	0.24	0.15	0.09	<0-0.50	2.69	1.97	1.71	36.3	0.57	24	36 (0.36)	25 (250)
16a	Loam, soft and fluid plastic consistency	fgQ_2dn								0.27	0.27	0.18	0.09	0.6-1.0	2.69	1.93	1.52	43.5	0.77	17	18 (0.18)	10 (100)

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, %						Uniformity coefficient Cv	Natural moisture of soil W	Limits		Plasti-city index Ip	Index of liquidity I_L	Solid particles density ρ_s, g/cm^3	Soil density ρ, g/cm^3	Soil skeleton density ρ_d, g/cm^3	Poro-sity n, %	Porosity fractions e	Internal friction angle φ, degree	Soil adhesion s, kPa (kgf/cm^2)	Deformation module E, MPa (kgf/cm^2)
			Gravel	Sand Fractions, mm							Liquid limit, W_L	Plastic limit, Wp										
			5-2	2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1														
16в	Clay with mixture of organic substances, intermediate-plasticity	fgQ_2dn								0.36	0.36	0.33	0.37	0.08	2.69	1.90	1.40	47.9	0.92	16	41 (0.41)	14 (140)
17	Fine sand, low-density, water-saturated	P_3hr								0.30					2.66	1.90	1.46	45.1	0.82	26	0	14 (140)
17a	Sandy silt, non-uniform by grain size composition,low-density, water-saturated	P_3hr				7.5	50.7	41.8	3.3	0.30					2.66	1.90	1.46	45.1	0.82	24	0	12 (120)
17б	Medium size sand, uniform by grain size composition, low-density, water-saturated	P_3hr	0.5	1.0	3.9	64.8	19.3	10.5	2.4	0.30					2.66	1.90	1.46	45.1	0.82	28	0	16 (160)
17в	Coarse sand, low-density, water-saturated	P_3hr								0.30					2.66	1.90	1.46	45.1	0.82	28	0	16 (160)
18	Sandy loam, high-plasticity	P_3hr								0.24	0.27	0.21	0.06	0.50	2.69	1.96	1.58	41.2	0.70	22	12 (0.12)	13 (130)
18a	Sandy loam, fluid-plastic consistency	P_3hr								0.30	0.28	0.23	0.05	1.40	2.69	1.98	1.52	43.5	0.77	18	9 (0.09)	9 (90)
19	Loam, from intermediate to low-plasticity	P_3hr								0.24-0.25	0.32	0.22	0.10	0.20-0.30	2.71	1.96	1.57	42.2	0.73	21	23 (0.23)	14 (140)
19a	Loam, fluid-plastic consistency	P_3hr								0.28	0.30	0.19	0.11	0.82	2.71	2.01	1.57	42.2	0.73	17	18 (0.18)	11 (110)

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, %: Gra-vel 5-2	Sand Fractions, mm: 2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1	Uniformity coefficient Cv	Natural moisture of soil W	Limits: Liquid limit, W_L	Plastic limit, Wp	Plasti-city index Ip	Index of liquidity I_L	Solid particles density ρ_s. g/cm³	Soil density ρ. g/cm³	Soil skeleton density ρ_d. g/cm³	Poro-sity n. %	Porosity fractions e	Internal friction angle φ. degree	Soil adhesion s.kPa (kgf/cm²)	Deformation module E.MPa (kgf/cm²)
19б	Clay, from intermediate to low-plasticity	P_3hr								0.34-0.38	0.60	0.27	0.33	0.21-0.33	2.71	1.82	1.34	50.5	1.02	12	34 (0.34)	10 (100)
19в	Clay, high plasticity	P_3hr								0.38	0.49	0.24	0.25	0.56	2.71	1.82	1.32	51.2	1.05	7	29 (0.29)	7 (70)
20а	Chalk, liquid and fluid-plastic consistency	K_2t								0.39					2.70	1.78-1.92	1.28-1.38	49.0-52.6	0.96-1.11	15	16 (0.16)	12 (120)
20б	Chalk, intensely fractured	K_2t								0.32					2.70	1.86-1,90	1.41-1.44	46.8-47.9	0.88-0.92	22	-	20(200)
20в	Chalk, fractured	K_2t								0.32					2.70	1.86-1,90	1.41-1.44	46.8-47.9	0.88-0.92	22	-	20(200)
20г	Chalk, massive, hard and soft-plastic consistency	K_2t								0.34					2.70	1.85-1.92	1.38-1.43	47.1-49.0	0.89-0.96	20	25 (0.25)	16 (160)

*) In the numerator – indicators are higher than the groundwater level (GWL), in the denominator – indicators are lower than GWL

№ EGE	Characteristics of the engineering geological element (EGE)	Stratig-raphic index	Granulometric texture, %						Uniformity coefficient Cv	Natural moisture of soil W	Limits		Plasti-city index	Index of liquidity	Solid particles density	Soil density	Soil skeleton density	Poro-sity	Porosity fractions	Internal friction angle	Soil adhesion	Defor mation module
			Gra-vel	Sand Fractions, mm																		
			5-2	2-1	1.0-0.5	0.5-0.25	0.25-0.1	<0.1			Liquid limit, W_L	Plastic limit, Wp	Ip	I_L	ρ_s. g/cm^3	ρ. g/cm^3	ρ_d. g/cm^3	n. %	e	φ. degree	s.kPa (kgf/cm^2)	E.MPa (kgf/cm^2)

Notes:

1 The table provides normative values for the iternal friction angle, adhesion and deformation module

2 The table is compiled using the survey materials by the Lviv "TeploEnergoProject" (1974), Lviv "AtomTeploElectroProject" (1986), KOAEP (1985, 1986).

3 The table presents average indicator values of the soil properties.

ATTACHMENT B

RNPP Location Point (including the town of Varash). Indicators of physical and mechanical properties of rocky soils

№ EGE	EGE characteristics	Stratig-raphic index	Water saturation	Humidity W	Solid particles density ρ_s,g/cm^3	Soil density ρ,g/cm^3	Soil skeleton density ρd,g/cm^3	Porosity n, %	Porosity fractions	Tensile strength in uniaxial compression, MPa (kgf/cm^2)				Softening factor, K_{saf}
										Soil conditions	$R^н c$	Rc_{II}	Rc_I	
21	Basalt conglomerate on the carbonaceous cement, firm, softenable, fractured, slightly weathered	K_2c_1	0.04	0.03	2.81	2.52	2.45	13.0	0.15	In air dried condition	954	917	883	0,78
										In water saturated condition	747	673	622	
23	Basalt, slightly weathered, firm, softenable, fractured, part of fractures is filled	PR_2br	0.03	0.03	2.91	2.65	2.58	11.5	0.13	In air dried condition	1350	1250	1180	0.74
										In water saturated condition	1000	930	890	

Note. The table provides average indicator values of the soil properties.

ATTACHMENT C

On-site. Indicators of physical and mechanical properties of rocky soils

№ EGE	EGE characteristics	Stratig-raphic index	Water saturation	Humidity W	Solid particles density ρ_s,g/cm^3	Soil density ρ,g/cm^3	Soil skeleton density ρd,g/cm^3	Porosity n, %	Porosity fractions	Tensile strength in uniaxial compression, MPa (kgf/cm^2)				Softening factor, K_{saf}
										Soil conditions	$R^н c$	Rc_{II}	Rc_I	
21	Basalt conglomerate on the carbonaceous cement, firm, softenable, fractured, slightly weathered	K_2c_1	0.04	0.03	2.81	2.52	2.45	13.0	0.15	In air dried condition	954	917	883	0.78
										In water saturated condition	747	673	622	
23	Basalt, slightly weathered, firm, softenable, fractured, part of fractures is filled	PR_2br	0.03	0.03	2.91	2.65	2.58	11.5	0.13	In air dried condition	1350	1250	1180	0.74
										In water saturated condition	1000	930	890	
Note. The table provides average indicator values of the soil properties.														

ATTACHMENT D

Region of Rivne NPP. Classificaiton and names of exogenic geological processes (EGP) and phenomena

Affecting factors	Distrribution of exogenic geological processes and phenomena					
	in the Rivne NPP 30-km area		In RNPP location point		on-site	
	local	site	local	site	local	site
Surface waters	1 *Erosion* –impact of linear run-off 1.1 Linear (in the river-beds and streams) 1.2 Gully erosion in temporary stream flows 1.2.1 cstabilized or temporarily stabilized 1.2.2 active or temporarily active 2 *Bogging*	1 *Erosion* – impact of planar run-off 1.1 Planar 1.2 Slope	1 *Erosion* linear (in the river-bed of the river Styr) – impact of linear run-off 2 *Bogging* of flood plain of the River Styr	*Erision* planar – impact of the planar run-off	Before the beginning of plant construction – planar erosion and bogging; in the construction process the processes were eliminated	
Ground waters	*Karst.* Karst pothole and other karst local forms	1 *Karst* 1.1 Covered karst 1.2 Semi-covered karst 1.3 Open karst 1.4 Suffosion-karst processes – up to	Activation of *suffosion-karst* processes under the influence of man-made factors	*Underflooding* of the territory of the town of Kuznetsovsk under the influence of man-made factors	Activation of the *suffosion-karst processes* under the influence of man-made factors (man induced karst)	*Underflooding* under the influence of man-made factors (change of the constituents that form the

Affecting factors	Distrribution of exogenic geological processes and phenomena					
	in the Rivne NPP 30-km area		In RNPP location point		on-site	
	local	site	local	site	local	site
		10 potholes per 1 km^2 2 Underflooding 2.1 As a result of damming of ground waters during river flood 2.2 On the built-up territories under the technogenesis influence 3 *Bogging* – flat bogs 4 *Topographic low* of unidentified genesis in the rocks of different age		(change of the constituents that form the groundwater regime)		(groundwater regime)
Weather	*Slides.* *Caving* of river banks	*Aeolian* processes (formation of hilly sands)				

ATTACHMENT E

External natural-geological and natural-manmade factors (ENF), their change under the RNPP manmade impact (within the plant site and plant location point)

The table is represented by the following principle:
In column 3: + ENF sufficiently studied, – ENF insufficiently studied.
In column 4: + ENF changes are possible, – not possible.
In column 5: – consequences are absent.
In column 6: + ENF influence the safety, – ENF do not influence the safety.
Absent: ENF do not occur at RNPP site.
GWL - groundwater level; GW - ground waters

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
1	2	3	4	5	6
1	**Seismicity**	+	During GW rise	-	+
2	**Tectonics**	+	-	-	-
2.1	Presence of active tectonic faults	+	Absent		

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
2.2	Presence of heavily dislocated rocks complicated with wrench-fault tectonics	+	Absent		
2.3	Mud volcanoes	Absent			
2.4	Neotectonic processes	+	-	-	+
3	**Geomorphological conditions, relief**	+	-	Conditions improved	-
3.1	Amount of geomorphological elements	+	-	-	-
3.2	Ruggedness of relief	+		Dismemberment decreased	-
3.3	Surface slope, presence of steep slopes	+			-
3.4	Oresence of gullies, lakes	Absent			
3.5	Presence of boggy areas	Absent			
4	**Adverse geological processes**	+	+	Activation is compensated by measures to protect the technological environment	+
4.1	karst (cave-in, subsidence of surface)	+	+		+
4.2	suffosion-karst (soil softening)	+	+		+
4.3	man-made karst	+	+		+
4.4	erosion	+	-	-	-
4.5	shoreline erosion of the River Styr	+	-	-	-

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
4.6	gravic slopes (slides, cavings, mudslides, creeps, risers, folded deformations)	Absent			
4.7	gullying	Absent			
4.8	bogging	+	+	Territory dry-out	-
5	**Geological structure**	+	-	-	-
5.1	Conditions for soft ground deposits	+	-	-	-
5.2	Conditions for rocky ground deposits	+	-	-	-
5.3	Lithological soil composition:	+	-	-	-
5.3.1	quaternary	+	-	-	-
5.3.2	cretaceous	+	-	-	-
5.3.3	upper proterozoic (basalts)	+	-	-	-
6	**Soil characteristics and properties**				
6.1	engineering geological elements (EGE) of the quaternary soils				
6.1.1	degree of uniformity by the genesis	+	-	-	-
6.1.2	the same by the age	+	-	-	-
6.1.3	the same by the lithological composition	+	-	-	-

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
6.1.4	the same by the bedding in the plan and by the depth	+	-	-	-
6.1.5	reduction of density by the depth	+	+	Performance declined	+
6.1.6	strength	+	+		+
6.1.7	deformation properties	+	+		+
6.1.8	dynamic properties (possible fluidization)	+	-	-	+
6.2	EGE of cretaceous soils				
6.2.1	degree of uniformity by genesis	+	-	-	-
6.2.2	the same by the age	+	-	-	-
6.2.3	the same by the lithological composition	+	-	-	-
6.2.4	the same by the bedding of different types (by fracture)	+	+	Fracture increased	+
6.2.5	strength	+	-	-	+
6.2.6	deformation properties	+	-	-	+
6.2.7	dynamic properties (thixotropy)	+	-	-	-
6.2.8	filtration properties	+	+	-	-
6.3	EGE of upper proterozoic rocky (basalts)				
6.3.1	degree of uniformity by genesis	+	-	-	-
6.3.2	the same by the age	+	-	-	-
6.3.3	the same by the bedding	+	-	-	-

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
6.3.4	the same by the composition	+	-	-	-
6.3.5	strength	+	-	-	-
6.4	Presence of specific soils	Absent			
6.4.1	soft soil, sagging, swelling, salinized				
6.4.2	karsting	+	+	Conditions improved	+
7	**Activities on technical soil melioration (chalk cementation)**	+	+	Conditions improved	+
8	**Hydro-geological conditions**				
8.1	aquifers – groundwaters, upper cretaceous, upper proterozoic	+	+	Formation of “perched-water”	+
8.2	groundwater level (GWL)	+	+	GWL increased	+
8.3	direction, speed of groundwater movement	+	-	-	-
8.4	piezometric level of cretaceous horizon	+	-	-	-
8.5	direction, speed of cretaceous horizon movement	+	-	-	-
8.6	area of groundwater intake	+	-	-	-
8.7	area of groundwater discharge	+	-	-	-

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
8.8	hydraulic connection with surface ground waters	+	-	-	-
8.9	temperature of ground waters	+	+	Increased	-
8.10	groundwaters mineralization and aggressivity	+	+	Increased	+
8.11	protectability of aquifers	+	-	-	-
8.12	sorption capacity of soils	+	-	-	-
8.13	usage of ground waters of upper cretaceous aquifer as a source of cooling water for the safety important systems and components (if needed)	+	-	-	-
9	**Site underflooding**				
9.1	spreading of backwater during the flood of the River Styr	+	-	-	-
9.2	outflows from water supply lines	+	+	GW regime change	+
9.3	infiltration of atmosphere precipitation	+	-	-	-
9.4	potential for undeflooding	+	+	GW regime change	+
10	**Man-made factors**				
10.1	presence of undermining areas	Absent			

Position number	List of ENF that influence the safe operation of RNPP	Sufficiently (+) or insufficiently studied (–)	ENF change under the manmade impact		ENF that affect safety
			possible and occurred	characteristics of occurred changed	
10.2	presence of oil and gas developments	Absent			
10.3	presence of water-retaining hydro-technical structures	+	-	-	-
10.4	presence of groundwater intakes directly under the site	Absent			

APPROVED

Director of NT Engineering

_______________R. V. Maraikin

"05" December 2018

REPORT

ON

SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 3 Volume 4

Water environment

Version 2

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ABSTRACT

Book 3, Volume 4 of this report — contains 80 pages of text, 10 figures, 42 tables, 3 appendices, 46 sources.

The subject of research is water environment of the location area and the site of SS "Rivne NPP", as well as impact of the NPP operation on this water environment.

The purpose of research is to provide detailed characteristics of the water environment and to develop the materials on assessment of impact of SS "Rivne NPP" operation on the water environment.

The research employs the analytical research method based on study of production documentation of SS "Rivne NPP", materials on water bodies monitoring, materials of scientific, environmental and ecological researches and investigations that have been conducted on design and operation stages of the nuclear facility life cycle of SS "Rivne NPP".

The report provides data on status of water bodies, surface and ground water in the area and on the site of SS "Rivne NPP", the results of monitoring of the water environment, as well as conclusions about the plant impact on hydrological, hydrodynamic and temperature regime of surface and ground water, their status in terms of radioactive and chemical pollution.

The report data define the measures implemented at SS "Rivne NPP" in order to mitigate the adverse impact of its operations on condition of the water environment, as well as define the predicted status and conditions of further environmentally sound operation of the nuclear power plant.

Keywords: SS "RIVNE NPP", SS RNPP, HYDROGEOLOGICAL CONDITIONS, AQUIFER, HYDROGEOLOGICAL REGIME, OBSERVATION WELLS, MAXIMUM PERMISSIBLE DISCHARGE, HYDROCHEMICAL COMPOSITION, RADIATION SAFETY, ENVIRONMENTAL SAFETY, MONITORING.

Terms of the report distribution: as per agreement.

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LIST OF DESIGNATIONS, SYMBOLS, UNITS, ABBREVIATIONS AND TERMS

ADSFSF	At-reactor dry storage facility of spent fuel
ARI	Acute respiratory infection
ARMS	Automated radiation monitoring system
CCR	Construction codes and regulations
ChNPP	Chornobyl Nuclear Power Plant
CRWME	State Special Enterprise “Central Radioactive Waste Management Enterprise”
CRWP	Complex for radioactive waste processing
CSRWP	Complex for solid radioactive waste processing
CSFSF	Centralized waste fuel storage facility
DBA	Design-basis accident
DEI	Deep evaporation installation
DL	Dose limit
E	East
EDR	Exposure dose rate
EIA	Environmental Impact Assessment
EI	Earthquake index
ENSREG	European Nuclear Safety Regulators Group
EPS	Environmental Protection Service
ERS	Emergency response system
ES	Evaporator sludge
GTU	Gas treatment unit
HAW	High activity waste
HD	Head department
HPP	Heat power plant
IAEA	International Atomic Energy Agency
IAW	Intermediate activity waste
INES	International Nuclear Event Scale
IRS	Ionizing radiation sources
ISF	Interim Spent Fuel Storage Facility (Wet Type)
ITF	Interagency task force
LAW	Low activity waste
LLR	Long-lived radionuclide
LRW	Liquid radioactive waste
MA	Monitoring area
MDA	Minimum detecting activity
MDBA	Maximum design-basis accident
MHU	Ministry of Health of Ukraine
MIPH	O.M. Marzeiev Institute for Public Health NAMSU
MM	Mass media
MPC	Maximal permissible concentration
MPD	Maximum permissible discharge
N	North
n/i	Not identified
NFC	Nuclear fuel cycle
NNEGC “Energoatom”	National Nuclear Energy Generating Company “Energoatom”

NPP	Nuclear power plant
NRS	Nuclear and Radiation Safety
NT-Engineering	Limited liability company “NT-Engineering”
OSA	Oblast State Administration
PC “Vector”	Production Complex “Vector”
PD	Permissible discharges
PE “STC”	Production Enterprise “Scientific and Technical Centre”
PJSC KIEP	Public Joint Stock Company “Kyiv Research and Design Institute Energoproject”
PL	Power line
PL-97	Permissible level of 137Cs and 90Sr concentration in food and water
PPE	Personal protective equipment
PSAR	Provisional safety analysis report
PUF	Plant utilization factor
“Radon”	Ukrainian State Corporation “Radon”
RCS	Reactor coolant system
RIG	Radioactive inert gas
RW	Radioactive wastes
RNPP	Rivne nuclear power plant
RNPP Doses	Dose calculation software for population from actual emissions and discharges
RRCA	Restrictions on radionuclide concentration in air
RRCW	Restrictions on radionuclide concentration in domestic use water
RRIRS	Restrictions on radionuclide intake through respiratory system
RRIDS	Restrictions on radionuclide intake through digestive system
RODOS	European system for forecasting of radiation accident consequences
RWS	Radioactive waste storage
S	South
SAUMEZ	State Agency of Ukraine on Exclusion Zone Management
SCP	Security check point
SEA	Sanitary and epidemiological authorities
SF	Solidification facility
SFA	Spent fuel assembly
SG	Steam generator
SM	Scheduled maintenance
SNF	Spent nuclear fuel
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SOARS	Dose calculation software for all residential settlements of the surveillance zone in the emergency case
SRSU	Safety radiation standards of Ukraine 1997
SRW	Solid radioactive waste
SRWS	Solid radioactive waste storage
SSE “ChNPP”	State specialized enterprise “Chernobyl nuclear power plant”
SSE “CRWPE”	State specialized enterprise “Central Radioactive Waste Processing Enterprise”
SS “Rivne NPP”	Separate subdivision “Rivne nuclear power plant”
SSTC NRS	State Enterprise “State Scientific and Technical Centre for Nuclear and Radiation Safety”

SWP	Special water purification
SZ	Surveillance zone
TC	Technical specifications
TS	Technical support
TVS	Technical vocational school
VVER-440	Water-cooled water-moderated power reactor with nominal capacity of 440 MWt
VVER-1000	Water-cooled water-moderated power reactor with nominal capacity of 1000 MWt
WWTF	Waterwaste treatment facilities
^{235}U	Uranium 235
UE	Ultrasound examination
URS	Unidentified radionuclide spectrum
US	Urban settlement
W	West
WANO	World Association of Nuclear Operators
WBC	Whole-body counter
WEL	Waste extraction location

1 OVERVIEW OF SS "RIVNE NPP" AND WATERWORKS IN THE REGION

The work "Environmental impact assessment for the SS "Rivne NPP" site. Water environment" has been performed under the topic "Conduct of environmental impact assessment for the SS "Rivne NPP" site".

The assessment is performed within the controlled area (CA), which is a 30-km zone around SS "Rivne NPP", as shown on Fig. 1.1.

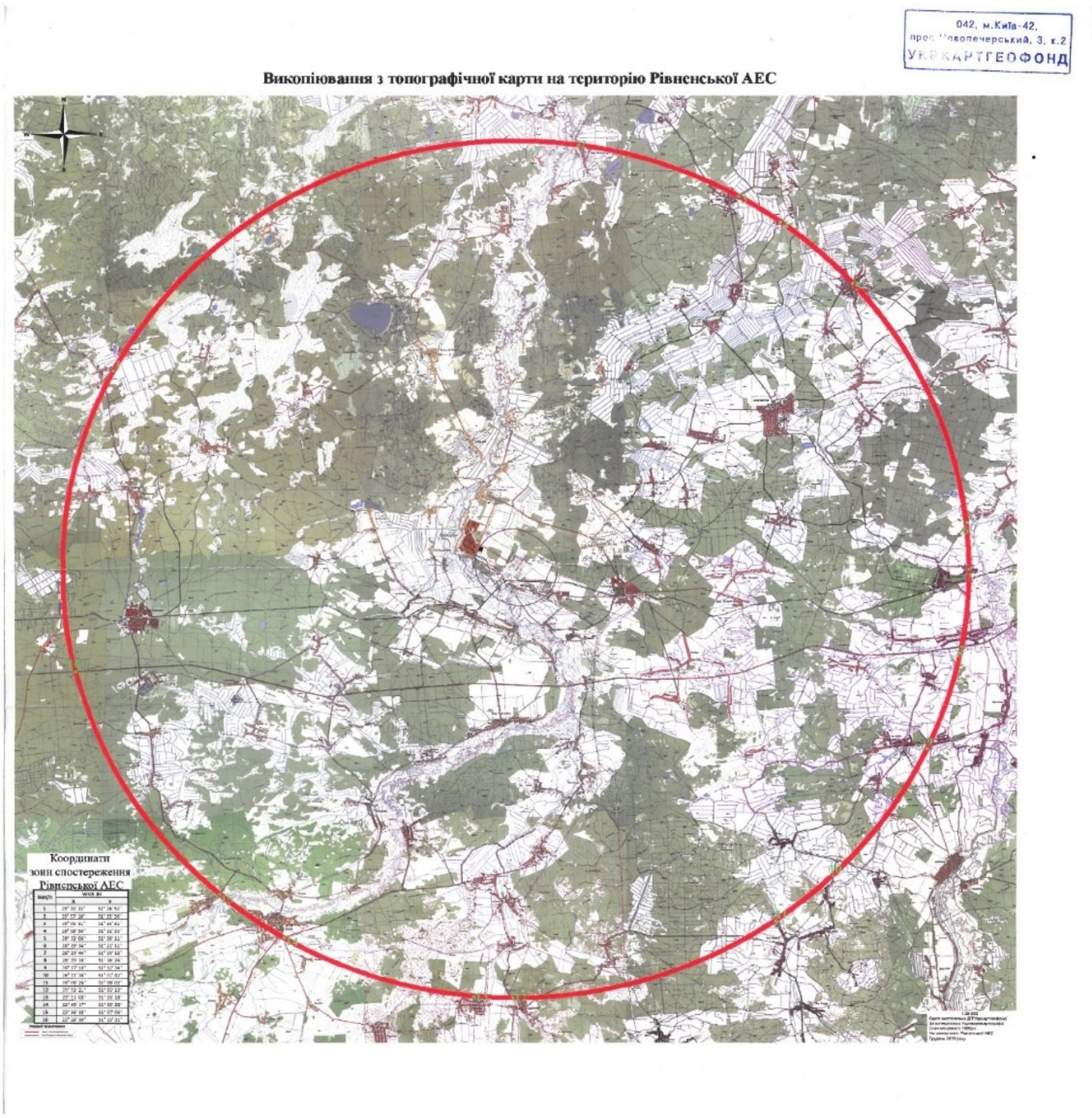

Fig. 1.1. Controlled area of SS "Rivne NPP"

This service on the subject "Conduct of environmental impact assessment for the SS "Rivne NPP" site" has been provided as per agreement No. 347 dated March "27", 2018, between the State Enterprise "National Nuclear Energy Generating Company 'Energoatom'" (SE NNEGC "Energoatom"), its separated subdivision — Rivne Nuclear Power Plant, and NT-Engineering Limited Liability Company.

The reasons for "Conduct of environmental impact assessment for the SS "Rivne NPP" site" are as follows:

- Energy Strategy of Ukraine for the period until 2030, approved by the Cabinet of Minister of Ukraine in the ordinance dated 24.07.2013, No. 1071-p. [1].
- Strategic Development Plan of the State Enterprise "National Nuclear Energy Generating Company 'Energoatom'" for the period 2017-2021 [2].
- Convention on Environmental Impact Assessment in a Transboundary Context, ratified by the Law of Ukraine No. 534-XIV dated 19.03.1999 [3].
- Minutes of meting of the Joint Coordination Council (JCC) on implementation of Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) in Ukraine, dated December 15, 2016 [4].
- The Law of Ukraine "On Environmental Impact Assessment" (Vidomosti Verkhovnoii Rady (VVR), 2017, No. 29, page 315) [5].
- Directive 2001/42/EC of the European Parliament and Council of June 27, 2001, on assessment of the effects of certain plans and programmes on the environment (Official Journal of the European Union, L 197, July 21, 2001) [6].
- The agreement of March "27", 2018, No. 347 "Conduct of environmental impact assessment for the SS "Rivne NPP" site" between SE NNEGC "Energoatom"), its separated subdivision - Rivne NPP, and NT-Engineering [7].
- Specification of the service: "Conduct of environmental impact assessment for the SS "Rivne NPP" site", 083-01-TB-COHC, approved by the chief engineer — first deputy director general of SS "Rivne NPP", dated 06.02.2018 [8].
- The Law of Ukraine "On Environmental Impact Assessment" (Vidomosti Verkhovnoii Rady (VVR), 2017, No. 29, page 315) [9].
- The Law of Ukraine "On Environmental Protection" dated 25.07.1991, No. 1264-XII [10].
- The Law of Ukraine “On Radioactive waste treatment”[11].
- The Law of Ukraine "On Permit Activity in the Field of Nuclear Energy" dated 11.01.2000, No. 1370-XIV [12].
- The Law of Ukraine "On Nuclear Energy Use and Radiation Safety" No. 39/95-VR dated 08.02.1995, No. 39/95-BP [13].
- The Law of Ukraine "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period till 2020" dated 21.12.2010 No. 2818-VI [14].
- The Law of Ukraine “On High Risk Facilities” dated 18.01.2001 [15].
- DSTU ISO 14001:2006 Environmental management systems. Requirements and guidelines [16].

The materials of environmental impact assessment (EAI) have been developed in order to access the impact on the natural environment due to operation of nuclear power plant SS "Rivne NPP", based on the results of environmental measures performed, multi-year results of environment sites monitoring and comparison of environment status around the NPP before operation and that during operation of the plant.

The EIA has been performed in accordance with "Recommendations on content of materials regarding environmental impacts of existing facilities" [17], DBN A.2.2-1-2003 "Composition and content of materials regarding environmental impacts (EIA)" [18] and the Guideline for development of materials on environmental impacts (to DBN A.2.2-1-2003) [19].

Along with:

- The Law of Ukraine “On Air Protection” dated 16.10.1992, No. 2707 [20];
- The Law of Ukraine “On Information” dated 02.10.1992, No. 2657 [21];
- Convention on Access to Information, Public Participation in Decision-making and Access

to Justice in Environmental Matters dated 06.07.1999, No. 832-14 [22];

- The Law of Ukraine “On Land Conservation” 19.06.2003, No. 0962 [23];
- The Law of Ukraine “On the Nature Reserve Fund of Ukraine” dated 16.06.1992, No. 2456 [24];
- The Law of Ukraine “On Flora” dated 09.04.1999, No. 0591 [25];
- The Law of Ukraine “On Fauna” dated 03.03.1993, No. 3041 and dated 13.12.2001, No. 2894 [26];
- Land Code of Ukraine dated 25.10.2001, No. 2768-14 [27];
- Resolution of the Cabinet of Ministers of Ukraine dated 27.07.1995, No. 554. List of activities and facilities that present high environmental risk [28];
- Order of the Ministry of Environment of Ukraine dated 18.12.2003 No. 168 on approval of Provision on Public Participation in Decision-making in the Field of Environmental Protection [29];
- Resolution of the Cabinet of Ministers of Ukraine dated 29.06.2011, No. 771 "On Approval of Procedure of Public Involvement in Discussion on Decision-making that can Affect the Environmental Conditions" [30].

"Conduct of environmental impact assessment for the SS "Rivne NPP" site" has been effected in 7 books.

Book 3 "Environmental impact assessment for the SS "Rivne NPP" site", Part 4 "Water environment" presents data on SS "Rivne NPP" and waterworks in the region and the 30-km area. The book provides a description of a status monitoring system for surface water, ground water, wells and drinking water. Particular attention was paid to radiation impact on waterbodies, such as rivers, lakes, ponds, ground water etc. Chemical impact on composition of surface water and ground water was investigated in detail. Calculated data and experimental data have been provided in the form of tables and graphic representations. Summaries and conclusions concerning the analytical work performed are given in the end of the book.

The Region of Rivne, as well as most of regions in the West and North of Ukraine, has plenty of surface water. The region area is crossed by 171 rivers over 10 km long and hosts 162 lakes, 12 storage reservoirs and 1688 ponds [31].

General description of water bodies is given in Table 1.1, location of water bodies within the 30-km area of SS "Rivne NPP" and hydrographic network of the Styr River intake and its individual parts is shown on Fig. 1.2.

Table 1.1. General description of water bodies in the Region of Rivne

Water body name	Quantity	Note
Rivers (over 10 km long), in total	171	Total length of rivers within the region is 4459 km
incl. large rivers	1	the Prypiat River
medium-sized	6	the Styr River, Ikva River, Horyn River, Sluch River, Stvyha River, Lva River
small	164	-
Lakes	162	total area is 34.25 km^2, total water volume is almost 108 million m^3.
incl. largest lakes	3	Nobel (4.99 km^2), Bile (4.53 km^2, 26.8 m deep), Ostrivske (1.12 km^2)
Storage reservoirs	12	total area is 2925 ha, total water volume is 47.8

Water body name	Quantity	Note
		million m^3.
incl. largest storage reservoirs	2	Khrinnytske on the Styr River (the District of Demydivka) Mlynivske on the Ikva River (the District of Mlyniv)
Ponds	1688	total area is 8515 ha, accumulated water volume is 93.797 million m^3.

The rivers flowing in the region belong to the basin of Prypiat River, the right-bank tributary of the Dnieper, and are fed mainly by melt water, snow water and, to a lesser extent, subsoil water and precipitation.

Main direction of river current is North-South, due to general reduction of surface altitudes in this direction.

The river network structure reflects the differences in relief of two physical and geographical zones, in which the region is located. Within Polesia, rivers have wide valleys with waterlogged floodplains and lots of oxbows and lakes. In the Southern part of the region, within the Volhynian Upland, the nature of rivers changes drastically. Due to significant topographic descent, velocity of rivers increases to 0.5-1 m/s, their valleys are narrow and deep, floodplains are rather narrow.

River network density is also uneven. River network is denser in the forest-steppe zone of the region and somewhat scarcer in Polesia.

Characteristics of rivers flowing in the region are given in Table 1.2.

Name	Extension within the region, km	Number of settlements along the shoreline, pcs.	Number of dams (storage reservoirs), pcs.	Number of pipelines crossing the river, pcs.				Number of pressure sewers crossing the water body, pcs
				Gas	Oil	Ammonia	Products	
Large rivers								
Prypiat	20	4	0	0	0	0	0	0
Total	20	4	0	0	0	0	0	0
Medium-sized rivers								
Styr	208	47	1	1	0	0	0	0
Horyn	386	94	1	3	1	0	1	6
Sluch	158	41	1	0	0	0	0	0
Ikva	93	26	1	2	2	0	1	2
Stvyha	60	7	0	0	0	0	0	0
Lva	111	13	1	0	0	0	0	0
Total	1016	228	5	6	3	0	2	8
Small rivers								
Stokhid	26	4	0	0	0	0	0	0
Prostyr	5	1	0	0	0	0	0	0
Zhabychi	22	15	0	1	0	0	0	0
Slonivka	27	13	0	1	2	0	1	0
Viliia	30	7	0	1	0	0	0	1

Name	Extension within the region, km	Number of settlements along the shoreline, pcs.	Number of dams (storage reservoirs), pcs.	Number of pipelines crossing the river, pcs.				Number of pressure sewers crossing the water body, pcs
				Gas	Oil	Ammonia	Products	
Ustia	68	19	1	0	2	0	1	6
Stubelka	86	31	1	2	0	0	0	0
Putylivka	27	2	0	0	0	0	0	0
Zamchysko	40	8	0	1	0	0	0	0
Korchyk	42	11	0	0	0	0	0	0
Buniv	27	5	0	0	0	0	0	0
Total	3423	116	7	6	4	0	2	7
All	4459	348	12	12	7	0	4	15

The lakes are concentrated mainly in the Polesia part of the region. The largest lakes of the Rivne Region are Nobel (4.99 km^2) and Bile (4.53 km^2). Maximum depth of Lake Bile is 26.8 m. Lake Nobel is located in floodplain of the Prypiat River, its maximum depth is 11.3 m. In addition, there are about 750 floodplain and oxbow water bodies in floodplains of large and medium-sized rivers; their areas, as well as shoreline and water storage, can vary within a quite broad range year by year and within the year. It is floodplain lakes that constitute the most numerous genetic group of natural water bodies of the Rivne Region. Another large group of natural water bodies in the region is represented by karst lakes, which are especially common in the North-West part of the region.

There are 12 storage reservoirs in the region, of which 7 are in-channel and 5 are off-channel. The largest storage reservoirs are: Khrinnytske on the River Styr and Mlynivske on the River Ikva.

The Rivne Region is evenly endowed with surface water (water bodies). Characteristics of surface runoff in the region are given in Table 1.3.

Table 1.3. Characteristics of surface runoff in the region

Runoff over a medium/high-water year, km^3/year		Runoff over a high-water year, km^3/year		Runoff over a low-water year, km^3/year		Level of runoff water supply per capita, thous. m^3	
local	total	local	total	local	total	local	total
2.33	6.4	69.17	190.0	0.26	0.63	1.96	5.38

As per hydrogeological zoning, the region area is located mainly within the Volhynia-Podolian artesian basin and partly (in the easternmost part of the Region of Rivne) within the Ukrainian fracture water basin, which is confined to the Ukrainian crystalline shield.

Total predicted ground water resource in the region is about 1314.913 million m^3/year, and the approved reserves are 195.798 million m^3/year, which is 14.9% of the predicted resource.

Within the Volhynia-Podolian artesian basin, hydrogeological conditions are very diverse. Not all aquifer systems of the Volhynia-Podolian artesian basin are used for water supply do to their low hydrogeological properties and low water quality, or due to high material cost of their development.

2 SURFACE WATER

2.1 Information on waterworks of SS "Rivne NPP"

The four-unit Rivne NPP is the largest natural water consumer in the region. Under the terms of permission, the plant has a right to draw 73.164 million m^3 of water per year from the Styr River without causing damage to nature. The plant actually draws smaller amounts of water. Every cubic meter of river water is re-used in the cooling system of SS "Rivne NPP" up to a hundred times. Water use by SS "Rivne NPP" is effected based on the permission for special water use УКР №1/Рвн dated 06.08.2015, in effect until 06.08.2020. Technical water supply for compensation of losses in the return water supply system (evaporation in cooling tower and from water surfaces of channels, carry-over and filtration, system purging) is arranged from the Styr River at the auxiliary water pump station (water intake limit is 73,164 thous. m^3/year, 267,840 m^3/day, 2.32 m^3/s). Water carry-over is minor due to special measures taken (water catchers, slope of the area toward cooling towers).

At average annual wind speed of 3.9 m/s, circulating water carry-over is 0.15% from cooling towers and 2% from spray cooling ponds (in total, 0.23% of circulating water consumption). Utility and drinking water supply of SS "Rivne NPP" is arranged from the underground water intake Rafalivske-1 (the Village of Ostriv), which comprises 9 wells (water intake limit is 3386 thous. m^3/year, 9277 m^3/day) [32].

The enterprise has developed "Standards of average annual water consumption and water discharge per product unit".

Cooling water supply system of SS "Rivne NPP" consists of recycling circulation systems, recycling cooling systems for essential consumers (that provide safety of SS "Rivne NPP") and non-essential consumers (normal operating equipment).

Water carry-over is minor due to special measures taken (water catchers, slope of the area toward cooling towers). At average annual wind speed of 3.9 m/s, circulating water carry-over is 0.15% from cooling towers and 2% from spray cooling ponds (in total, 0.23% of circulating water consumption).

Volume of cooling towers purging is 0.42% of circulating water. Currently, there are six same-type cooling towers in operation. Circulation water losses for units No. 1, 2 are 91000 m^3/h per unit, and those for units No. 3, 4 are 188920 m^3/h per unit.

In order to ensure sustainable use of water resources, water is re-used after treatment of waste water contaminated with petroleum products and rainwater runoffs.

Volumes of water lifted, used, spent (evaporation in cooling tower, evaporation from surface, carried away by wind, water seepage into soil), re-used, recycling water supply, discharged (returned) to the Styr River are recorded and presented via statistical reporting on form 2-ТП (water management).

Use of surface water from the Styr River, waste water discharge depending on electrical energy generation, recycling water supply and re-used water over the 2010 to 2017 period are given in Table 2.1.

Table 1.2. Data on use of surface water from the Styr River over the last 7 years.

Year	Electrical energy generation, million kWh	Water intake from the Styr River, thous. m^3	Waste water discharge to the Styr River, thous. m^3	Recycling water supply, thous. m^3	Re-used water, thous. m^3
2010	16841.2	51003.7	13838.6	3672402.4	981.438
2011	17551.7	55011.2	13061.9	4023911.9	1347.2

Year	Electrical energy generation, million kWh	Water intake from the Styr River, thous. m^3	Waste water discharge to the Styr River, thous. m^3	Recycling water supply, thous. m^3	Re-used water, thous. m^3
2012	17891.9	55066.5	12952.6	4131547.5	1846.3
2013	16158.8	48746.9	10875.8	3912077.3	1790.3
2014	18238.9	54547.3	13774.6	4160324.5	1744.3
2015	18932.0	55848.7	12512.0	4235410.4	1501.7
2016	17468.2	50063.0	11505.6	3853860.1	1495.3
2017	19792.8	58493.3	12788.3	4235537.0	1623.1

SS "Rivne NPP" draws fresh drinking ground water for centralized and non-centralized water supply (except for packed fresh water production) from the Ravalivske-1 field located in Western environs of the Village of Ostriv, the District of Volodymyrets, the Region of Rivne. Subsoil use is effected under the special permission No. 2263 dated 09.10.2000, valid for 2 years, which was reissued on 19.05.2015 due to change of SE NNEGC "Energoatom" corporate address (street renaming), as provided in Appendix C.

The first stage comprises 8 wells 130 to 350 m deep. Water draw-off is being recorded. On the second stage station, 2 fresh water tanks with capacity of 1000 m^3 each are installed. Limit of ground water draw-off from artesian wells of the Ostriv Village is 3386.0 thous. m^3 per year. In addition, fresh ground water is drawn from artesian wells on the site to meet the utility and drinking needs of the Recreation and Health Complex (RHC) "Bile ozero" with water draw-off limit of 12.8 m^3/year.

Artesian water is used only for sanitary and drinking needs.

Hydrogeographic characteristics of waterworks in the 30-km zone of SS "Rivne NPP".

The Styr River is one of the largest tributaries of the Prypiat River. The river is 494 km long (which includes 424 km within the territory of Ukraine), its basin area is 12900 and 12370 km^2 respectively.

Its largest right-bank tributary is the Ikva River, which is 156 km long, with basin area of 2250 km^2. The Ikva River falls into the Styr River beyond the 30-km zone of SS "Rivne NPP".

Within the 30-km zone, the Styr River has 12 tributaries more than 10 km long and 94 tributaries less than 10 km long falling into it. The river crosses the NPP area in the South-North direction.

The East part of the SS "Rivne NPP" area is occupied by left-bank tributaries of the Horyn Riven, and the North-West part hosts the Veselukha River basin.

Within th 30-km zone of SS "Rivne NPP", there are 85 lakes with total water surface area of 16.57 km^2, including 15 lakes with water surface area > 0.10 km^2. The greatest number of lakes was recorded in basins of the Vyrok River, the Okinka River and the Behuchiv Stream. There are no storage reservoirs in the SS "Rivne NPP" area.

Hydrographic network of the entire catchment area of the Styr River and its individual parts up to design cross sections is shown on Fig. 1.2. Hydrographic characteristics of water bodies in the 30-km zone of SS "Rivne NPP" are specified in tables of Appendices A and B.

2.2 Main characteristics of waterworks in the 30-km zone of SS "Rivne NPP"

The Styr River. This is the main river flowing in the 30-km zone of SS "Rivne NPP". Total river length is 494 km, total catchment area is 12900 km^2. The Styr River enters the 30-km zone at 268 km from its source (226 km from the mouth), in the UTS of Kolky, and leaves the zone at 400 km from its source (113 km from the mouth), in the Village of Mlynok. Thus, the river flows 113 km within the zone of SS "Rivne NPP".

Within the zone, catchment area of the Styr River is 1850 km^2; the upstream catchment area (from the source to the head cross section in the UTS of Kolky) is 9050 km^2, and total area from the river source to the egress from the zone of SS "Rivne NPP" (the Village of Mlynok) is 10900 km^2.

Water intake facility of SS "Rivne NPP" is located at 326.7 km from the Styr River source (167.3 km from the mouth and dams the catchment area of 10400 km^2 [31].

The largest tributaries of the Styr River within the 30-km zone are the Kormyn, Okinka, Stubla and Zheleznytsia. The rest of the river network is comprised by small rivers, first and second order tributaries. Catchment areas for tributaries of the rivers that fall into the Styr River within the SS "Rivne NPP" zone lie virtually completely within the zone.

Morphometric characteristics of the Styr River valley, floodplain and bed change with distance from the source. In the upper reaches, where land forms are mostly of ravine and gully type, the valley is 1.0-1.5 km, and in the middle and lower reaches the width increases to 2-4 km. The floodplain width is 0.3-0.7 km in the river head, it increases to 2-3 km in the middle reaches and 4 km in the lower reaches. The floodplain is of meadow type, with some waterlogged plots, in some places crossed with dead river channels. waterlogged parts of the floodplain are largely reclaimed. During the spring flood, the Styr River floodplain gets flooded to a depth of 0.20-0.50 m. In some cases, the floodplain can also be flooded with storm floods.

The river bed is winding (very winding in some places), 10-20 m wide in the upper reaches and 30-60 m wide in the middle and lower reaches. In the lower reaches, the river bed has some branching sections that form small islands. Beaches and sand spits are rare. Width of the Styr River bed in the SS "Rivne NPP" zone varies from 30 km at the head cross section to 40-50 m at the river egress from the zone.

The river has steep banks 1-3 m high that are formed by sandy and clay deposits and are prone to retrogression. In some places the banks are dumose.

Stretch parts of the river are 1.5-2.0 m deep (in some places up to 2.8-3.5 m deep). The depths decrease on the riffles to 0.7-1.0 m.

Midstream speed is 0.40-0.50 m/s at medium and low water levels; when the river is high, maximum speeds increase to 2-4 m/s.

River slopes vary within 0.15-0.20%.

Surface of the upper catchment area is mainly plowed. Forest ranges occupy small areas on gully slopes and in river valleys. Forest coverage increases in the lower catchment area, at the river egress to the Polesian Lowland.

The Styr River is navigable by low-displacement boats in the middle and lower reaches.

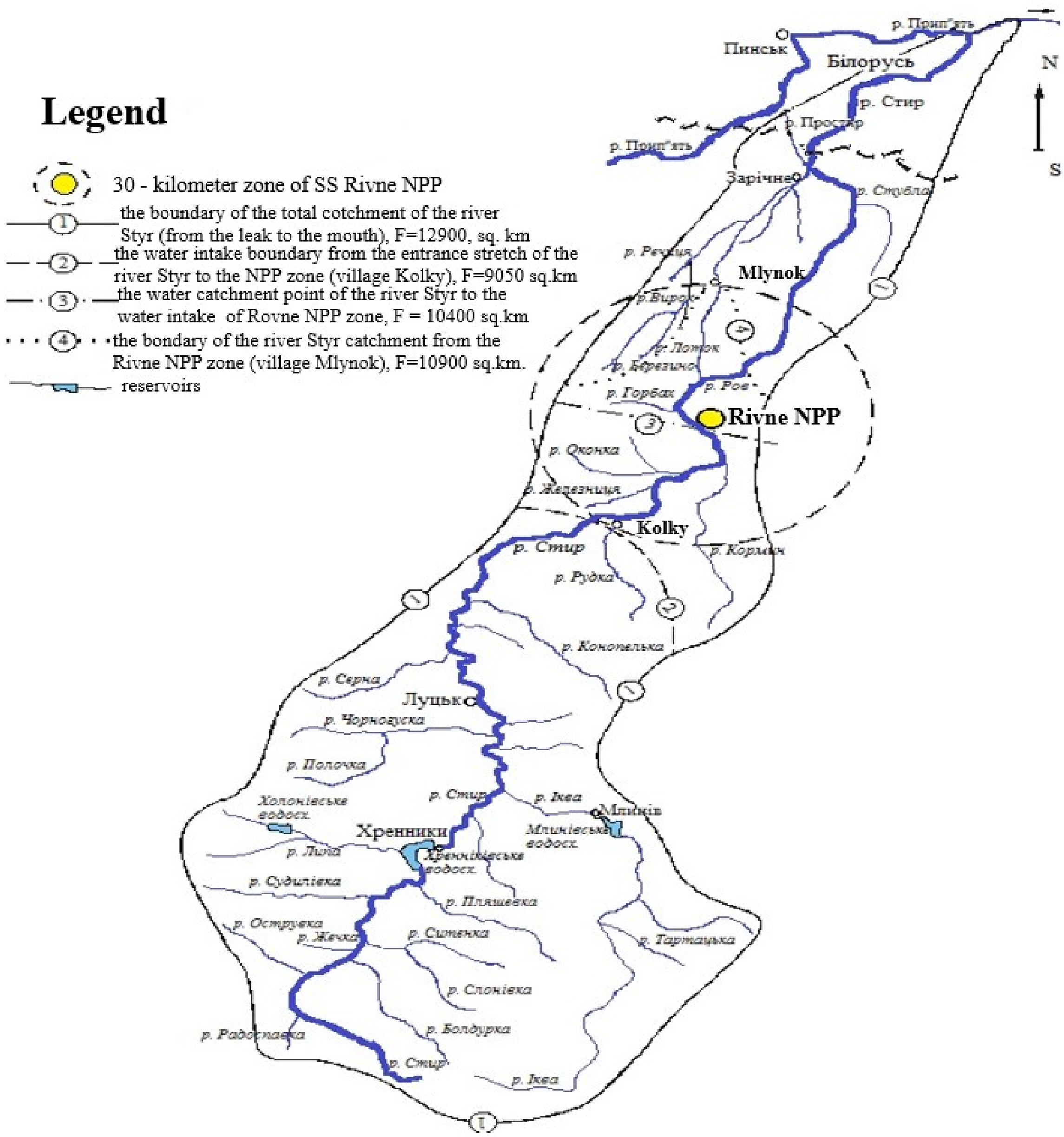

Fig. 2.1. Hydrographic network of the entire catchment area of the Styr River and its individual parts

The Kormyn River is a right-bank tributary of the Styr River. The Kormyn River is 53 km long, total catchment area is 824 km^2. The Kormyn River falls into the Styr River 16.7 km upstream of the water intake of SS "Rivne NPP".

The Kormyn River flows 27 km within the 30-km zone (middle and lower reaches of the river). Sources of the Kormyn river are located beyond the zone of SS "Rivne NPP". In the 30-km zone of SS "Rivne NPP", the river has 1 tributary > 10 km long (the Krosokha River) and 4 tributaries less than 10 km long.

The left-bank tributary, Krosokha, falls into the Kormyn River at 12 km from the Kormyn River mouth. There is also a network of reclamation channels on the floodplain of the tributaries.

The river bed is canalized. Depth of the bed near the river mouth is 20 m on top and 11 m at the bottom. During the low-water period, the depths are 0.5 m.

The river is a catch-water for the network of reclamation channels that collect water from the waterlogged part of the catchment area. The densest network of reclamation channels is located on the right bank of the Kormyn River, in the Village of Mala Osnytsia. The channels are 5-12 m wide and 2.0-2.5 m deep.

The Riv River is a right-bank tributary of the Styr River that falls into the latter 34 km downstream of the water intake of SS "Rivne NPP". The entire basin of the Riv River lies within the 30-km zone of SS "Rivne NPP". The river is regulated (its mouth is dammed with a highway embankment, which serves a retaining site at the same time). River flow-off that accumulates near the highway embankment is pumped into the adjacent Stubla River and into the Styr River.

Bed of the Riv River is canalized, 10 m wide and 2.0 m deep. The bottom is sandy, silted-up in some places. The bed receives flow-offs from the reclamation channels.

The Stubla River is a right bank tributary of the Styr River that falls into the Styr River beyond the 30-km zone of SS "Rivne NPP", 92.3 km downstream of RNPP water intake.

The Stubla River is 70 km long, of which it flows about 30 km within the zone of SS "Rivne NPP". Total catchment area is 593 km^2, of which 241 km^2 within the zone of SS "Rivne NPP".

The river basin is a flat plain with tussock microrelief. Most part of the basin is waterlogged.

The floodplain is bilateral, waterlogged, 1-2 km wide, with a tussock surface, dissected by drain channels and bridged with peaty soils. The bed is canalized, connected with the Riv River by the means of a channel located in the upper reaches. This channel transfers parts of the Riv River runoff from the reservoir located near the dam to the Stubla River.

The Zheleznytsia River is a left-bank tributary of the Styr River, falling into the Styr River in the zone of SS "Rivne NPP" 24.7 km upstream of RNPP water intake. Total river length is 22 km, of which 16 km are within the zone of SS "Rivne NPP". Total catchment area is 94 km^2, with 61 km^2 within the RNPP zone.

The valley is 2 km wide, floodplains of the river are 1.5 km wide. The bed is canalized. Bed width is 6 m.

At a distance of 1.2 km from the river mouth, an unnamed tributary falls into the Zheleznytsia River. At present, this tributary is a main channel of a reclamation system that collects water from the network of drain channels. The densest network of drain channels is located in the upper reaches of the River Zheleznytsia basin. Here intake channels are 12 m wide and 1.5 m deep.

The Okinka River is a left-bank tributary of the Styr River, falling into the Styr River 14.7 km upstream of SS "Rivne NPP" water intake. Total river length is 25 km, total catchment area is 286 km^2. The entire catchment area of the Okinka River lies within the 30-km zone of SS "Rivne NPP". The largest tributaries of the Okinka River are the Pidhorets Stream and the Cherniavka Stream.

The valley is 3-4 km wide, floodplains of the river are 1.0-1.5 km wide. Beds of the Okinka River and its tributaries are canalized, 6-10 m wide. The river receives flow-offs from a network of reclamation channels. Channel network is very dense, especially in the upper and middle reaches. Depth of the canalized bed is 0.8-1.5 m.

Basin of the Okinka River is characterized by major discharges of karstic water to the catchment area surface and its further losses in the channel network.

The Horbakh River is a left-bank tributary of the Styr River, falling into the latter 13 km downstream of SS "Rivne NPP" water intake. River length is 17 km, catchment area is 72.4 km^2. The entire catchment area lies within the zone of SS "Rivne NPP". The valley is 1.5-1.8 km wide, floodplains of the river are 0.3-0.5 km wide (near the mouth of the Horbakh River, its floodplain merges with that of the Styr River). The bed is canalized, 6.0 m wide.

There is a network of drain channels 5 m wide and 2 m deep in the upper reach of the basin.

Peat digging takes place here. There are several fish ponds on the river near the Village of Kostiukhnivka.

The Melnytsia River is a left-bank tributary of the Horyn River, flowing in the Eastern part of the 30-km zone of SS "Rivne NPP". Out of total area of 432 km^2, 217 km^2 of the Melnytsia River catchment area falls within the zone of SS "Rivne NPP". The largest tributaries of this river, the Holubytsia River and the Chepilka River, are located here.

Basin of the Melnytsia River comprises large reclaimed areas. Floodplain land is drained by the network of open channels.

The Berezhanka River is a left-bank tributary of the Horyn River. The Berezhanka River is 34 km long, flowing 12 km of them within the zone of SS "Rivne NPP" (the upper reaches). 135 km^2 of catchment area of the Berezhanka River are located within the zone of SS "Rivne NPP". River head is waterlogged. There is a dense network of reclamation channels.

The valley is about 4 km wide, floodplains are 0.5 km wide and bed is 5 m wide. The bed is canalized and is a catch-water for waste water flowing from the reclamation system.

Hydrogeographic characteristics of rivers in the 30-km zone of SS "Rivne NPP" are given in Appendix A of this book.

Bile Lake. Bile Lake is the largest lake within the 30-km zone of SS "Rivne NPP", located at a distance of 18 km from RNPP to NNW. The lake is oval, elongated in the East-West direction (Fig. 2.2). The lake is 1.5-2.0 km wide, 2.5 km long, its average depth is 9.6 m, and maximum depth is 23 m. Water surface area is 4.11 km^2, water storage in the lake is 40 million m^3, water catchment area of the lake is 85 km^2.

The lake is surrounded by forest and marshes on all sides. In the South and East parts of the lake, the marsh approaches the encroachment part; in the North part, the bank is 0.3-0.5 m high.

The lake is of running-water type. In the East and South-East parts of the lake, a reclamation channels and a small stream flow out of the lake and merge with the Lotok River. In the South part of the lake, a stream falls into the lake. Both streams and the channel flow through a waterlogged floodplain, therefore, their shape is indeterminate. Channels and streams are about 1 m wide and 0.10-0.40 m deep. Constant water level in Bile Lake is maintained due to water mass outflow from the lake to the Lotok River.

The lake bottom is sandy, peaty in some places. The riparian zone is covered with reeds to a depth of 1.0-1.5 m almost everywhere, and there is a floating species of algae at depths of 2-3 m.

During the low-water period, there are only wind currents in Bile Lake; in spring, discharge currents are also quite likely. Speed of wind currents is low. When the weather is calm (at wind speeds of 1-2 m/s), current velocities on the lake surface are 1-2 cm/s; at wind speed of 6-7 m/s, current velocities in the surface layer of the lake reach 5-6 cm/s. Current direction is the same as wind direction.

Water temperature in the lake is characterized by well-defined stratification. If water temperature in the surface layer is 26.0-27.4 ^{0}C, temperature jump is located at a depth of 6 m, and below this level water temperature decreases gradually to minimum values in the near-bottom layer (6-9 ^{0}C).

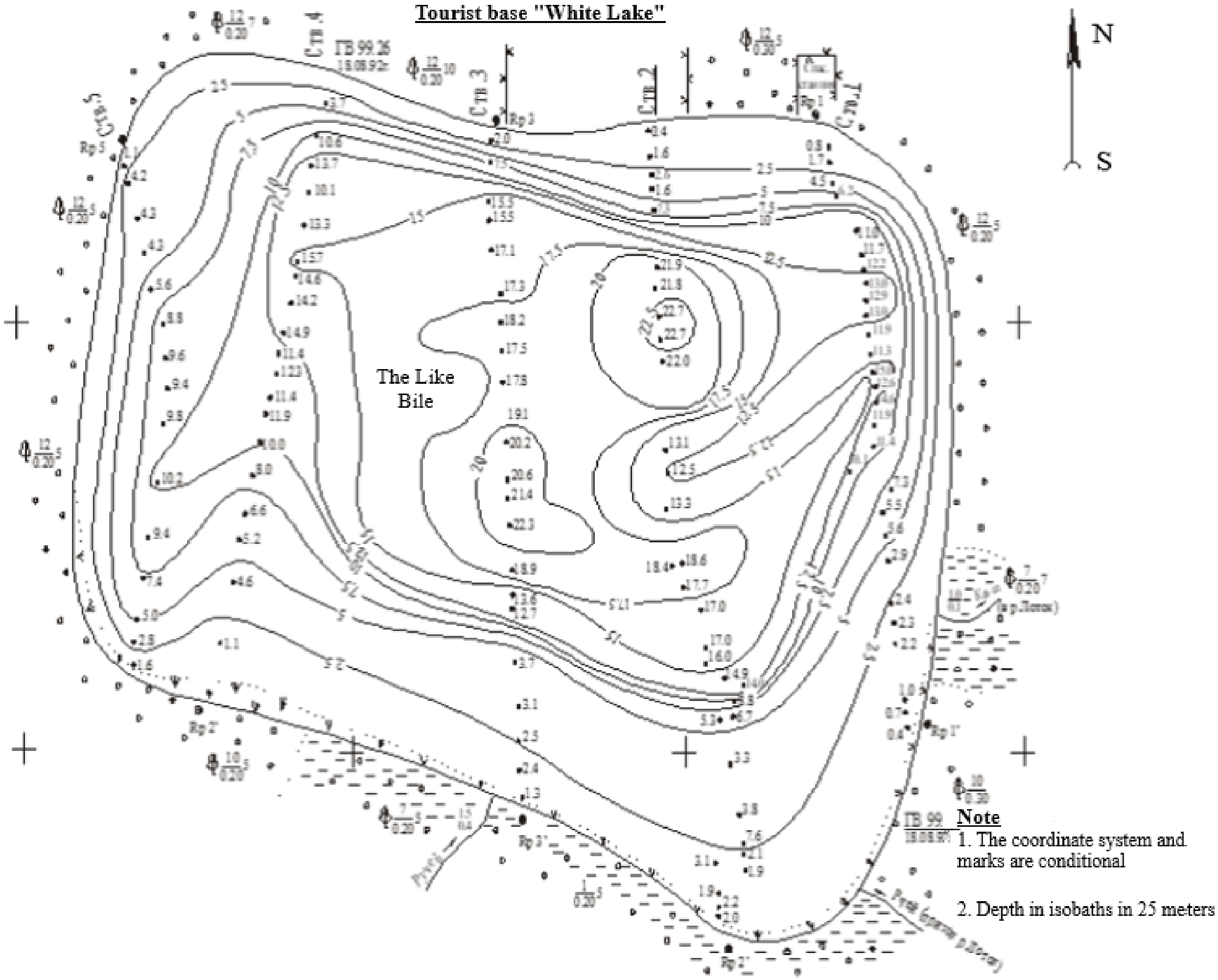

Fig. 2.1. Bile Lake

Hydrogeographic characteristics of lakes and ponds in the 30-km zone of SS "Rivne NPP" are given in Appendix Б of this book.

2.3 Monitoring of the surface water status

Environmental impact of liquid effluents is monitored through monitoring of effluents from SS "Rivne NPP", monitoring of intermediate process water at the NPP, monitoring of ground water activity, bottom sediments, algae and surface water of the Styr River.

All spent water of SS "Rivne NPP" that contains radioactive compounds is collected into individual radioactive drains systems and sent for treatment. Treated effluents of SS "Rivne NPP" are mainly used in the recycling water supply systems for process needs, but part of them is discharged into the municipal sewer. The enterprise SS "Rivne NPP" continuously monitors activity of liquid effluents being discharged into the Styr River.

Table 2.2. Total activity of liquid effluents from SS "Rivne NPP" in 2016, MBq

Nuclide	Industrial and storm sewage system	Sanitary sewage system	Maximum permissible discharge (MPD)	MPD index, %
^{51}Cr	< 130	< 1.5	5.3×10^{7}	< 0.00026
^{54}Mn	< 7.3	0,358	4.9×10^{5}	< 0.0016
^{58}Co	< 7.9	< 0.09	4.5×10^{5}	< 0.0018
^{59}Fe	< 14	< 0.16	2.9×10^{5}	< 0.0049
^{60}Co	< 5.8	1.34	5.2×10^{4}	< 0.0140
^{65}Zn	< 13	< 0.15	2.7×10^{5}	< 0.0049
^{95}Nb	< 10	< 0.11	2.6×10^{6}	< 0.00041
^{95}Zr	< 15	< 0.16	2.0×10^{5}	< 0.0078
^{106}Ru	< 78	< 0.87	8.4×10^{5}	< 0.0094
^{110m}Ag	< 11	< 0.31	2.9×10^{6}	< 0.00038
^{131}I	< 33	< 0.36	1.2×10^{6}	< 0.0028
^{134}Cs	< 11	0.783	5.7×10^{4}	< 0.02
^{137}Cs	125	5.53	8.3×10^{4}	0.158
^{144}Ce	< 110	< 1.20	3.1×10^{5}	< 0.037
^{90}Sr	42.1	< 0.198	1.3×10^{5}	0.0325
^{3}H	6140000	3490	2.4×10^{9}	0.256
Total discharge index				0.55

Total index of radionuclides discharge into the Styr River if 0.55 % of the permissible discharge. Main contributors to total index for discharge of isotopes with activity, that exceeds minimum permissible activity, are ^{3}H – 46.4%, ^{137}Cs – 28.6%, ^{90}Sr – 5.9 %. During the year 2016, excesses of maximum permissible discharges and reference discharge levels have not been recorded.

Most of liquid effluents from SS "Rivne NPP" kake their way to the Styr River together with industrial and storm water of the enterprise.

In order to monitor environmental impact of liquid effluents produced by the enterprise, monitoring of radionuclides content in surface water of the Styr River is effected quarterly, using three control points (the Village of Maiunychi 10 km upstream of the SS "Rivne NPP" discharge; 1 km downstream of the industrial and storm sewage discharge of SS "Rivne NPP"; the Village of Sopachiv, 10 km downstream of the NPP discharge) [31-34].

Table 2.3. Specific activity of radionuclides in surface water of the Styr River in 2016,

Bq/m^3

Control point	Control date	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
The Village of Maiunychi	1 quarter	<36	536	<2.4	<3.8	<5.1	<3.8	<4.2
	2 quarter	<32.6	593	<2.6	<3.3	<4.8	<5.2	<3.6
	3 quarter	<45	531	<3.7	<7.1	<6.7	<5.4	<5.8
	4 quarter	<19	463	<1.3	<2.5	<2.7	<2.4	<1.8
Downstream of the industrial and storm sewage discharge of RNPP	1 quarter	<36	667	<2.7	<3.9	<5.2	<3.9	<4.1
	2 quarter	<22	752	<1.6	<2.4	<3.3	<2.8	<2.5
	3 quarter	<31	579	<2.9	<3.6	<4.9	<3.9	<4.4
	4 quarter	<29	501	<3.6	<5.4	<3.2	<4.2	<4.0
The Village of Sopachiv	1 quarter	<23	203	<1.6	<2.6	<3.7	<2.3	<2.9
	2 quarter	<22	168	<1.6	<2.4	<3.1	<2.1	<2.0
	3 quarter	<36	185	<2.3	<5.4	<4.8	<3.5	<4.2
	4 quarter	<12	129	<1.5	<1.8	<1.3	<1.6	<1.5

Minor traces of technogenic pollution have been detected in surface water of the Styr River downstream of the SS "Rivne NPP" discharge.

In 2016, specific activity of caesium radionuclide ^{137}Cs in all samples of surface water taken from the Styr River was below the limit of minimum permissible activity. Maximum ^{137}Cs concentration was 2778 times lower than permissible concentration of this isotope in drinking water. Maximum activity of the most significant tritium radionuclide ^{3}H was 69500 Bq/m^3, i.e. 432 times lower than permissible concentration of this isotope in drinking water.

Surveying of bottom sediments, algae and fish of the Styr River was effected in 4 settlements of the controlled area of SS "Rivne NPP". In 2016, specific acticity of ^{137}Cs was 1.45-4.22 Bq/kg in bottom sediments, 0.125-0.377 Bq/kg in algae, 0.75-1.69 Bq/kg in fish. Specific activity of isotope ^{137}Cs in all taken samples of fish was lower than the permissibl level of radionuclide content for fish, which equals 150 Bq/kg. The results of measurement of ^{137}Cs specific activity in bottom deposits, algae and fish in 2016 are given in Table 2.4 [31, 32, 34].

Table 2.4. Specific activity of ^{137}Cs in bottom deposits, algae and fish in 2016, Bq/kg.

Name of settlement in the controlled area of SS "Rivne NPP"	Bottom deposits	Algae	Fish
the Village of Maiunychi	4.22	0.222	1.69
the City of Varash	1.45	0.125	<0.8
the Village of Sopachiv	2.08	0.377	<1.2
the Village of Telkovychi	2.40	0.286	<0.75

Water supply for recycling systems make-up and other technical needs at SS "Rivne NPP" is arranged from the Styr River.

Utility and drinking water supply is arranged from water intake in the Village of Ostriv, Ravalivske-1 field. The water intake comprises 9 artesian wells.

The water intake from the Styr River is equipped with stationary fish protection devices based on electrical gradient and rotating return meshes along with a protective curtain. Amount of water being drawn is recorded by the means of water meters: two ultrasonic fluid meters Ergomer-120 on water conduits and two redundant devices КС-2-004 of orifice type at pump discharge. Drawn water amount is recorded in a log book on standard form ПОД-11.

In 2017, 58573110 m^3 of water were drawn from the Styr River, of which 58493393 m^3 were used for production needs.

Sanitary protection zones of the first belt are marked and fenced. Drawn water amount is recorded on the second stage station by the means of three ultrasonic water meters of Vzliot brand, type РС-У УРСВ-010. On the second stage station, 2 fresh water tanks with capacity of 1000 m^3 each are installed. Ground water draw-off from artesian wells of the Ostriv Village in 2017 was 1607663 thous. m^3.

Summary data on use of river (service) water and ground (drinking) water by SS "Rivne NPP", as well as on waste water discharge, are given in Table 2.5. Utility and drinking needs of the RHC "Bile ozero" are satisfied from the artesian well. According to permission for special water use УКР № 454/Рвн dated 15.01.2014, water draw-off limit is 12.8 thous. m^3/year. According to form 2-ТП (water management), 6.25 thous. m^3 of ground water were drawn in 2017. Data on water consumption by the RHC "Bile ozero" are given in Table 2.5.

Table 2.5. Summary data on water consumption by SS "Rivne NPP".

№	Name of water type and source	Limit, thous. m^3	Drawn per quarter, thous. m^3	Drawn since the start of the year, thous. m^3	Actually used per quarter, thous. m^3	Actually used since the start of the year, thous. m^3
1.	Service water the Styr River	73164	14420.540	58573.110	14414.318	58493.393
2.	the Village of Ostriv	3596	392.678	1607.663	119.069	583.636
3.	Artesian water RHC "Bile ozero"	12.8	-	6.25	-	6.25

Water is discharged from the SS "Rivne NPP" site via the gravity sewer of industrial and storm sewage system (ISSS) through one outlet into the Styr River as partially clean water without treatment. According to form 2-ТП (water management), return water discharge into the Styr River in 2017 was 12788.332 thous. m^3 [34].

Apart from industrial and storm sewage system, there are other sewage systems to collect the following non-radiactive waste water from the NPP site: sanitary sewage, waste water contaminated with petroleum products, rain water. Treatment facilities for waste water contaminated with petroleum products and settlers of rain water collected on the site (except for rain water from the territory of units No. 1 and 2) don't have outlets to the river. Once treated at these facilities, waste water is used in circulation systems.

Sanitary sewage from the site is delivered to treatment facilities with a rate of 700 m^3/day. Treatment facilities consist of an inlet chamber, two sand traps, primary settlers, aerotanks, secondary settlers and sludge drying beds. Once treated, waste water is supplied to treatment facilities of the municipal public utility. In 2017, waste water discharge to municipal treatment facilities after treatment was 120.738 thous. m^3.

Amount of pollutants discharged into the water body together with return water by SS "Rivne NPP" is given in Table 2.6.

Table 2.6. Amount of pollutants in return water less background concentration.

No	Name of indicator value	Water body to receive the return water	Approved permissible concentrations, mg/dm^3	MPD, t/year	Average concentration (ISSS – background) mg/dm^3	Total annual water discharge thous. m^3	Actual discharge of pollutants, t
1.	Biochemical oxygen demand – 5 day test (BOD-5)	the Styr River	5.75	105.9	0.068	12788.332	0.869607
2.	Suspended matter		15.0	276.1	2.510	12788.332	32.09871
3.	Mineralization		1000	18409	325.486	12788.332	4162.423
4.	Chlorides		200.0	3681.8	41.458	12788.332	530.1787
5.	Sulphates		250	4602.3	132.860	12788.332	1699.058
6.	Ammonia nitrogen		1.08	19.88	0.131	12788.332	1.675271
7.	Nitrates		40.04	737.1	17.212	12788.332	220.1128
8.	Nitrites		0.197	3.627	0.000	12788.332	0.0000
9.	Petroleum products		0.32	5.861	0.009	12788.332	0.115095
10.	Iron		0.502	9.241	0.041	12788.332	0.524322
11.	Zinc		0.031	0.571	0.003	12788.332	0.038365
12.	Copper		0.301	5.541	0.152	12788.332	1.943826
13.	Phosphates		3.12	57.44	0.096	12788.332	1.22768
14.	Synthetic surfactants		0.200	3.682	0.011	12788.332	0.140672
15.	Chemical oxyhen demand (COD)		116.4	2142.8	35.771	12788.332	457.4493
16.	HEDP		0.9	16.57	0.226	12788.332	2.890163
17.	Monoethanolamine		0.010	0.184	0.005	12788.332	0.063942
18.	Sodium polyacrylate		4.0	73.64	-	-	-

Waste water from the RHC "Bile ozero" is delivered to the pump station (commissioned in 2006) with an integrated biological treatment unit.

Purified and disinfected water is subjected to tertiary treatment at the bioengineered facilities (bioplateau), then flows into the reclamation channel and further into the water body – the Styr River. Based on results of the departmental ecological and chemical laboratory, in 2017 treatment facilities of the RHC "Bile ozero" were working efficiently. 6.25 thous. m^3 of treated waste water were discharged into the reclamation channel.

Amount of pollutants discharged into the water body together with return water by the RHC "Bile ozero" of SS "Rivne NPP" is given in Table 2.7.

Table 2.7. Amount of pollutants discharged into the water body together with return water

by the RHC "Bile ozero" of SS "Rivne NPP".

No	Name of indicator value	Water body to receive the return water	Approved permissible concentrations, mg/dm^3	MPD t/year	Average concentration, mg/dm^3	Total water discharge, thous m^3	Actual discharge of pollutants, t
1.	BOD-5	р. Стир	19.60	0.2352	4.276	6.25	0.00428
2.	Suspended matter		23.25	0.2790	9.342	6.25	0.00934
3.	Mineralization		1000	12.00	138.417	6.25	0.13842
4.	Chlorides		150.0	1.800	3.882	6.25	0.00388
5.	Sulphates		100.0	1.200	18.884	6.25	0.11803
6.	Ammonia nitrogen		4.09	0.0491	0.716	6.25	0.00072
7.	Nitrates		20.00	0.2400	1.651	6.25	0.00165
8.	Nitrites		3.300	0.0396	0.175	6.25	0.00018
9.	Petroleum products		0.1000	0.00120	0.046	6.25	0.00005
10.	Iron		0.6760	0.008112	0.261	6.25	0.00026
11.	Phosphates		6.860	0.08232	0.627	6.25	0.00063
12.	Synthetic surfactants		0.200	0.0024	0.006	6.25	0.00001
13.	Chemical oxyhen demand (COD)		80.00	0.9600	31.717	6.25	0.03172

Data on water consumption at SS "Rivne NPP" over the last 6 years are given in Table 2.8.

Table 2.8. Dynamics of water use amounts at SS "Rivne NPP".

Name of water supply source	Amount of water used, thous. m^3					
	2012	2013	2014	2015	2016	2017
Service water	55066	48746	54547	55848.763	50145.260	58573.110
Artesian water	1914/321*	1744/344*	1705/361*	1700/385*	1632/531*	1607/583*

/* – amount of water drawn from the water supply source / used at the facility.

In general, water use at SS "Rivne NPP" meets the established limits, water use conditions and MPD limit values. Amount of river and artesian water used in percents of the limit is specified in Table 2.9.

Table 2.9. Amount of river water used.

Water	% of the limit					
	2012	2013	2014	2015	2016	2017
Amount of river water used	75.26	66.74	75.01	76.8	68.84	80.05
Amount of artesian water used	53.22	53.56	55.87	59.87	82.62	44.68

2.3.1 Non-radiation impact on chemical composition of the surface water

The design solution of service water cooling in cooling towers and spray cooling ponds instead of a cooling pond enabled maximum reduction of adverse plant impact on the ecosystem and preservation of valuable floodplain of the Styr River with its meadow, shrub and forest complexes. Cooling water supply system of SS "Rivne NPP" consists of recycling circulation systems, recycling cooling systems for essential consumers (that provide safety of SS "Rivne NPP") and non-essential consumers (normal operating equipment).

Water carry-over is minor due to special measures taken (water catchers, slope of the area toward cooling towers). At average annual wind speed of 3.9 m/s, circulating water carry-over is 0.15 % from cooling towers and 2 % from spray cooling ponds (in total, 0.23 % of circulating water consumption). Volume of cooling towers purging is 0.42 % of circulating water.

Circulation systems blowdown water and other return water from the power units site is collected by the industrial and storm sewage system and discharged into the river through one outlet located 30 m downstream of the water intake. The permission for special water use provides for discharge of 18409.0 thous. m^3 of water per year.

In 2017, SS "Rivne NPP" actually discharged into the river 111.106 thous. m^3 of partially clean water [32, 34].

Chemical composition of return water and river water upstream the water intake of SS "Rivne NPP" is monitored by the certified laboratory stations. Laboratory of Heat and Underground Utilities Department withdraws and analyses the samples at least 6 times a day (petroleum products and pH). In 2017, ecological and chemical laboratory of the Environmental Protection Service (EPS) conducted 7011 laboratory investigations of surface water and return (waste) water. Analysis of the controlled indicators shows that there were no excesses of maximum permissible discharges (in tons) in 2017, and operation of Rivne NPP does not cause any significant changes in surface water quality.

Average indicators of surface water status for year 2017 are given in Table 2.10.

In the locations of sludge collector and construction and industrial waste landfill of SS "Rivne NPP", the analysis is conducted by the ecological and chemical laboratory.

Table 2.10. Average indicators of surface water status.

No	Name	Maximum permissible concentration of substance (MPCs), mg/dm^3	Approved permissible concentrations, mg/dm^3	River (upstream of NPP) mg/dm^3 per year	River (upstream of NPP) mg/dm^3 per year	River (downstream of NPPP), mg/dm^3 per year
1	Mineralization	Not rated	1000	693.01	367.52	399.5
2	Sulphates	100	250.0	192.98	60.12	61.28
3	Chlorides	300	200.0	56.14	14.68	14.23
4	Calcium	180	-	130.06	102.00	96.99
5	Magnesium	40	-	34.90	22.25	23.96
6	Ammonia nitrogen	0.39	1.08	0,551	0.482	0.536
7	Nitrites (NO_2)	0.08	0.197	0.046	0.082	0.066

No	Name	Maximum permissible concentration of substance (MPCs), mg/dm^3	Approved permissible concentrations, mg/dm^3	River (upstream of NPP) mg/dm^3 per year	River (upstream of NPP) mg/dm^3 per year	River (downstream of NPPP), mg/dm^3 per year
8	Nitrates (NO_3)	40.0	40.04	26.38	9.165	9.802
9	Phosphates	2.14	3.12	0.506	0.420	0.417
10	Iron	0.10	0.502	0.257	0.249	0.267
11	Copper	0.001+back ground	0.301	0.160	0.008	0.006
12	Zinc	0.01	0.031	0.008	0.006	0.006
13	Dissolved oxygen	≥ 4	≥ 4	8.67	10.53	10.17
14	Suspended matter	25.00	15.0	11.65	9.39	10.65
15	Petroleum products	0.05	0.32	0.054	0.066	0.068
16	Synthetic surfactants	0.25	0.200	0.021	0.010	0.012
17	BOD-5	3.00	5.75	1.73	2.39	2.51
18	Chemical oxyhen demand (COD)	50.00	116.4	73.30	39.16	43.48
19	pH, units	6.5÷8.8	6.5÷-9.0	8.63	8.23	8.27
20	Etidronic acid (HEDP)	0.90	0.9	0.399	0.180	0.185
21	Monoethanolamine	0.01	0.01	0.005	-	-
22	Transparency	-	> 20 sm	> 20 см	27.99	27.90
23	Temperature, °C	Not rated	25°C (winter) 41°C (summer)	24.24	10.92	11.09

Table 2.11. Dynamics of surface water status change in the Styr River (downstream of the NPP) (in terms of chemical pollutants content).

Indicators of chemical pollutants	Content of chemical pollutants, mg/dm^3					
	2012	2013	2014	2015	2016	2017
Mineralization	351.9	411.2	339.32	393.90	414.50	374.350
Sulphates	30.093	28.711	23.79	24.52	35.90	61.281
Chlorides	16.49	12.97	13.93	15.19	17.75	14.232
Calcium, mg·eq/dm^3	4.47	4.45	4.73	4.27	4.52	4.844
Magnesium, mg·eq/dm^3	1.86	1.03	1.07	1.34	1.19	1.974
Ammonia nitrogen	0.45	0.487	0.391	0.442	0.46	0.536
Nitrites	0.079	0.069	0.107	0.086	0.103	0.066
Nitrates	4.652	5.35	6.96	5.74	6.63	9.802
Phosphates	0.29	0.223	0.284	0.296	0.49	0.417

Indicators of chemical pollutants	Content of chemical pollutants, mg/dm^3					
	2012	2013	2014	2015	2016	2017
Iron	0.512	0.422	0.400	0.394	0.269	0.267
Copper	0.013	0.002	0.004	0.008	0.006	0.006
Zinc	0.017	0.015	0.011	0.006	0.008	0.006
Dissolved oxygen	10.10	9.54	9.84	10.65	10.37	10.174
Suspended matter	6.69	6.99	7.69	9.11	9.76	10.653
Petroleum products	0.10	0.069	0.084	0.044	0.05	0.068
Synthetic surfactants	0.025	0.01	0.016	0.018	0.013	0.012
BOD_5	2.3550	1.500	1.91	2.82	2.84	2.518
COD	41.16	42.44	45.62	54.63	39.66	43.477
pH, units	8.140	8.04	8.20	8.35	8.35	8.269
Temperature, °C	12.48	13.0	12.14	11.91	0.082	11.092

Analysis of the controlled indicators shows that operation of SS "Rivne NPP" does not cause any significant changes in surface water quality. In 2017, water status in the Styr River (reference cross section) was preserved on the level of previous years' indicators. Dynamics of surface water status change in the Styr River (downstream of the NPP) in terms of chemical pollutants content over the last 5 years is shown in Table 2.11.

2.3.1.1 Hydrological measurements of the Styr River status

A stream gauge is arranged on the Styr River downstream of the water intake within the development area of the Town of Varash in order to monitor hydrological status of the Styr River and prevent reduction of sanitary and ecological consumption below 8.8 m^3/s according to permission for special water use УКР № 1/Рвн dated 06.08.2015 (in effect until 06.08.2020), which is provided in Appendix C.

The control was exerted according to "Hydrometeorological stations and facilities manual. Issue 2. Part 2. Leningrad, 1975. Issue 6. Part 1. Leningrad, 1978" [35] and "Provisions on measurements of hydrological regime of the Styr River at the stream gauge ГТЦ 172-2-П-ГТЦ" [36].

Level and temperature of the Styr River are measured twice a day (except for weekends) at 8 AM and 4 PM; water consumption is determined when the level changes by 10-15 cm, but at least once per 10 days. Hydrological indicators used for determination of water consumption values are measured in the stream gauge cross section. During flood, if water level exceeds elevation of 160, 160, 15 m, water consumption values are not determined. Hydrological measurements of water consumption from the Styr River are provided in Table 2.12.

Average annual water temperature in the Styr River for year 2017 is 11.1°C.

Average annual consumption is 29.9 m^3/s. Annual amplitude of water level fluctuation is 1.7 m.

Table 2.12. Hydrological measurements of water consumption from the Styr River

Indicator (per quarter)	Average temperature, °C			Average consumption m^3/s	Fluctuation amplitude, cm	Minimum consumption, m^3/s	Maximum consumption, m^3/s	Min. absolute level elevation, m	Max. absolute level elevation, m	Absolute level elevation, m
1	2.3			50.8	1.22	29.8	59.4	158.71	159.93	159.90
	0.1	0.7	6.1			24.01.17	23.03.17	06.01.17	28.03.17	31.03.17
2	16.0			29.7	1.5	13.1	57.5	158.37	159.87	158.37
	10.5	16.3	21.2			27.06.17	05.04.17	30.06.17	03.04.17	30.06.17
3	20.6			13.3	0.35	11.3	19.0	158.29	158.64	158.64
	22.1	22.9	16.7			31.08.17	29.09.17	21.08.17	29.09.17	29.09.17
4	5.7			37.9	1.28	25.3	54.5	158.71	159.99	159.99
	10.1	4.9	2.1			06.10.17	22.12.17	02.10.17	29.12.17	29.12.17

2.3.2 Radiation impact on the surface water

2.3.2.1 Effluents activity control at SS "Rivne NPP"

According to radiation control regulation 132-1-Р-ЦРБ, samples were taken twice a week for each discharge scheme (ISSS, sanitary sewage system (SSS)) in order to monitor water discharge from SS "Rivne NPP".

Four litres of water from each sample were poured through ion-exchange resins (anionite, cationite) in order to extract the radionuclides. Resin samples were measured on a γ-spectrometer.

For the purpose of radiochemical extraction of ^{90}Sr, 5 litres of each sample were being accumulated during the month. Samples with monthly extraction of ^{90}Sr were being measured on MPC-9604 radiometers for 10000 s.

Activity of tritium in the collected water was determined based on volume quota of each sample on a liquid scintillation radiometer Tri-Carb 3170 TR/SL. Duration of measurement was 3600 s.

If activity of a radionuclide was below MDA, total discharge activity was calculated based on concentration equal to 0.5 MDA.

Permissible water discharge of SS "Rivne NPP" is calculated, according to provisions of NRBU-97, based on the dose limit quota for population and is independent of the NPP power. The PD (permissible discharge) value will not be exceeded, if the following inequality is valid:

$$\sum_{i=1} \frac{C_i}{ПC_i} \leq 1$$

where C_i is actual annual discharge of the i-th radionuclide;

$ПC_i$ is the limit for annual discharge of the i-th radionuclide.

The results of water discharge control in 2017 are given in Tables 2.13-2.16. Value of total discharge index in relation to permissible discharge over the last 10 years of operation is shown on Fig. 2.3.

Table 2.13. Liquid discharge by individual radionuclides in 2017

Nuclide	ISSS, MBq/year	SSS, MBq/year	RL (reference level), MBq/year	КР, МБк/рік	ПС, MBq/year	RL index, %	ПС index, %
^{51}Cr	<1.80E+02	<1.20E+00	<1.80E+02	-	5.30E+07	-	<3.50E-04
^{54}Mn	<1.10E+01	3.74E-01	<1.10E+01	-	4.90E+05	-	<2.30E-03
^{58}Co	<1.10E+01	<1.30E-01	<1.10E+01	-	4.50E+05	-	<2.40E-03
^{59}Fe	<1.80E+01	<1.70E-01	<1.90E+01	-	2.90E+05	-	<6.40E-03
^{60}Co	<1.10E+01	1.26E+00	<1.20E+01	2.16E+02	5.20E+04	<5.6	<2.30E-02
^{65}Zn	<1.70E+01	<1.60E-01	<1.70E+01	-	2.70E+05	-	<6.40E-03
^{95}Nb	<1.40E+01	<1.10E-01	<1.40E+01	-	2.60E+06	-	<5.40E-04
^{95}Zr	<2.00E+01	<1.60E-01	<2.00E+01	-	2.00E+05	-	<1.00E-02
^{106}Ru	<1.10E+02	<8.00E-01	<1.10E+02	-	8.40E+05	-	<1.30E-02
^{110m}Ag	<1.40E+01	5.38E-01	<1.50E+01	-	2.90E+06	-	<5.10E-04
^{131}I	<4.50E+01	<3.00E-01	<4.50E+01	-	1.20E+06	-	<3.70E-03
^{134}Cs	6.9E+01	8.66E-01	6.88E+01	2.40E+02	5.70E+04	28.7	1.21E-01
^{137}Cs	1.89E+02	4.71E+00	1.94E+02	2.88E+03	8.30E+04	6.7	2.34E-01
^{144}Ce	<1.50E+02	<8.90E-01	<1.50E+02	1.32E+03	3.10E+05	<11.4	<4.80E-02
^{90}Sr	6.11E+01	8.22E-02	6.12E+01	7.68E+02	1.30E+05	8.0	4.71E-02
^{3}H	7.10E+06	2.76E+03	7.10E+06	6.72E+07	2.40E+09	10.6	2.96E-01
Total discharge index							0.82

Table 2.14. Discharge of radioactive substances from SS "Rivne NPP" into outside water bodies in 2017 by months

Month	Джерело	Об’єм, м^3	^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{51}Cr	^{90}Sr	^{3}H
			MBq/month							
January	ISSS	5.93E+05	1.40E+01	<4.70E-01	3,46E+00	<400E-01	1.26E+00	<7.40E+00	2.76E+00	5.92E+05
	SSS	1.16E+04	7.78E-01	1.13E-01	2,83E-01	4,67E-02	1.06E-01	<8.90E-02	5.40E-03	4.30E+02
February	ISSS	7.98E+05	3.39E+00	<7.10E-01	<4,40E-01	<5,70E-01	<6.90E-01	<9.80E+00	2.02E+01	2.93E+05
	SSS	1.08E+04	5.90E-01	8.34E-02	7,60E-02	<5,90E-03	2.88E-02	<8.60E-02	<4.30E-03	2.96E+02
March	ISSS	5.76E+05	4.27E+00	<4.40E-01	<2,60E-01	<3,80E-01	<3.60E-01	<6.60E+00	4.18E+00	5.71E+05
	SSS	1.17E+04	4.38E-01	5.97E-02	7,07E-02	<5,00E-03	3.56E-02	<8.50E-02	1.85E-02	3.15E+02
April	ПЛК	1.17E+06	1.42E+01	<1.80E+00	<1,20E+00	<1,70E+00	<1.40E+00	<2.50E+01	6.35E+00	7.85E+05
	SSS	1.09E+04	4.82E-01	<1.50E-02	1,51E-01	<1,10E-02	4.54E-02	<1.60E-01	1.44E-02	3.24E+02
May	ISSS	8.90E+05	2.81E+01	1.12E+01	<5,60E-01	<8,50E-01	<9.20E-01	<1.20E+01	3.40E+00	1.49E+05
	SSS	1.09E+04	5.69E-01	1.60E-01	1,62E-01	<6,70E-03	8.64E-02	<1.00E-01	<3.20E-03	1.69E+02
June	ISSS	1.56E+06	3.77E+01	1.70E+01	<7,60E-01	<1.00E+00	<9.70E-01	<1.80E+01	8.47E+00	1.21E+06
	SSS	9.30E+03	2.73E-01	9.76E-02	1,36E-01	<7.90E-03	<8.00E-03	<8.20E-02	<3.30E-03	2.19E+02
July	ISSS	1.45E+06	1.83E+01	7.82E+00	<8,70E-01	<1.20E+00	<1.00E+00	<2.00E+01	2.41E+00	2.35E+05
	SSS	1.09E+04	5.22E-01	1.74E-01	1,91E-01	<1.70E-02	<1.70E-02	<2.00E-01	<3.50E-03	1.89E+02
August	ISSS	1.36E+06	2.22E+01	7.07E+00	<1,10E+00	<1.50E+00	<1.30E+00	<2.80E+01	3.16E+00	5.44E+05
	SSS	9.80E+03	2.48E-01	<1.10E-02	6,27E-02	<7.30E-03	<7.90E-03	<1.30E-01	5.34E-03	2.27E+02
September	ISSS	1.07E+06	1.43E+01	4.80E+00	<4,30E-01	<6.70E-01	<7.00E-01	<1.10E+01	2.34E+00	3.86E+05
	SSS	9.08E+03	2.01E-01	4.02E-02	4,87E-02	<3.80E-03	<3.80E-03	<6.50E-02	9.76E-03	2.19E+02
October	ISSS	1.21E+06	1.19E+01	5.26E+00	<6,40E-01	<8.60E-01	<7.70E-01	<1.50E+01	3.00E+00	1.30E+06
	SSS	8.91E+03	2.10E-01	2.34E-02	2,91E-02	<6.70E-03	<7.60E-03	<5.00E-02	<2.10E-03	1.66E+02
November	ISSS	1.05E+06	1.28E+01	4.79E+00	<6,10E-01	<9.10E-01	<8.00E-01	<1.70E+01	<2.90E-01	2.92E+05
	SSS	8.88E+03	2.35E-01	5.83E-02	4,53E-02	<5.90E-03	2.35E-02	<1.00E-01	<3.60E-03	1.26E+02
December	ISSS	1.37E+06	7.87E+00	6.58E+00	<5,80E-01	<8.30E-01	<8.50E-01	<1.30E+01	4.51E+00	7.42E+05
	SSS	7.98E+03	1.68E-01	2.99E-02	<3,20E-03	<3.60E-03	<3.60E-03	<5.50E-02	8.83E-03	1.05E+02
Total over the NPP, MBq/year		1.32E+07	1.94E+02	6.88E+01	1,22E+01	<1.10E+01	1.14E+01	<1.84E+02	6.12E+01	7.10E+06

Table 2.15. Total discharge volume in 2017, m^3

Period / Facility	1 quarter	2 quarter	3 quarter	4 quarter	2017	2017/2016
ISSS	1.97E+06	3.62E+06	3.88E+06	3.63E+06	1.31E+07	1.15↑
SSS	3.41E+04	3.11E+04	2.98E+04	2.58E+04	1.21E+05	1.05↑
Total over SS RNPP	2.00E+06	3.65E+06	3.91E+06	3.66E+06	1.32E+07	1.14↑

Table 2.16. Activity of benchmark radionuclides discharge in 2017, MBq

Period	1 quarter	2 quarter	3 quarter	4 quarter	2017 р.	2017 2016	На 1000 МВт
^{137}Cs	2.35E+01	8.13E+01	5.58E+01	3.32E+01	1.94E+02	1.48↑	68.4
^{60}Co	4.59E+00	2.97E+00	2.70E+00	1.91E+00	1.22E+01	1.70↑	4.3

Table 2.17. Values of DL index (CRDW index — coefficient of radionuclides discharge into water bodies) over the last 5 years

Nuclide	ПС index, %				
	2013	2014	2015	2016	2017
^{51}Cr	4.20E-04	3.90E-04	2.45E-04	2.60E-04	3.50E-04
^{54}Mn	2.40E-03	3.60E-03	2.02E-03	1.60E-03	2.30E-03
^{58}Co	2.90E-03	4.10E-03	2.16E-03	1.80E-03	2.40E-03
^{59}Fe	7.70E-03	1.10E-02	5.52E-03	4.90E-03	6.40E-03
^{60}Co	2.00E-02	3.00E-02	1.56E-02	1.40E-02	2.30E-02
^{65}Zn	8.20E-03	1.20E-02	5.93E-03	4.90E-03	6.40E-03
^{95}Zr	1.30E-03	9.10E-04	4.23E-04	4.10E-04	5.40E-04
^{95}Nb	1.30E-02	1.70E-02	8.50E-03	7.80E-03	1.00E-02
^{106}Ru	1.60E-02	2.00E-02	9.88E-03	9.40E-03	1.30E-02
^{110m}Ag	6.40E-04	8.50E-04	4.14E-04	3.80E-04	5.10E-04
^{131}I	4.50E-03	4.50E-03	2.58E-03	2.80E-03	3.70E-03
^{134}Cs	3.10E-02	4.40E-02	4.81E-02	2.00E-02	1.21E-01
^{137}Cs	2.00E-01	1.72E-01	1.93E-01	1.58E-01	2.34E-01
^{144}Ce	6.20E-02	4.40E-02	3.23E-02	3.70E-02	4.80E-02
^{90}Sr	3.29E-02	2.96E-02	2.83E-02	3.25E-02	4.71E-02
^{3}H	2.19E-01	2.69E-01	3.04E-01	2.56E-01	2.96E-01
Total	0.62	0.66	0.66	0.55	0.82

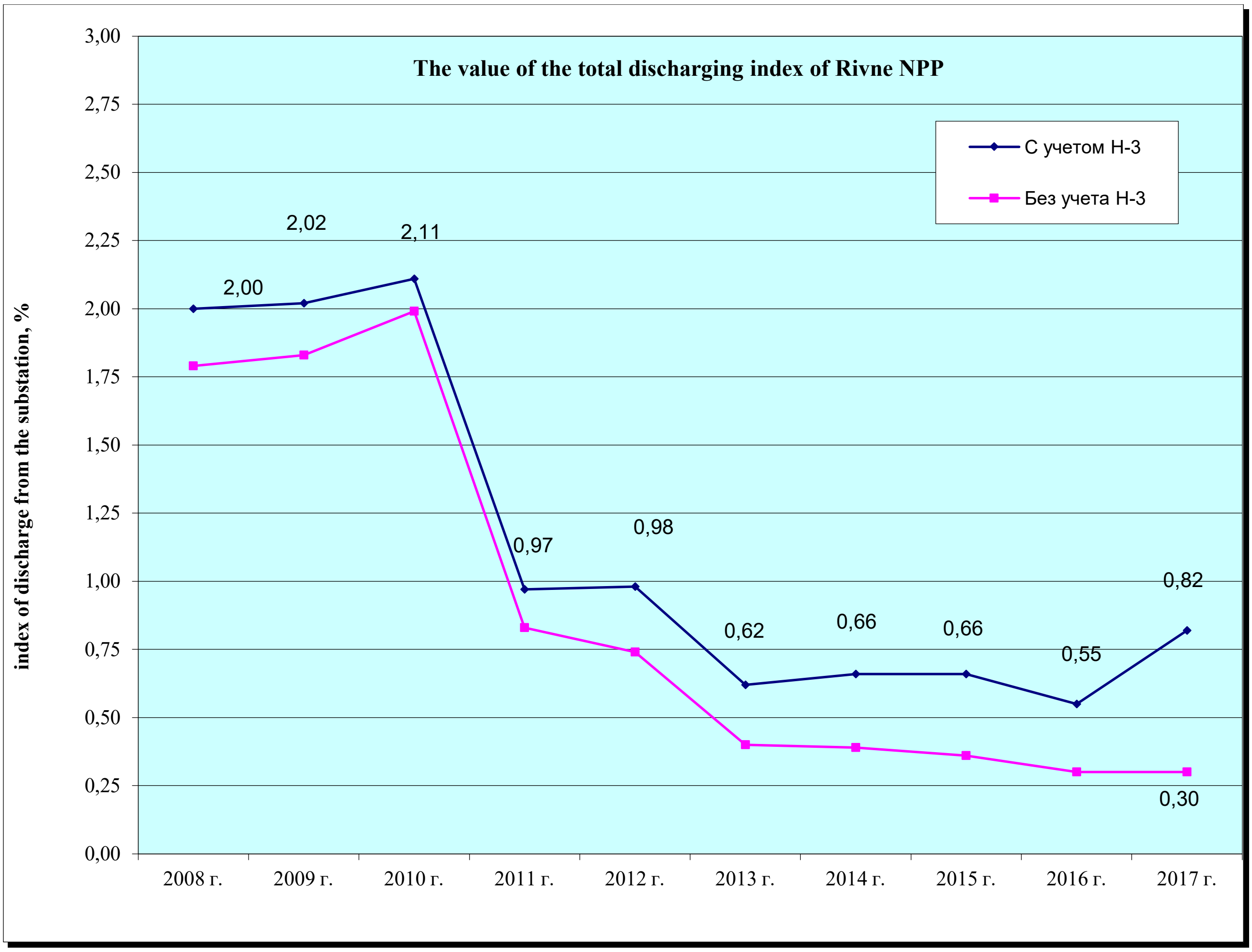

Fig. 2.3. Dynamics of change of total discharge index (CRDW) at SS "Rivne NPP" over the period of 2008-2017

2.3.2.2 Trend analysis of liquid radioactive effluents

During the period under review, excesses of administrative and process levels, reference discharge levels and radioactive substances discharge limits have not been recorded at SS "Rivne NPP".

Total index of radioactive substances discharge into the Styr River over the year 2017 was 0.82% of the permissible discharge and has increased with respect to indicators of year 2016 (0.55% of PD).

Discharge of ^{137}Cs during the period under review has increased by 48.1% compared to year 2016, and discharge of ^{60}Co has increased by 70.2%.

In 2017, tritium contribution to PD index was 36.3% (46.4% in 2016).

Content of radioactive substances in water of the Styr River.

Water of the Styr River is monitored in three points:

- Maiunychi – 10 km upstream;
- downstream of the point of ISSS discharge;
- Sopachiv – 10 km downstream, downstream of the point of SSS discharge.

Samples were taken every ten-day period, each of 10 litres. Of these, 4 litres of water were poured through ion-exchange resins (anionite, cationite) in order to extract the radionuclides. Resin samples were measured on a γ-spectrometer.

Activity of tritium was determined based on volume quota of each sample on a liquid scintillation radiometer Tri-Carb 3170 TR/SL. Duration of measurements was 3600 s.

Table 2.18. Average content of radioactive substances in water of surface water bodies in 2017, Bq/m^3.

Name of radionuclide	River (upstream of NPP) the Village of Maiunychi	River (reference cross section) Sopachiv
^{137}Cs	< 2.20E+00	< 2.70E+00
^{134}Cs	< 2.10E+00	< 2.60E+00
^{60}Co	< 1.40E+00	< 2.10E+00
^{90}Sr	-	-
^{3}H	6.70E+03	1.61E+04

According to "Radiation control regulation" 132-1-Р-ЦРБ, SS "Rivne NPP" does not carry out any control of ^{90}Sr content in water of surface water bodies under normal operation [37].

Based on "zero background" data, activity of ^{137}Cs in water of the Styr River prior to start-up of SS "Rivne NPP" was within 3.7-22.2 Bq/m^3. Maximum content of significant radionuclide ^{3}H was recorded in the monitoring point at the Village of Sopachiv: 5.40E+04 Bq/m^3.

Specific activity of radionuclides in the Styr River over the period of 2009-2016 is presented in Table 2.19.

Table 2.20. Specific activity of radionuclides in the Styr River (2009-2016), Bq/m^3 [32].

Sampling point	^{3}H	^{60}Co	^{134}Cs	^{137}Cs
2009 year				
Maiunychi	7.76E+03	<1.53E+01	<1.70E+01	<1.90E+01
Sopachiv	1.29E+04	<1.30E+01	<1.50E+01	<1.69E+01
2010 year				
Maiunychi	7.29E+03	<1.60E+01	<1.80E+01	1.99E+01
Sopachiv	1.02E+04	<1.70E+01	<1.80E+01	<2.00E+01
2011 year				
Maiunychi	8.03E+03	<4.38E+00	<5.70E+00	<605E+00
Sopachiv	1.15E+04	<4.48E+00	<5.68E+00	6.08E+00
2012 year				
Maiunychi	6.30E+03	<2.40E+00	<3.1E+00	3.21E+00
Sopachiv	1.45E+04	<2.70E+00	4.21E+00	4.45E+00
2013 year				
Maiunychi	6.90E+03	<4.60E+00	<6.73E+00	<6.90E+00
Sopachiv	5.27E+04	<3.90E+00	<5.15E+00	<4.44E+00
2014 year				
Maiunychi	6.46E+03	<4.25E+00	<4.68E+00	<5.28E+00
Downstream of ISSS discharge	1.43E+04	<4.38E+00	<4.90E+00	<4.74E+00
Sopachiv	1.36E+04	<2.60E+00	<3.48E+00	<4.03E+00
2015 year				

Sampling point	^{3}H	^{60}Co	^{134}Cs	^{137}Cs
Maiunychi	6.64E+03	<2.48E+00	<3.50E+00	<3.75E+00
Downstream of ISSS discharge	1.87E+04	<2.52E+00	<3.43E+00	<4.05E+00
Sopachiv	1.98E+04	<1.99E+00	<3.05E+00	<3.08E+00
2016 year				
Maiunychi	7.71E+03	<2.50E+00	<4.20E+00	<3.85E+00
Downstream of ISSS discharge	2.07E+04	<2.70E+00	<3.70E+00	<3.75E+00
Sopachiv	1.94E+04	<1.75E+00	<2.38E+00	<2.65E+00

During the monitoring period, maximum activity of the most significant radionuclide ^{3}H was 6.95×104 Bq/m^3 (in 2016) in the Sopachiv monitoring point, which is 432 lower than the permissible concentration of this isotope in drinking water PC_B^{Ingest}.

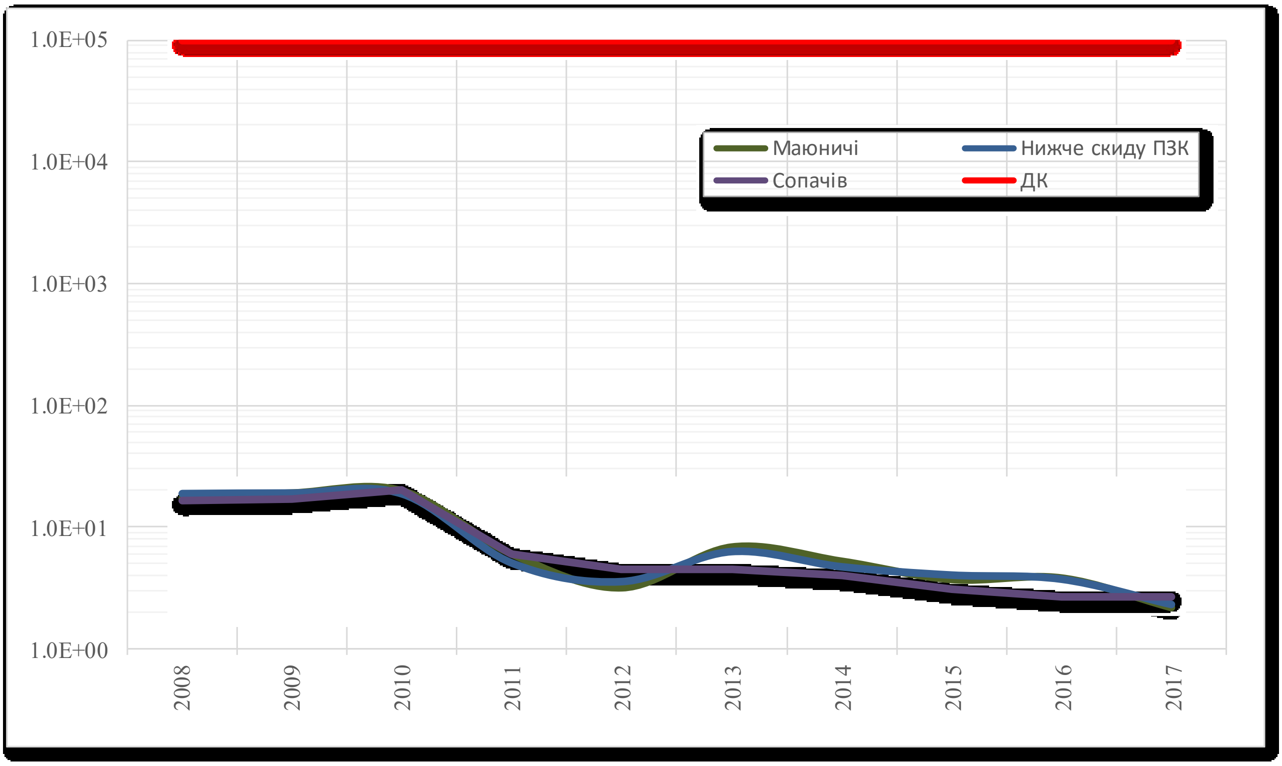

Fig. 2.4. Average volumetric activity of ^{137}Cs in water of the Styr River, Bq/m^3

Table 2.21. Volumetric activity of radionuclides in water of the Styr River by quarters, Bq/m^3.

Monitoring point	Sampling date	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Maiunychi	31.03.2017	<2,5E+01	6,09E+02	<2,0E+00	<3,3E+00	<4,1E+00	<2,6E+00	<3,1E+00
Maiunychi	30.06.2017	<2,2E+01	5,39E+02	<1,5E+00	<2,5E+00	<3,1E+00	<2,2E+00	<2,4E+00
Maiunychi	30.09.2017	<2,5E+01	5,43E+02	<1,7E+00	<3,1E+00	<4,2E+00	<2,6E+00	<2,4E+00
Maiunychi	31.12.2017	<8,1E+00	5,38E+02	<5,4E-01	<1,1E+00	<1,2E+00	<8,6E-01	<9,2E-01
Downstream of ISSS discharge	31.03.2017	<2,0E+01	5,68E+02	<2,4E+00	<3,2E+00	<3,3E+00	<2,6E+00	<2,8E+00
Downstream	30.06.2017	<1,2E+01	6,86E+02	<8,4E-01	<1,4E+00	<1,9E+00	<1,3E+00	<1,4E+00

Monitoring point	Sampling date	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
of ISSS discharge								
Downstream of ISSS discharge	30.09.2017	<3,6E+01	7,42E+02	<2,7E+00	<4,3E+00	<5,8E+00	<3,8E+00	<4,1E+00
Downstream of ISSS discharge	31.12.2017	<6,7E+00	1,06E+03	<1,2E+00	<1,2E+00	<5,9E-01	<1,2E+00	<9,7E-01
Sopachiv	31.03.2017	<3,4E+01	1,51E+02	<2,6E+00	<4,9E+00	<6,0E+00	<4,0E+00	<4,1E+00
Sopachiv	30.06.2017	<3,8E+01	6,40E+01	<4,1E+00	<5,4E+00	<6,8E+00	<4,5E+00	<4,9E+00
Sopachiv	30.09.2017	<7,2E+00	9,81E+01	<1,2E+00	<1,4E+00	<9,7E-01	<1,3E+00	<1,1E+00
Sopachiv	31.12.2017	<6,1E+00	1,94E+02	<4,5E-01	<6,9E-01	<8,1E-01	<6,9E-01	<7,1E-01

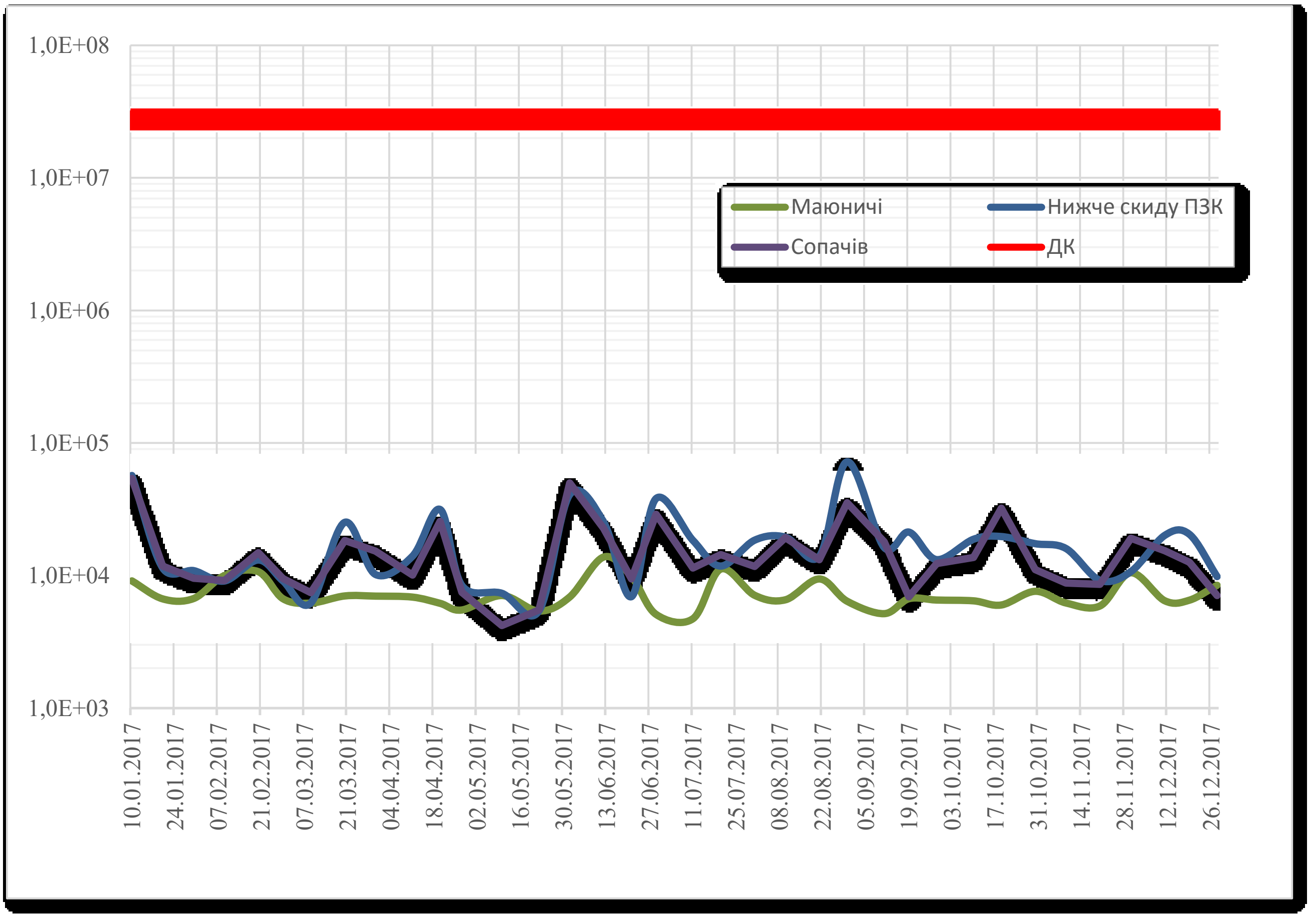

Fig. 2.5. Volumetric activity of ^{3}H in water of the Styr River in 2017, Bq/m^{3}

Maximum volumetric activity of ^{137}Cs in water of the Styr River in 2017 (26.8 Bq/m^{3}), that has been recorded in the Sopachiv monitoring point, is 3731 times lower than permissible content of this radionuclide in drinking water (PC_{B}^{Ingest}).

Maximum value of ^{3}H volumetric activity was 7.22E+04 Bq/m^{3} in the Sopachiv monitoring point, which is 416 times lower than permissible content of this radionuclide in drinking water (PC_{B}^{Ingest}).

2.3.2.3 Water sediments and algae monitoring in the Styr River

Activity of ^{137}Cs in algae of the Styr River prior to start-up of SS "Rivne NPP" was within 0.33-1.9 Bq/kg.

Activity of ^{137}Cs in bottom sediments of the Styr River prior to start-up of SS "Rivne NPP" was within 1.2-6.7 Bq/kg.

Bottom sediments and algae of the Styr River are sampled for monitoring annually in August. Once withdrawn and prepared to measurements, samples are checked using γ-spectrometers. Activity of algae is calculated on a wet sample weight basis.

Data of spectrometric measurements of bottom sediments and algae in the Styr River over the period of 2004-2016 are given in Tables 2.22 and 2.23.

As the tables show, minor algae and bottom sediments pollution (compared to "zero background") with isotope ^{137}Cs has been observed in the Styr River downstream of ISSS and SSS discharge of SS "Rivne NPP".

That said, it is worth noting that pollution level is significantly below the rated values and trends downward, and activity of the most notable technogenic radionuclide ^{137} is ten-folds lower than activity of the natural radionuclide ^{40}K.

Table 2.22. Specific activity of bottom sediments in the Styr River, Bq/kg.

Sampling point	^{40}K	^{60}Co	^{131}I	^{134}Cs	^{137}Cs
2004 year					
Maiunychi	3,74E+02	<1,60E+00	<3,40E+00	<8,40E-02	7,95E-02
RNPP site	2,56E+02	<7,60E-01	<1,10E+00	9,65E-02	5,53E-01
Sopachiv	1,37E+02	<4,00E-01	<4,00E-01	<3,90E-01	7,35E-01
2005 year					
Maiunychi	3,15E+02	<1,40E+00	<6,60E+00	<5,60E-02	4,39E-01
RNPP site	2,26E+02	<5,40E-01	<1,50E+00	<1,90E-01	3,20E-01
Sopachiv	2,40E+02	<7,10E-01	<1,80E-01	<7,80E-02	5,23E-01
2006 year					
Maiunychi	3,47E+02	<9,40E-01	<3,10E+00	<3,50E-02	1,44E-01
RNPP site	3,16E+02	<9,70E-01	<9,10E+00	4,39E-02	3,91E-01
Sopachiv	2,50E+02	<1,10E+00	<2,90E+00	3,30E-02	4,91E-01
2007 year					
Maiunychi	3,92E+02	<2,70E-01	<7,80E-01	<3,00E-02	2,66E-01
RNPP site	2,31E+02	<5,80E-02	<3,40E-01	<8,80E-02	4,46E-01
Sopachiv	2,75E+02	<2,30E-01	<5,20E-01	<5,40E-02	2,59E-01
2008 year					
Maiunychi	3,35E+02	<1,30E-01	<4,60E-01	<1,10E-01	1,99E-01
RNPP site	2,58E+02	<1,80E-01	<1,10E+00	<1,00E-01	1,78E-01
Sopachiv	2,36E+02	<2,30E-01	<1,50E+00	8,10E-02	6,14E-01
2009 year					
Maiunychi	3,83E+02	<1,90E-01	<5,50E-01	<1,20E-01	2,61E-01
RNPP site	3,23E+02	<2,30E-01	<4,50E-01	<1,60E-01	6,68E-01
Sopachiv	2,19E+02	<1,80E-01	<3,60E-01	1,20E-01	8,86E-01
2010 year					
Maiunychi	3,24E+02	<2,00E-01	<7,60E-01	<6,70E-02	9,61E-02
Kuznetsovsk	2,75E+02	<2,20E-01	<1,00E+00	<1,30E-01	1,09E+00

Sampling point	^{40}K	^{60}Co	^{131}I	^{134}Cs	^{137}Cs
Sopachiv	2,45E+02	<1,90E-01	<9,20E-01	<7,50E-02	5,44E-01
2011 year					
Maiunychi	3,32E+02	<6,30E-01	<1,40E+00	<1,10E-01	1,31E-01
Kuznetsovsk	2,12E+02	<6,30E-01	<1,40E+00	<1,30E-01	1,97E-01
Sopachiv	4,81E+02	<9,90E-01	<1,70E+00	<1,50E-01	1,90E-01
2012 year					
Maiunychi	1,93E+02	<9,60E-02	<2,50E-01	<1,10E-01	1,93E-01
Kuznetsovsk	1,39E+02	<2,20E-01	<4,40E-01	4,42E-02	5,73E-01
Sopachiv	1,27E+02	<8,20E-02	<2,30E-01	<9,20E-02	9,45E-01
2013 year					
Maiunychi	1,74E+02	<1,70E-01	<4,40E-01	<4,90E-02	2,65E-01
Kuznetsovsk	1,43E+02	<3,10E-01	<4,60E-01	<1,10E-01	6,44E-01
Sopachiv	1,94E+02	<1,80E-02	<3,90E-01	<9,20E-02	5,55E-01
2014 year					
Maiunychi	3,83E+02	<3,30E-01	<9,40E-01	<3,10E-02	1,55E-01
Kuznetsovsk	3,05E+02	<3,80E-01	<9,30E-01	<1,20E-01	3,20E-01
Sopachiv	1,15E+02	<1,90E-01	<5,20E-01	<3,00E-02	1,80E-01
2015 year					
Maiunychi	3,64E+02	<1,30E-01	<3,10E-01	<6,10E-02	<7,10E-02
Kuznetsovsk	1,97E+02	<1,00E-01	<2,10E-01	<5,60E-02	1,51E-01
Sopachiv	1,66E+02	<1,10E-01	<2,80E-01	<6,40E-02	4,71E-01
2016 year					
Maiunychi	2,23E+02	<4,90E-02	<1,00E-01	<5,50E-02	2,22E-01
Kuznetsovsk	9,22E+01	<2,90E-02	<7,10E-02	<2,10E-02	1,25E-01
Sopachiv	1,01E+02	<3,80E-02	<7,10E-02	<1,20E-01	3,77E-01

Bottom sediments and algae of the Styr River were sampled annually in August. The samples were subjected to γ-spectrometric analysis. Activity of radionuclide in algae samples is calculated on a fresh sample weight basis.

Table 2.23. Specific activity of radionuclides in bottom sediments of the Styr River, Bq/kg.

Sampling point	^{7}Be	^{40}K	^{58}Co	^{60}Co	^{110m}Ag-	^{131}I-	^{134}Cs	^{137}Cs
Maiunychi	8.63E-01	1.23E+02	<5.8E-02	<5.0E-02	<7.8E-02	<1.6E-01	<8.5E-02	1.38E+00
Varash	6.69E+00	1.96E+02	<8.0E-02	<6.8E-02	<1.1E-01	<2.5E-01	<1.4E-01	2.05E+01
Sopachiv	7.29E+00	1.45E+02	<8.6E-02	<7.3E-02	<1.0E-01	<1.4E-01	<1.3E-01	5.11E+00
Telkovychi	1.97E+01	1.31E+02	<7.9E-02	<6.9E-02	<1.0E-01	<1.7E-01	<1.4E-01	8.70E+00

Table 2.24. Specific activity of radionuclides in algae of the Styr River, Bq/kg

Sampling point	^{7}Be	^{40}K	^{58}Co	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Maiunychi	4.64E+00	5.80E+01	<2.3E-02	<1.9E-02	<3.1E-02	<6.5E-02	<3.4E-02	4.19E-01
Varash	6.29E+00	4.24E+01	<3.3E-02	<4.9E-02	<5.0E-02	<4.4E-02	<5.3E-02	6.23E-01
Sopachiv	2.06E+00	1.33E+02	<4.3E-02	<4.7E-02	<5.5E-02	<7.0E-02	<5.3E-02	2.68E-01
Telkovychi	2.07E+00	8.93E+01	<3.9E-02	<5.1E-02	<5.7E-02	<4.3E-02	<5.0E-02	5.37E-01

2.3.2.4 Fish monitoring in the Styr River

Fish was caught in the Village of Maiunychi and downstream of ISSS discharge of SS "Rivne NPP". Fish catching and preparation were followed by ɣ-spectrometric measurements.

Table 2.25 provides data on spectrometric measurements of fish over the period of 2004-2016. Fish pollution with the most significant isotope ^{137}Cs its average activity is ten-folds below the permissible level of this nuclide content in fish (DR-2006) [38].

Table 2.25. Specific activity of fish samples from the Styr River (2004-2016), Bq/kg [32].

Sampling point	^{40}K	^{60}Co	^{131}I	^{134}Cs	^{137}Cs
2004 year					
Maiunychi	8.37E+01	<4.90E-01	<1.40E+00	<3.90E-01	4.69E-01
RNPP site	1.66E+02	<4.20E-01	<9.70E-01	<4.00E-01	5.61E-01
Sopachiv	1.28E+02	<4.70E-01	<3.60E+00	<4.20E-01	7.20E-01
2005 year					
Maiunychi	9.93E+01	<1.80E-01	<3.1E-01	<1.70E-01	9.62E-01
RNPP site	1.18E+02	<5.60E-01	<9.50E-01	<5.00E-01	8.18E-01
Sopachiv	9.76E+01	<1.20E-01	<3.40E-01	<1.20E-01	1.54E-01
2006 year					
Maiunychi	8.53E+01	<9.40E-01	<8.30E-01	<8.40E-01	5.49E-01
RNPP site	8.66E+01	<1.40E+00	<2.40E+00	<1.20E+00	1.50E+00
Sopachiv	-	-	-	-	-
2007 year					
Maiunychi	6.13E+01	<1.00E+00	<2.10E+07	<1.20E+00	1.30E+00
RNPP site	8.61E+01	<1.20E-01	<3.70E-01	<1.00E-01	7.99E-01
Sopachiv	8.76E+01	<5.80E-01	<1.10E+00	<7.40E-01	2.86E+00
2008 year					
Maiunychi	1.59E+02	<1.50E+00	<5.80E+01	<1.40E+00	2.98E+00
RNPP site	7.13E+01	<9.10E-01	<1.70E+00	<1.20E+00	2.46E+00
Sopachiv	1.34E+02	<6.30E-01	<9.70E-01	<6.00E-01	7.73E+00
2009 year					
Maiunychi	1.74E+02	<1.60E+00	<2.20E+00	<1.70E+00	1.88E+00
RNPP site	1.47E+02	<6.80E-01	<1.20E+00	<8.20E-01	8.78E-01
Sopachiv	1.51E+02	<5.40E-01	<8.00E-01	<5.60E-01	-
2010 year					
Maiunychi	1.21E+02	<8.70E-01	<1.60E+00	<1.10E+00	<1.40E+00
Kuznetsovsk	1.40E+02	<9.70E-01	<1.60E+00	<1.10E+00	<1.30E+00
Sopachiv	9.37E+01	<1.40E+00	<2.10E+00	<1.30E+00	1.49E+00
2011 year					
Maiunychi	1.37E+02	<1.70E+00	<1.50E+00	<1.60E+00	<1.73E+00
Kuznetsovsk	2.18E+02	<1.90E+00	<1.80E+00	<2.00E+00	1.36E+00
Sopachiv	1.48E+02	<1.40E+00	<1.50E+00	<1.90E+00	<1.8E+00
2012 year					
Maiunychi	1.68E+02	<1.00E+00	<1.40E+00	<1.40E+00	<1.50E+00
Kuznetsovsk	1.29E+02	<1.50E+00	<1.80E+00	<1.30E+00	1.17E+00
Sopachiv	1.22E+02	<1.10E+00	<1.30E+00	<1.50E+00	1.73E+00
2013 year					
Maiunychi	1.11E+02	<8.40E-01	<1.60E+00	<1.40E+00	9.91E-01

Sampling point	^{40}K	^{60}Co	^{131}I	^{134}Cs	^{137}Cs
Kuznetsovsk	1.23E+02	<9.40E-01	<1.70E+00	<1.10E+00	<1.80E+00
Sopachiv	1.05E+02	<2.20E+00	<2.10E+00	<2.25E+00	<2.80E+00
2014 year					
Maiunychi	<5.00E+01	<8.90E-01	<1.30E+00	<1.80E+00	<1.50E+00
Kuznetsovsk	1.29E+02	<9.00E-01	<1.20E+00	<1.20E+00	<1.20E+00
Sopachiv	1.218E+02	<1.50E+00	<1.30E+00	<1.50E+00	1.29E+00
2015 year					
Maiunychi	1.79E+02	<7.40E-01	<1.00E+00	<8.90E-01	<1.20E+00
Kuznetsovsk	1.23E+02	<6.70E-01	<1.10E+00	<6.60E-01	<8.80E-01
Sopachiv	<3.90E+01	<9.20E-01	<1.70E+00	<1.50E+01	<1.60E+00
2016 year					
Maiunychi	1.58E+02	<2.20E-01	<6.20E-01	<3.50E-01	1.69E+00
Kuznetsovsk	1.75E+02	<5.00E-01	<8.40E-01	<6.70E-01	<8.00E-01
Sopachiv	2.12E+02	<7.70E-01	<9.70E-01	<9.30E-01	<1.20E+00

In 2017, fish catching from the Styr River took place in August, in 4 monitoring points: the Village of Maiunychi (10 km upstream), the Town of Varash (downstream of ISSS discharge), in the Village of Sopachiv (10 km downstream) and in the Village of Telkovychi (at the Styr River egress from the CA). Fish catching was followed by γ-spectrometric investigations.

Table 2.26. Specific activity of fish from the Styr River, investigations of 2017, Bq/kg

Точка контролю	^{40}K	^{60}Co	^{134}Cs	^{137}Cs
Maiunychi	1.58E+02	<2.2E-01	<3.5E-01	1.69E+00
Varash	1.75E+02	<5.0E-01	<6.7E-01	<8.0E-01
Sopachiv	2.12E+02	<7.7E-01	<9.3E-01	<1.2E+00
Telkovichi	1.69E+02	<5.2E-01	<6.6E-01	<7.5E-01
Average activity	1.78E+02	<5.1E-01	<6.5E-01	1.10E+00

2.3.2.5 Drinking water monitoring

Until 2007, cold and hot water samples were withdrawn in amounts of 2 litres, then boiled down to dry residue and measured for Σβ activity. Dry residues were accumulated during the quarter and tested for content of γ-emitting radionuclides. Since 2007, cold and hot water are withdrawn weekly in amounts of 4 litres. The water is poured through ion-exchange resins (anionite, cationite) in order to extract the radionuclides. Resin samples were measured on a γ-spectrometer.

Since 2007, drinking water is monitored for content of tritium, which is the most significant radionuclide in the samples. Activity of tritium was determined based on volume quota of each sample on a liquid scintillation radiometer Tri-Carb 3170 TR/SL. Duration of measurement was 3600 s. MDA of tritium measurement is 5.0×10^3 Bq/m^3. Average volumetric activity of ^3H in cold (drinking) water is 7.84×10^3 Bq/m^3, which is 3828 below its permissible content (PC_B^{Ingest}).

Tables 2.18 and 2.19 provide data on spectrometric measurements of radionuclides specific activity in cold and hot water samples over the period of 2004-2016. Activity of technogenic radionuclides, except for ^{137}Cs, is below MDA in all cold and hot water samples. Tritium is the main technogenic contributor to specific activity of drinking water. Tables 2.27 and 2.28 show activity indexes for isotopes ^{137}Cs and ^3H in relation to PC_B^{ingest}.

Table 2.27. Specific activity of radionuclides in cold water.

Year	^{40}K, Bq/m^3	^{60}Co, Bq/m^3	^{131}I, Bq/m^3	^{134}Cs, Bq/m^3	^{137}Cs, Bq/m^3	Index ^{137}Cs, %	^{3}H, Bq/m^3	Index ^{3}H, %
2004	9.82E+02	<5.10E+00	<2.50E+02	<2.20E+00	4.79E+00	4.79E-03	-	-
2005	<8.60E+01	<4.40E+00	<2.60E+02	<5.00E+00	7.58E+00	7.58E-02	-	-
2006	1.03E+02	<3.10E-01	<6.20E+01	<8.00E-01	3.85E+00	3.85E-03	-	-
2007	2.12E+03	<1.67E+01	<3.30E+01	<1.96E+01	<2.00E+01	<2.00E-02	2.30E+04	7.67E-02
2008	1.83E+03	<1.50E+01	<2.70E+01	<1.70E+01	<1.93E+01	<2.00E-02	8.69E+03	2.90E-02
2009	2.27E+03	<1.60E+01	<3.30E+01	<1.80E+01	<1.96E+01	<1.96E-02	9.02E+03	3.01E-02
2010	2.49E+03	<1.81E+01	<3.60E+01	<2.00E+01	<2.18E+01	<2.18E-02	9.35E+03	3.12E-02
2011	2.10E+03	<2.45E+01	<3.79E+01	<2.99E+01	<3.17E+01	<3.17E-02	7.95E+03	2.65E-02
2012	1.11E+03	<2.00E+01	<4.40E+01	<3.00E+01	<2.98E+01	<2.98E-02	7.50E+03	2.50E-02
2013	1.63E+03	<3.30E+00	<6.90E+01	<4.70E+01	<5.04E+01	<5.04E-02	6.82E+03	2.27E-02
2014	3.78E+02	<8.12E+00	<1.15E+01	<1.14E+01	9.25E+00	9.25E-03	6.97E+03	2.32E-02
2015	1.68E+02	<6.30E+00	<1.30E+01	<8.70E+00	<9.60E+00	<9.60E-03	7.52E+03	2.51E-02
2016	1.92E+02	<4.60E+00	<8.90E+00	<7.40E+00	<7.70E+00	<7.70E-03	8.37E+03	2.79E-02

Table 2.28. Specific activity of radionuclides in hot water.

Year	^{40}K, Bq/m^3	^{60}Co, Bq/m^3	^{131}I, Bq/m^3	^{134}Cs, Bq/m^3	^{137}Cs, Bq/m^3	Index ^{137}Cs, %	^{3}H, Bq/m^3	Index ^{3}H, %
2004	4.19E+02	<5.10E+00	<1.00E+02	<4.90E+00	3.67E+00	3.67E-03	-	-
2005	<2.00E+01	<4.40E+00	<5.30E+01	6.37E+00	3.10E+01	3.10E-02	-	-
2006	5.71E+01	<3.10E-01	<4.30E+01	<7.62E-01	5.95E+00	5.95E-02	-	-
2007	2.01E+03	<1.67E+01	<2.93E+01	<1.74E+01	<1.84E+01	<1.84E-02	2.40E+04	8.00E-02
2008	2.01E+03	<1.50E+01	<2.93E+01	<1.74E+01	<1.84E+01	<1.84E-02	3.69E+04	1.32E-01
2009	2.20E+03	<1.60E+01	<2.70E+01	<1.50E+01	<1.68E+01	<1.68E-02	2.35E+04	7.83E-02
2010	2.39E+03	<1.81E+01	3.15E+01	3.47E+01	<2.00E+01	<2.00E-02	3.29E+04	1.10E-01
2011	2.05E+03	<2.45E+01	<3.63E+01	<3.08E+01	<3.13E+01	<3.13E-02	1.43E+04	4.77E-02
2012	1.30E+03	<2.00E+01	<5.00E+01	<3.40E+01	<3.31E+01	<3.31E-02	7.16E+03	2.39E-02
2013	1.61E+03	<3.30E+00	<7.10E+01	<5.50E+01	<5.70E+01	<5.70E-02	6.43E+03	2.14E-02
2014	4.49E+02	<8.12E+00	<1.20E+01	<1.00E+01	<1.00E+01	<1.00E-02	6.22E+03	2.70E-02
2015	1.84E+02	<6.30E+00	<1.30E+01	<8.50E+00	<9.80E+00	<9.80E-03	6.97E+03	2.32E-02
2016	2.34E+02	<4.60E+00	<8.80E+00	<7.60E+00	7.67E+00	7.67E-03	7.58E+03	2.53E-02

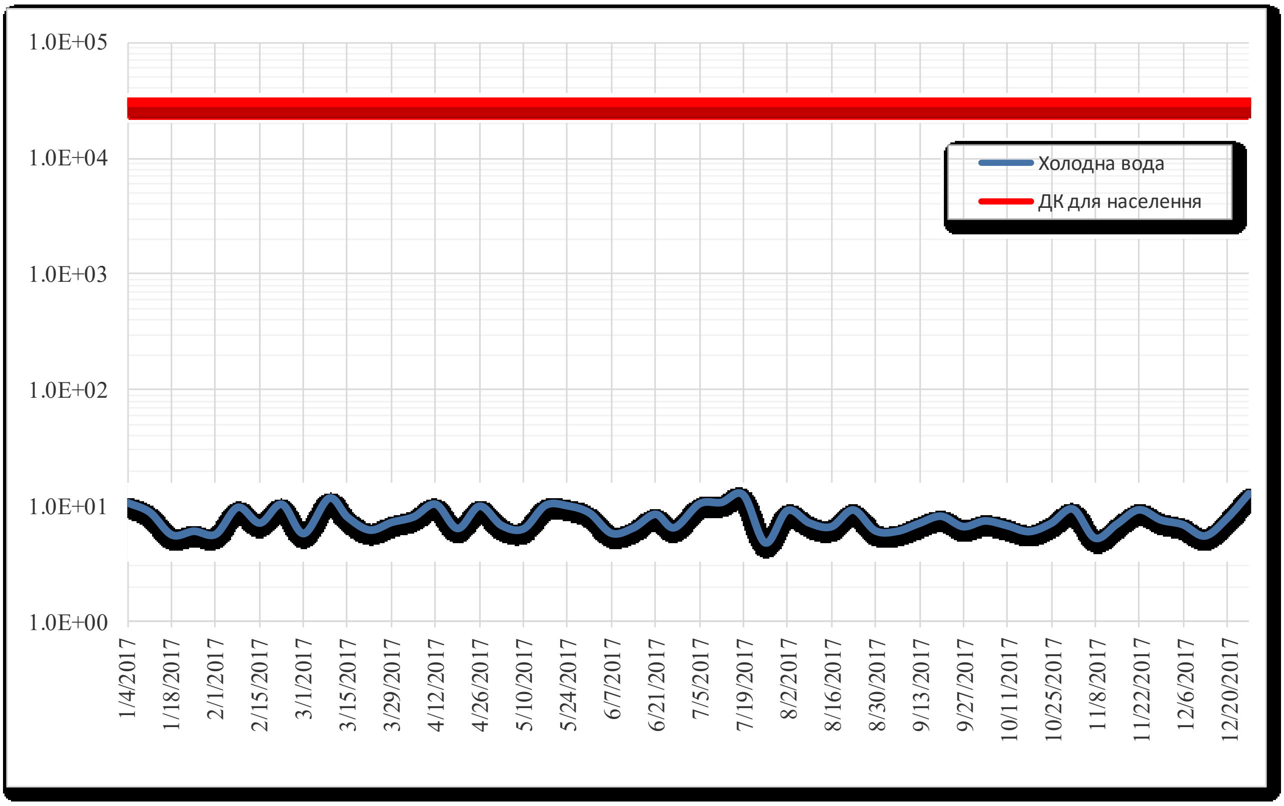

Fig. 2.6. Volumetric activity of ^{3}H in cold water in 2017, Bq/m^{3}

Table 2.29. Volumetric activity of radionuclides in cold water by months, Bq/m^{3}

Sampling date	^{40}K	^{54}Mn	^{58}Co	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs	^{3}H
31.01.2017	2.14E+02	<5.3E+00	<3.8E+00	<2.9E+00	<4.8E+00	<4.1E+00	<4.3E+00	<4.7E+00	7.76E+03
28.02.2017	<6.3E+01	<3.0E+00	<2.7E+00	<2.3E+00	<3.5E+00	<4.5E+00	<3.9E+00	<3.2E+00	7.72E+03
31.03.2017	2.37E+02	<3.3E+00	<3.2E+00	<2.4E+00	<4.1E+00	<4.4E+00	<3.9E+00	<4.2E+00	8.23E+03
30.04.2017	1.63E+02	<4.2E+00	<3.5E+00	<3.3E+00	<5.4E+00	<4.5E+00	<4.6E+00	<5.1E+00	8.28E+03
31.05.2017	2.70E+02	<4.9E+00	<5.2E+00	<2.5E+00	<4.0E+00	<5.4E+00	<5.1E+00	<4.3E+00	8.78E+03
30.06.2017	1.39E+02	<4.6E+00	<4.6E+00	<3.4E+00	<6.0E+00	<7.1E+00	<5.5E+00	<6.4E+00	6.80E+03
27.07.2017	1.47E+02	<2.8E+00	<2.5E+00	<2.5E+00	<4.1E+00	<3.3E+00	<3.4E+00	<3.1E+00	9.48E+03
30.08.2017	1.48E+02	<3.7E+00	<3.8E+00	<3.4E+00	<4.9E+00	<5.8E+00	<4.5E+00	<5.0E+00	7.26E+03
30.09.2017	<1.2E+02	<6.6E+00	<6.0E+00	<4.8E+00	<1.0E+01	<9.2E+00	<6.8E+00	<8.0E+00	6.96E+03
27.10.2017	2.51E+02	<4.8E+00	<4.3E+00	<2.7E+00	<5.2E+00	<6.0E+00	<4.7E+00	<5.1E+00	7.32E+03
30.11.2017	3.17E+02	<7.2E+00	<6.1E+00	<4.6E+00	<7.2E+00	<8.6E+00	<6.7E+00	<6.9E+00	7.26E+03
31.12.2017	2.26E+02	<5.6E+00	<5.5E+00	<4.6E+00	<8.2E+00	<6.8E+00	<7.0E+00	<6.7E+00	8.21E+03
Amid	1.91E+02	<4.7E+00	<4.3E+00	<3.3E+00	<5.6E+00	<5.8E+00	<5.0E+00	<5.2E+00	7.84E+03
Index PC_B^{Ingest}, %		<5.9E-04	<7.2E-04	<4.1E-03	<2.8E-03	<2.9E-02	<7.1E-03	<5.2E-03	2.61E-02

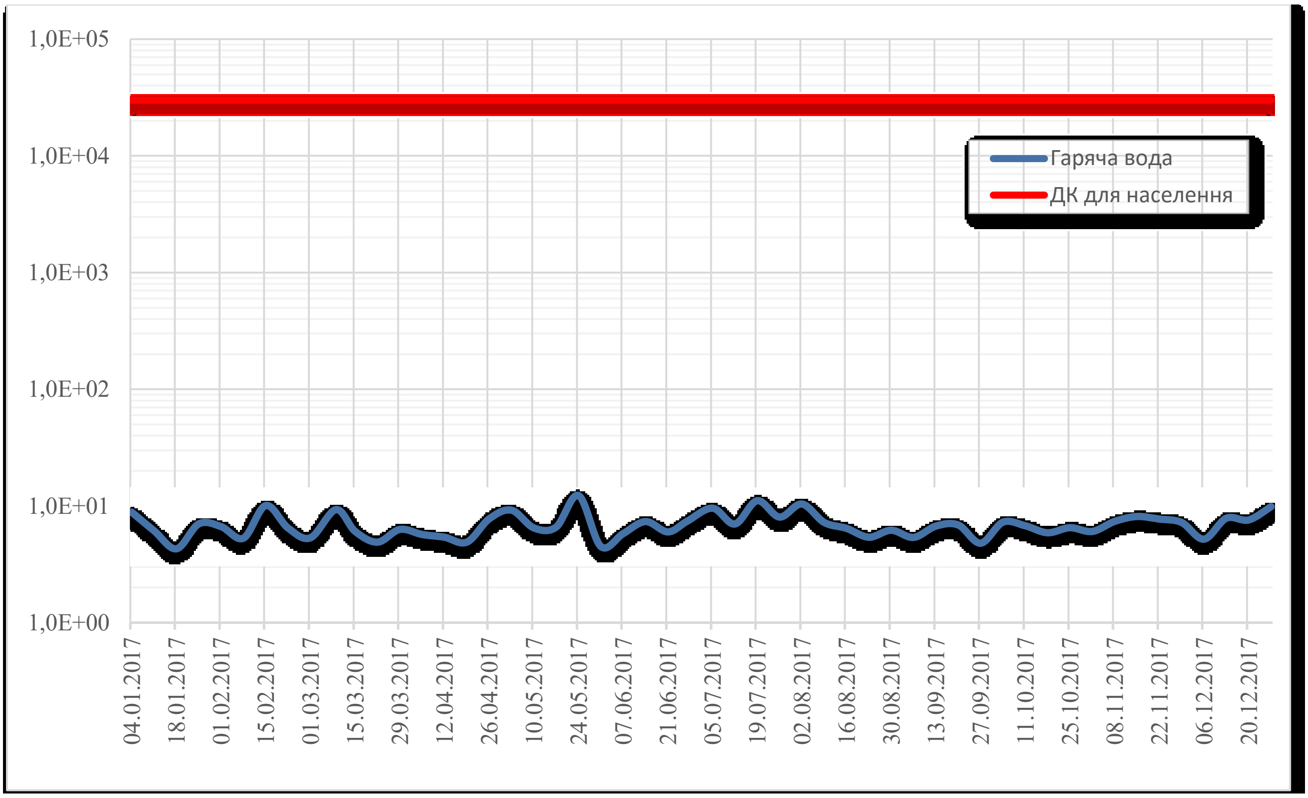

Fig. 2.7. Volumetric activity of ^{3}H in hot water in 2017, Bq/m^3

Table 2.30. Volumetric activity of radionuclides in hot water by months (gross samples), Bq/m^3.

Sampling data	^{40}K	^{54}Mn	^{58}Co	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs	^{3}H
31.01.2017	2.83E+02	<3.9E+00	<4.7E+00	<3.8E+00	<6.1E+00	<4.2E+00	<5.1E+00	<5.7E+00	6.58E+03
28.02.2017	<8.1E+01	<5.3E+00	<4.5E+00	<3.5E+00	<7.3E+00	<6.4E+00	<5.8E+00	<5.5E+00	6.77E+03
31.03.2017	2.05E+02	<1.8E+00	<1.8E+00	<1.5E+00	<2.9E+00	<2.8E+00	<2.5E+00	<2.4E+00	6.64E+03
30.04.2017	3.20E+02	<3.0E+00	<2.7E+00	<2.6E+00	<3.4E+00	<3.4E+00	<3.6E+00	<3.9E+00	6.59E+03
31.05.2017	1.87E+02	<2.4E+00	<2.1E+00	<2.2E+00	<2.5E+00	<3.8E+00	<2.9E+00	<2.8E+00	7.47E+03
30.06.2017	1.47E+02	<1.8E+00	<1.8E+00	<1.6E+00	<2.5E+00	<2.3E+00	<2.2E+00	<2.0E+00	6.64E+03
27.07.2017	2.72E+02	<3.4E+00	<3.3E+00	<2.7E+00	<5.0E+00	<5.6E+00	<4.3E+00	<4.4E+00	9.23E+03
30.08.2017	1.28E+02	<4.2E+00	<4.0E+00	<4.5E+00	<6.2E+00	<3.4E+00	<4.8E+00	<3.6E+00	6.32E+03
30.09.2017	1.36E+02	<3.9E+00	<3.7E+00	<3.3E+00	<5.3E+00	<5.8E+00	<4.7E+00	<5.1E+00	5.95E+03
27.10.2017	2.21E+02	<2.3E+00	<2.0E+00	<1.9E+00	<2.9E+00	<2.7E+00	<2.3E+00	<2.3E+00	6.50E+03
30.11.2017	9.50E+01	<4.0E+00	<4.0E+00	<3.7E+00	<5.4E+00	<5.8E+00	<5.3E+00	<5.0E+00	7.62E+03
31.12.2017	<8.9E+01	<4.3E+00	<3.7E+00	<3.8E+00	<4.9E+00	<4.6E+00	<4.5E+00	<4.9E+00	7.63E+03
Amid	1.80E+02	<3.4E+00	<3.2E+00	<2.9E+00	<4.5E+00	<4.2E+00	<4.0E+00	<4.0E+00	6.99E+03
Index PC_B^{Ingest}, %		<4.3E-04	<5.3E-04	<3.6E-03	<2.3E-03	<2.1E-02	<5.7E-03	<4.0E-03	2.3E-02

2.3.3 Radiation status of surface water in the Region of Rivne

Radioactive contamination of surface water in the region is determined mainly by impact of Rivne and Khmelnytskyi Nuclear Power Plants. Radiation status of surface water in the region is monitored by:

- Rivne Regional Hydrometeorological Center;
- Rivne Hydrogeological Meliorative Expedition of Rivne Regional Directorate of Water Resources.

The Regional Hydrometeorological Center was withdrawing samples of surface water within the coverage area of Rivne and Khmelnytskyi NPPs for subsequent gamma-spectrometric analysis for ^{137}Cs content.

Analysis of radioactive contamination of surface water around the NPPs is presented in Table 2.31.

Facility, benchmark	I half of the year	II half of the year	Average	Max	Min
Rivne NPP	11.04.2016	12.10.2016			
1. The Styr River, stream gauge upstream of the NPP	3.27	3.19	3.23	3.27	3.19
2. The Styr River, the Village of Babka, industrial effluents, downstream of the NPP	2.92	2.93	2.93	2.93	2.92
Khmelnytska NPP	14.04.2016	19.10.2016			
1. The Horyn River, the Village of Polian, upstream of the NPP	2.94	2.17	2.56	2.94	2.17
2. The Horyn River, the Village of Velbivne, downstream of the NPP	2.51	2.01	2.26	2.51	2.01

In 2016, radiation situation in the areas of operating Rivne and Khmelnytskyi NPP was stable. Specific activity of ^{137}Cs in surface water of control points of the Hydrometeorological Center around the Rivne NPP was significantly lower than the permessible levels (DR-2006) [38].

Radiological laboratory of the Rivne Hydrogeological Meliorative Expedition has performed radiological analyses, including gamma-spectrometric (for ^{137}Cs) and radiochemical (for ^{90}Sr) analysis, of surface water bodies in the coverage areas of SS "Rivne NPP", SS "Khmelnytskyi NPP" and control points bordering the Republic of Belarus.

Analysis of surface water contamination with radionuclides in the coverage area of SS "Rivne NPP" and SS "Khmelnytskyi NPP" and in the border control points is presented in Table 2.32.

Table 2.32. Results of water samples analysis for ^{137}Cs and ^{90}Sr, pCi/l.

No	Names of control point	Concentration of ^{137}Cs				Concentration of ^{90}Sr			
		Average annual value		Max over	Min over	Average annual over		Max over	Min over
		2015	2016	2016	2016	2015	2016	2016	2016
Rivne NPP coverage area									
1	The Styr River (RNPP water intake)	2.05	2.03	2.1	2.0	0.10	0.13	0.15	0.09
2	The Styr River, the Village of Sopachiv (downstream of RNPP)	2.03	2.04	2.2	2.0	0.12	0.13	0.17	0.09
3	Industrial effluents of RNPP	2.92	2.47	3.9	2.0	0.14	0.13	0.17	0.09
4	Storm effluents of RNPP	2.19	2.14	2.5	2.0	0.12	0.13	0.18	0.09
Khmelnytskyi NPP coverage area									
5	The Horyn River, the UTS of Netishyn (upstream of KhNPP)	203	2.03	2.2	2.0	0.12	0.12	0.15	0.09
6	The Horyn River, the Village of Velbivne (downstream of KhNPP)	2.03	2.03	2.2	2.0	0.13	0.12	0.15	0.09
7	The Hnylyi Rih River, KhNPP cooling pond	2.13	2.04	2.3	2.0	0.13	0.14	0.22	0.10
8	The Viliia River, the Town of Ostroh (KhNPP coverage area)	2.03	2.13	2.2	2.0	0.12	0.10	0.11	0.09
Border control points									

No	Names of control point	Concentration of ^{137}Cs				Concentration of ^{90}Sr			
		Average annual value		Max over	Min over	Average annual over		Max over	Min over
		2015	2016	2016	2016	2015	2016	2016	2016
9	The Styr River, the UTS of Zarichne	2.05	2.08	2.2	2.0	0.14	0.11	0.14	0.09
10	The Horyn River, the Village of Vysotsk	2.15	2.03	2.1	2.0	0.13	0.18	0.22	0.15
11	The Prypiat River, the Village of Senchytsi	2.00	2.00	2.0	2.0	0.12	0.15	0.20	0.12
12	The Lva River, the Village of Perebrody	2.03	2.00	2.0	2.0	0.17	0.17	0.22	0.12
13	The Stvyha River, the Village of Poznan	2.03	2.03	2.1	2.0	0.16	0.15	0.17	0.14

In the control area of Rivne NPP, the highest content of ^{137}Cs in 2016 was observed in waste water, as well as industrial and storm effluents from RNPP; quantitative values of ^{137}Cs specific activity were within 2.0-3.9 pCi/l, i.e. did not exceed the permissible levels of 54 pCi/l established by DR-2006. The maximum value was recorder in industrial effluents of SS "Rivne NPP" in May 2016, and was equal to 3.9 pCi/l, i.e. did not exceed the permissible levels (DR-2006). Content of radiocaesium is maintained within the normal range of 0.09-0.18 pCi/l and does not exceed the permissible levels (see Fig. 2.8).

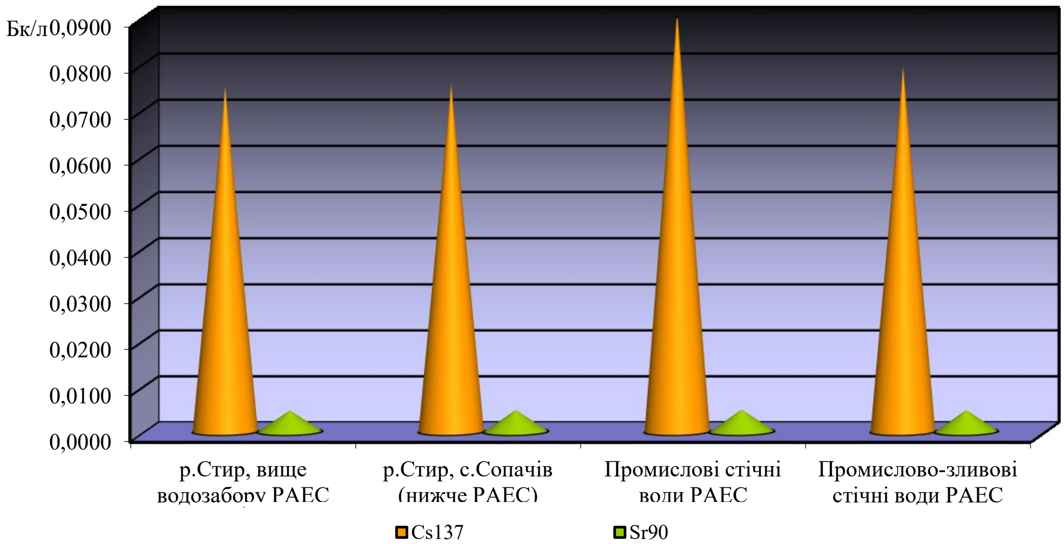

Fig. 2.8. Radioactive contamination of surface water in the coverage area of SS "Rivne NPP".

3 GROUND WATER

The Region of Rivne lies within three artesian basins: Volhynia-Podolian, Prypiat and Ukrainian basin of fracture and stratal water basin.

Total predicted ground water resource in the region is about 1314.913 million m^3/year, and the approved reserves are 195.798 million m^3/year, which is 14.9 % of the predicted resource. Ground water reserves by administrative-territorial districts as of 01.01.2017 are given in Table 3.1

Table 3.1. Status of ground water in the region

No	District name	Ground water reserves		
		Predicted resources, million m^3/year	Approved reserves, million m^3/year	% of predicted resources
1	the District of Volodymyrets	97.309	20.502	21.1
2	the District of Berezne	64.788	6.570	10.1
3	the District of Hoshcha	129.612	23.361	18.0
4	the District of Dubno	92.637	14.600	15.8
5	the District of Dubrovytsia	145.124	9.676	6.7
6	the District of Zarichne	66.905	6.935	10.4
7	the District of Zdolbuniv	55.553	13.870	25.0
8	the District of Korets	12.629	3.395	26.9
9	the District of Kostopil	135.488	7.300	5.4
10	the District of Mlyniv	-	-	-
11	the District of Demydivka	101.762	7.180	7.1
12	the District of Ostroh	51.867	3.062	5.9
13	the District of Rivne	165.820	57.907	34.9
14	the District of Rokytne	21.718	1.862	8.6
15	the District of Sarny	133.992	14.450	10.8
16	the District of Radyvyliv	39.712	5.128	12.9
	Total in the region	1314.913	195.798	14.9

From chemical and bacteriologic point of view, ground water is of good quality, with mineralization up to 1 g/dm^3, of hydrocarbonate calcium type. Only ground water of Horbashiv aquifer are different in chemical composition at water intakes of the City of Rivne, where the aquifer descends to a significant depth – the water becomes of hydrocarbonate type, but even having such a composition they fully comply with requirements of DSTU in effect.

At active water intakes of the region, fall in water levels of operational aquifers over the multi-year period does not exceed the permissible limits.

In 2016, water was not sampled in the Region of Rivne, new pollution centres have not been detected.

Among other resources, that can supplement economic base of the Rivne Region, mineral water are given a significant role. Balneological water properties and low cost of their production are the basis for development of this promising branch. The most prospective type of mineral water is sodium chloride water of Myrhorod type, which is the commonest in the region. It mainly leans towards Vendian and Paleozoic volcanogenic and terrigenous rocks, and occurs at depths from 70-80 m to 750 m. These water reserves are proven in the Villages of Zhobryn and Oleksandriia of the Disctrict of Rivne, the UTS of Stepan of the Disctrict of Sarny, and in the Town of Ostroh. At these three deposits (Zhobryn, Ostroh and Stepan deposits), medicinal and table mineral water is produced and bottled on a commercial basis into glass and polyethylene packaging for internal use.

During the period under review, gain of reserves was due to the Vodohraina site of Zhobryn mineral water deposit, with operating reserves in place approved in the Upper Vendian Kanyliv series under the categories: A – 12.000 m^3/day, B – 68.00 m^3/day, and Malyi Mydsk mineral water deposit with reserves in place approved in the Upper and Middle Riphaean Polesian series under the category: B – 10.000 m^3/day.

Sodium sulphate water of drinking quality, with mineralization of 3-6 g/dm^3, has been found in the District of Dubno.

Radon mineral water occurs near the Villages of Vyry (the Disctrict of Sarny) and Marynyn (the District of Berezne).

Proven reserves of radon water in the Town of Korets make 280 m^3/day with concentration of 20 nCi/dm^3 and are used by the Public Institution "Korets Regional Hospital of Medical Rehabilitation" for treatment of locomotor system.

Ground water resources of the region deserve further investigations and utilization. Main tasks in this field are the following:

- to complete the geological exploration works at the Moshkiv mineral water deposit in the District of Mlyniv and at the Nadsluchanske deposit in the District of Berezne;
- to increase production of mineral water in PET bottles by 20-25% at the mineral water plant TOV "Ostrozkyi Zavod Mineralnykh Vod".

For many years, Rivne Geological Expedition conducts systematic studies of ground water status by routine observation of subsoil water levels regime and hydrochemical water indicators in 31 control points located in different natural and technogenic conditions (pressure on water intakes, drainage, within industrial and settlement zones etc.). In 2016, water has not been sampled for chemical analyses due to irregular funding of this type of works.

Main conclusions on transformation of ground water in the region:

- deep-lying (artesian) water, that are used for main water supply, are not subject to qualitative changes and generally comply with sanitary standards for drinking water;
- post-Chornobyl contamination with radionuclides has not been detected;
- the part of subsoil water nearest to the surface is substantially transformed, with ongoing qualitative changes of chemical content.

On a regional scale, changes were observed in chemical content of ground water on areas with low forest coverage, relatively high technogenic pressure, increased application of mineral fertilizers, which leads to certain problems with subsoil water self-purification.

Notable sources of ground water pollution include industrial enterprises and especially their waste water, which accumulates in containment ponds, settlers on filtration beds and treatment facilities, then leaks into subsoil water and flows into deeper aquifers.

A significant threat is posed by disordered stocks of toxic chemicals, fuel and lubricants, landfills, settlements without a sewage network.

Potential sources of ground water pollution include abandoned wells or faulty wells that need sanitary and engineering plug back, wells without ordered zones of sanitary and engineering regime, especially if the are located directly next to pollution sources and do not have permanent sealing.

Continuous control is exerted over sources of drinking water pollution within the depression zone, that developed in the coverage area of Horbakiv water intake which is the largest source of water supply for the City of Rivne and some settlements in the Districts of Hoshcha and Rivne. The area, where exploitation of the main aquifer affects the Meso-Cenozoic aquifer system, is mapped based on the research findings.

According to data of continuous laboratory control carried out by the enterprise Rivneoblvodokanal, water supplied from artesian wells of water intakes, located in the Hoshcha (4 wells) and Rivne (107 wells) districts of the enterprise, fully complies with hygienic requirements to water quality for sources of main utility and drinking water supply of 2nd class, except for turbidity index, which is sometimes exceeded.

In settlements, where quality of water produced from ground sources of main water supply does not meet the requirements of effective regulatory standards (in particular, for content of iron), its improvement to regulatory limits is envisaged by the means of treatment at water purification plants (deferrization stations) and implementation of measures on advanced treatment, and drinking water is disinfected.

To measure volume of produced ground water and to control its supply, licensees that run business in the field of main water supply use cold water metering devices. For example, in 2016 Rivne Regional Production Public Enterprise of Water and Sewage Utilities (RRPPE WSU) Rivneoblvodokanal pumped up 14.71 million m^3 of ground water and supplied 14.14 million m^3 to all consumers.

In 2016, RRPPE WSU "Rivneoblvodokanal" purified 8.2 million m^3 of effluents at own sewage treatment facilities and disposed of 14.69 millions m^3 (part of effluents was pumped to PAT Rivneazot).

In addition, measures were taken under the regional and local programs "Drinking water", with total funding in 2016 of 8.86 millions UAH from all funding sources.

In particular, a deferrization station with a capacity of 100 m^3/day was built in the Town of Korets, 5.6 km of water supply networks were built in microdistricts of Straklov, Volytsia and meat packing plant in the Town of Dubno, failing and old water supply sections were reconstructed in 8 streets of the City of Rivne, as well as first stage water supply system in the UTS of Rokytne and one compact plant (КУ-200) of treatment facilities in the Town of Korets.

3.1 Hydrological measurements of the ground water regime

Systematic hydrogeological measurements of the ground water regime were conducted on the site of SS "Rivne NPP" on a continuous basis, starting from 1980. Until 1983, stationary observation wells network included only 11 monitoring points. In the period of 1983-1985, an additional network of wells was created based on regime of three aquifers – Quarternary (subsoil water), Upper Cretaceous and upper part of the Upper Proterozoic aquifer. In the subsequent years the network was extended and damaged wells were renovated when necessary.

Water level in the wells, temperature and chemical composition of ground water are controlled on a regular basis. Periodicity of level and temperature monitoring on the site is once per ten-day period, periodicity of chemical composition monitoring is one or two times a year.

In terms of completeness, the materials of hydrogeological monitoring can be estimated as quite informative, since they are filled with continuous information for a long period (over 20 years).

As of 2003, number of observation wells was as follows:

- for subsoil water – 140;
- for the Upper Cretaceous aquifer – 47;
- for upper part of the Upper Proterozoic aquifer – 12.

Locations of monitoring wells on the site of SS "Rivne NPP" as of 2017 is given in Table 3.2. Network of piezometer wells consists of 20 wells located within the site.

Table 3.2. Locations of monitoring wells on the site of SS "Rivne NPP"

Location	Numbers of monitoring wells
Power unit No. 1	267, 268
Power unit No. 2	270, 271, 272
Power unit No. 3	241, 242, 243, 244, 245, 246
Power unit No. 4	Пс-1, Пс-2, Пс-3а, Пс-4
Special building-1 (SB-1)	261, 262, 263, 264, 265, 266, 11316н
Special building-2 (SB-2)	247, 248, 249, 250, 251, 252, 253, 254
Industrial waste storage	273, 274, 275
Solid radioactive waste storage	49H, 50H

During the period under consideration, a new well No. 11316H was added in 2009, and well No. 269 ceased to exist in 2005.

Samples from monitoring wells are combined by facilities, and samples of piezometer wells are combined by layers, i.e. the Quarternary and Cretaceous aquifers. The combined samples undergo gamma-spectrometric analysis.

Radiation status of ground water (Table 3.6 and Table 3.7) is satisfactory, content of 226Ra, 137Cs and 90Sr are way below the values rated by NRBU-97 [44] and DR-2006 [30].

During routine review of Radiation control regulation of Rivne NPP 132-1-Р-ЦРБ [37], monitoring of piezometric wells was excluded from the scope of radiation control and was performed up to and including the first half of year 2014.

3.2. Ground water level (GWL)

3.2.1 Subsoil water

During construction and operation of SS "Rivne NPP" subsoil water regime was being formed under the influence of both natural and technogenic factors. As stated above, prior to start of construction on the site subsoil water table was of mound type, maximum absolute elevation in the mound centre was 178.600 m, the centre was located in the area of cooling towers No. 5 and No. 6. At the same time, absolute elevations were 172.000 to 175.000 m in the central part of the site, and 174.000 to 177.000 m in the area of the delivery channel.

Due to infiltration of process water, subsoil water level has increased. As early as during construction in 1974, level rise by 2-3 m was recorded in materials of investigations performed by the institute "LvivTEP".

Later, at a time of operation of SS "Rivne NPP", a subsoil water mound formed on the site with a centre in the area of the unit pump station (UPS) and delivery channel; elevation of subsoil water level in June, 1982, was 185.200 m, i.e. level depth was equal to 3.3 m, level rise was 10 m. Mound centre was located in the area of well No. 3H – between the cooling tower No. 1 and the channel.

After measures on discharge reduction were taken and water infiltrated into the soil, subsoil water level dropped, especially in the centre of the mound. In the first quarter of 1985, elevation of subsoil water level was 179.600 m; difference between this level and the primary level (year 1969) was 4 m here.

Level recession trend was clearly traced during several years after taking action on discharge reduction.

During 1985-1987, the level was dropping on the site. At that, the mound centre shifted into the area of cooling towers and the delivery channel. Value of level recession over the period of 1986-1988 were from 1.6 to 5.5 m in different areas of the site, 3-4 m on average.

After that, in most of monitored wells stabilization of water level was recorded, and a tendency towards new rise of level (minor at first) was occasionally observed in some points.

During 1989-1990, stabilization of subsoil water level was being observed, Elevations of water level in the mound centre (in the area of cooling towers) and near the delivery channel were 179.000-181.000 m.

During the period from 1991 to 1993, the level increased. At the same tome, micromounds related to places of process water discharge and infiltration were recorded on the site surface, against the background of the overall mound. The most significant level rise in this period was in the area of well No. 240 (near the delivery channel). Level elevation here was 182.560 m in June 1993, and reached 183.650 m in September 1993.

During the period from 1994 to 1995, stabilization of the levels were observed. At that, level elevations in wells No. 236H-240H (near the UPS and the take-out channel) dropped to 180.500-180.800 m, but a sharp jump to elevation of 183.250 m was recorded in well No. 240H in December 1995.

During the period of 1996-1997, subsoil water level regime was more stable than in 1994-1995. Maximum level elevations (i.e. the mound centre) were recorded, as before, near the UPS and the take-out channel, absolute elevations of water level in this area were 180.200-180.500 m (December 1997). In the central part of the site, absolute elevations (and depths) of water level were:

under main buildings of power units No. 1 and No. 2 – 174.000-178.000 m (14.5-10.0 m);

under main building of power unit No. 3 – 178.500-180.000 m (10.0-8.5 m);

under main building of power unit No. 4 – 178.000-180.000 m (10.5-8.5 m);

Absolute elevations of water level were decreasing to 166.000 m towards the South-West periphery of the site and to 168.000 m towards the South periphery.

Thus, dynamic balance was maintained during several years, then there again was some rise of subsoil water level (SWL), and a sharp rise in the second half of 1998. The mound centre somewhat shifted along the take-off channel. At that time, SWL increased over the entire area of the site, although with unequal rate in its different places. This was due to both natural and technogenic factors.

In 1998, total annual amount of precipitation was 994 mm – that was much more than amount of precipitation in the last 15 years.

Consequently, the maximum of precipitation infiltration was accompanied by increase of SWL everywhere, in including the site. This is evidenced by analysis of SWL fluctuations in well No. 24H, which is located on the South-West periphery of the site (beyond the sources of technogenic waterlogging), where excess of SWL in 1998 was 1.0 m. By the end of 1999, SWL dropped here by 0.5 m; by the end of 2001 – by another 0.5 m; during 2002, amplitude of SWL fluctuations dropped to 0.5 m, and before the end of the year reduction was approximately by 0.5 m. Here SWL was not affected by technogenic factors. Thus, maximum elevations of SWL in 1998 indicate general increase of SWL during this period due to infiltration of precipitation.

At the same time, this is not the only reason of SWL rise – on a part of the site area, level rise resulted not only from natural factors (sharp increase of precipitation), but also from technogenic ones – i.e. process water infiltration due to discharges from hydraulic structures, primarily from the delivery channel.

In November 1998, there was a sharp rise of level (by 3.5-4.5 m) in the area of the delivery and take-off channels, with maximum elevation exceeding 184 m (well No. 7H). At that, subsoil water mounds moved to the connection node of the delivery and take-off channels. This mound was maintained during 1998-2003, although there were some fluctuations of SWL with time: in the end of 2000, water level in the mound centre dropped by 1.0-1.5 m; in the end of 2001, it increased again by 1.0-1.5 m; after that, minor fluctuations were observed. In 2000, maximum level elevation in the mound centre was 184.100-183.300 m, i.e. 4.4 m from the ground surface; in 2001 – 183.100-184.000 m, in 2002 – 184.000-183.300.

Since 2003, subsoil water mound moved from the area of the open delivery channel of power units No. 1 and No. 2 to the territory of power unit No. 4.

During the period from 2007 through 2010, subsoil water mound was located within the territory of power unit No. 4, with a peak in the area of the open delivery channel of power unit No. 4 (well No. 350H).

In 2011, subsoil water mound was located within the territory of power units No. 3 and No. 4, between the delivery channel of power units No. 1, 2, 3 and cooling tower No. 6.

During 2012, the peak of the subsoil water mound migrated from well No. 133H to well No. 236H (area of the delivery channel of power unit No. 3 and cooling tower No. 6) with absolute elevation of the mound from 182.14 to 182.63 m.

As of the end of 2012, subsoil water mound was located between the turbine hall of power unit No. 3 and cooling tower No. 6. Mound peak was located in the area of the open delivery channel of power unit No. 3 and chlorine storage house with absolute elevation of 182.27 m.

All in all, reduction of subsoil water level by an average of 0.5 m was observed during the year 2012 in the wells of the SS "Rivne NPP" site.

During the period from 01.01 to 30.03.2017 (I quarter), the site of SS "Rivne NPP" and the adjacent area experienced rise of subsoil water level by an average of 0.15 m.

As of 31.03.2017, subsoil water mound was located within the territory of power units No. 3, 4 – between the delivery channel of unit No. 3, turbine hall of unit No. 3, cooling tower No. 3 and rainfall runoff collector of unit No. 4 – it had an indistinct shape with a slight "peak" around the well No. 350н, which is located near the open channel of unit No. 4, with an absolute elevation of 180.65 m.

During the period from 01.04 to 30.06.2017 (II quarter), the site of SS "Rivne NPP" and the adjacent area experienced rise of subsoil water level by an average of 0.13 m.

As of 31.06.2017, subsoil water mound was located within the territory of power units No. 3, 4 – between the delivery channel of unit No. 3, turbine hall of unit No. 3, cooling tower No. 3 and rainfall runoff collector of unit No. 4 – it had an indistinct shape with a slight "peak" around the well No. 349н, which is located near the open channel of unit No. 4, with an absolute elevation of 180.77 m.

During the period from 01.07 to 30.09.2017 (III quarter), the site of SS "Rivne NPP" and the adjacent area experienced drop of subsoil water level by an average of 0.15 m.

As of 30.09.2017, subsoil water mound was located within the territory of power units No. 3, 4 – between the delivery channel of unit No. 3, turbine hall of unit No. 3, cooling tower No. 3 and rainfall runoff collector of unit No. 4 – it had an indistinct shape with a slight "peak" around the well No. 350н, which is located near the open channel of unit No. 4, with an absolute elevation of 180.68 m.

During the period from 01.10 to 30.12.2017 (IV quarter), the site of SS "Rivne NPP" and the adjacent area experienced rise of subsoil water level by an average of 0.14 m.

As of 30.12.2017, subsoil water mound was located within the territory of power units No. 3, 4 – between the delivery channel of unit No. 3, turbine hall of unit No. 3, cooling tower No. 3 and rainfall runoff collector of unit No. 4 – it had an indistinct shape with a slight "peak" around the well No. 350н, which is located near the open channel of unit No. 4, with an absolute elevation of 180.84 m.

Compared to absolute elevation of level in the centre of subsoil water mound during the period from 1969 through 1972 (area of the take-off channel of power unit No. 4 and cooling towers No. 5, 6), which was 178.600 m, subsoil water level in this area as of December 30, 2012, exceeds the natural level by 3.60-4.50 m.

Summarizing the dynamics of subsoil water level on the site of SS "Rivne NPP", it is worth noting that:

- prior to start of construction on the site, subsoil water surface was of mound type; elevation of subsoil water level in the mound centre (in the area of cooling towers No. 5 and No. 6) was 178.600 m;
- during construction and operation of SS "Rivne NPP", subsoil water level increased and SWL mound shifted due to technogenic impact; level rise in the mound centre was 10 m. After taking a set of special measures, significant reduction of level has been reached, but but it was not possible to reduce the level to its initial elevations (in 1985, difference between the actual level and the initial level was 4.0 m);
- during the following years, water level regime was generally in dynamic balance, although micromounds of subsoil water surface were traced in some parts of the site; fluctuations of level resulted from impact of technogenic factors during construction and operation, especially discharges of process water from channels, water transfer utilities etc.;
- infiltration of process water is uneven over the entire territory of the site – it is concentrated on certain areas of different shapes and dimensions in plan view;

- in the second half of 1998 there was another sharp rise in level, the mound centre somewhat shifted along the take-off channel. At that time, SWL increased over the entire area of the site, although with unequal rate in its different parts. This was related to both natural and technogenic factors; the take-off channel was the discharge centre at that moment;
- in 2000, maximum level elevation in the mound centre (well No. 7H) was 184.100 m (March – June), i.e. 4.4 m from the ground surface; in 2001 – 184.000 m (December), in 2002 – 184.000 m (March) to 183.200 m (December); the increase with respect to the initial level (1969) was unequal in different parts of the site, being 4.0-5.0 m in its central part;
- from 2003 to 2010, subsoil water mound was located within the territory of power unit No. 4, and since 2011 it was located within the territory of power units No. 3 and No. 4;
- during 2012, the observed absolute elevations of the mound were from 182.140 to 182.630 m, and significant drop of subsoil water by an average of 0.5 m was observed in wells;
- compared to absolute elevation of level in the centre of subsoil water mound from 1969 through 1972 (area of the take-off channel of power unit No. 4 and cooling towers No. 5, 6), which was 178.60 m, ground water level in this area as of December 30, 2012, exceeds the natural level by 3.60-4.50 m;
- technogenic impact during operation of SS "Rivne NPP" affected the piezometer level of the Upper Cretaceous aquifer, which is below elevations of GWL. Dynamics of fluctuations in levels of subsoil water and the Upper Cretaceous aquifer was mainly synchronous.

3.2.2. Ground water temperature and chemical composition

Analysis of the materials of ground water regime monitoring on the site of SS "Rivne NPP" shows the NPP impact on temperature and chemical composition of ground water, both subsoil water and the Upper Cretaceous aquifer.

3.2.2.1 Ground water temperature

Impact of technogenic factors on ground water temperature is the result of warm water infiltration from the delivery and take-off channels, cooling towers, other water utilities and, possibly, warm-up of the soils where hot water transfer conduits are laid (for example, the area of well No. 8H).

During many years of hydrogeological observations, almost constant increase of ground water temperature was recorded in some areas of the site. This has formed a so-called "temperature field", which can be notionally called a "temperature mound". Background water temperature is 8-12 ^{0}C (depending on season and temperature of the ambient air). Range of areal fluctuations of ground water temperature within the site during the entire monitoring period was 10-12 ^{0}C; only in the early 1980s a temperature of 27.5 ^{0}C was recorded in some points, with the range of areal temperature fluctuations reaching the subsoil water temperature.

During the entire monitoring period, "temperature micromounds" were recorded and maintained within the overall "temperature field" across the site – near the main building of power units No. 1 and No. 2, near UPS No. 2, near the main building of power unit No. 3. The previously recorded "temperature micromound" in the area of hydraulic structures (wells No. 3H and 5H) shifted to the North from the take-off channel, with an increase of maximum temperature here in 2002.

In the course of SS "Rivne NPP" operation, a subsoil water temperature field was recorded within the site for a considerable time, while the background temperature was 9-10 ^{0}C. The subsoil water temperature field is not continuous and consists of several plots:

- in the West part of power unit No. 1;
- in the area of the take-off channel;
- between cooling towers No. 1, No. 4 and the delivery channel;
- in the South-East part of power unit No. 3.

The nature of temperature field distribution has been virtually preserved for many years, while the increased water temperature on the said plots has been 18-23 ^{0}C. Range of areal change of subsoil water temperature over the year reached 16 ^{0}C. Rise of subsoil water temperature on the said plots is due to impact of technogenic factors (and warm water infiltration).

The field of increased subsoil water temperature – up to 23-28.8 ^{0}C (at various times) – is persistently preserved, while background temperature during this period does not exceed 10 0C. The thermal temperature field has its centre at the East wall of the delivery channel, where hot water conduits are passing. Subsoil water temperature long the delivery channel does not exceed 19-20 ^{0}C, but temperature fluctuations with time are observed in all wells and make 3.4 to 9.6 ^{0}C. Maximum temperature was recorded in November 2002, in late February – early March of 2003 it dropped almost everywhere.

From 01.01.2017 through 30.03.2017 (I quarter), a subsoil water temperature field was recorded with a background temperature of 12.0-14.0 ^{0}C.

From 01.04.2017 through 30.06.2017 (II quarter), a subsoil water temperature field was recorded with a background temperature of 12.0-14.0 ^{0}C.

From 01.07.2017 through 30.09.2017 (III quarter), a subsoil water temperature field was recorded with a background temperature of 12.0-14.0 ^{0}C.

From 01.10.2017 through 30.12.2017 (IV quarter), a subsoil water temperature field was recorded with a background temperature of 12-14 ^{0}C, which corresponds to seasonal fluctuations of atmospheric air temperature.

Thus, the four "temperature micromounds" listed above have been traced on the site for many years with some fluctuations of water temperature in their centre, but subsoil water warm-up is local and is not spreading beyond the site.

3.2.2.2 Temperature of the Upper Cretaceous aquifer

Technogenic impact of SS "Rivne NPP" has affected temperature of the Upper Cretaceous aquifer, although to a lesser extent than it affected the subsoil water regime.

Due to hydraulic connection present between the subsoil water and the Upper Cretaceous aquifer, the nature of subsoil water distribution for the latter is generally similar. However, since number of wells on the Cretaceous aquifer is less than on the subsoil water, "temperature mounds" on hydroisotherm maps of the Cretaceous aquifer have somewhat different shape. At the same time, temperature of water of the Upper Cretaceous aquifer in the centres of "temperature mounds" is somewhat lower – by 1-6 ^{0}C. Maximum temperature over the period under consideration was 18-19 ^{0}C, while minimum (background) temperature was 8-11 ^{0}C. Maximum range of areal change in water temperature during the year was 10 ^{0}C, i.e. lower than that for the subsoil water.

In the second half of 2002 – first half of 2003, within the subsoil water mound in the area of the delivery and take-off channels, distribution of temperature fields of the Upper Cretaceous aquifer and the subsoil water is generally identical, but at the same time water temperature of water of the Upper Cretaceous aquifer is below 6 ^{0}C in the centre of "temperature micromound" (well No. 3HM) and 18-20 ^{0}C (well No. 5HM).

Rise of water temperature in f the Upper Cretaceous aquifer is caused by "heat flow" from the Quaternary to the Upper Cretaceous aquifer, i.e. penetration of warm water from the Quaternary aquifer into the Upper Cretaceous aquifer.

Temperature of the Upper Proterozoic aquifer is lower than that of the Upper Cretaceous aquifer, it was 10- 14 ^{0}C. Range of measured areal water temperature over the year was 2 to 5 ^{0}C. Areal variations of water temperature are mainly associated with meteorological conditions.

The increased subsoil water temperature may be caused by permanently high water temperature in the take-off and delivery channels (11-17 ^{0}C in winter 20-30 ^{0}C during other seasons), as well as by technogenic losses of heated water from the utilities and soil warming-up by these utilities.

3.2.2.3 Ground water chemical composition

Technogenic factors under operation of SS "Rivne NPP" have had an impact not only on hydrodynamic and temperature regimes of ground water (especially subsoil water), but also, to some extent, on its chemical composition, although changes in chemical composition are not as significant as changes of hydrodynamic and temperature regimes.

Prior to start of construction of SS "Rivne NPP", amount of dry residue in the subsoil water was up to 100 mg/dm^3. In the course of operation of SS "Rivne NPP", increase of dry residue amount in ground water was recorded in some points – up to 300-400 mg/dm^3, and even more in some places.

At that, increase of water mineralization on different plots is unequal. For example, ground water mineralization in a zone located in the area of the delivery channel is higher than on the site in general, which confirms discharges of process water from the channel and maybe from other hydraulic structures.

Table 3.3. Content of dry residue, sulphates, calcium and pH value in subsoil water on the site of SS "Rivne NPP".

Components	Values	Вміст
Total salt content (dry residue), mg/dm^3	Prevailing values	206 – 588
	Anomalous values	812 – 1718
SO_4^{2-}, mg/dm^3	Prevailing values	56 – 247
	Anomalous values	320 – 1113
Ca2+, mg/dm^3	Prevailing values	20 – 120
	Anomalous values	200 – 320
pH	Prevailing values	6,9 – 8,5
	Anomalous values	4,2 – 5,8; 8,8 – 8,9

Higher ground water mineralization in certain currents can also be caused not only by water enrichment with salts due to process water infiltration, which is the result of discharges from hydraulic structures, but also by additional dissolution of salts in the soils during water infiltration into the soil.

In general, changes in chemical composition of ground water on the site of SS "Rivne NPP" are relatively low (except for some plots), which evidences that there is almost no chemical pollution of ground water, except for the chemical water treatment (CWT) area, where "technogenic perched water" has formed and subsoil water has been polluted. Mineralization of this "perched water" is high: amount of dry residue is 25700 mg/dm3, while content of HCO_3^{-} is 4607 mg/dm3, CO_3^{2-} – 7080 mg/dm3, Cl^{-} – 1846 mg/dm^3, SO_4^{2-} – 2525 mg/dm^3, Na+ + K+ – 8073 mg/dm^3, bicarbonate alkalinity is 8720.

Consequently, mineralization of subsoil water on this plot is much higher than on the rest of the site: amount of dry residue is 1328-5250 mg/dm3, due to high content of cationites and anionites; value of bicarbonate alkalinity is 260-640. The Upper Cretaceous aquifer has almost not been polluted.

In general, during operation of power units No. 1-4 amount of dry residue in subsoil water on the SS "Rivne NPP" site has increased to 200-400 mg/dm^3 compared to the preoperational period, when amount of dry residue was 50-100 mg/dm^3. Local technogenic pollution of subsoil water has been observed in the CWT area, where mineralization of subsoil water is much high than on the rest of the site: amount of dry residue is 1328-5250 mg/dm^3, value of bicarbonate alkalinity is 26-64 German degrees.

3.2.2.4 Chemical composition of the Upper Cretaceous aquifer

Occasional and non-ubiquitous increase of dry residue amount in the Upper Cretaceous aquifer is lower than in subsoil water (up to 100-300 mg/dm^3); consequently, content of sulphates (generally not more than 100 mg/dm^3) and calcium (up to 50 mg/dm^3) is also lower – that is, impact of technogenic factors on chemical composition of water in the Upper Cretaceous aquifer is lower than their impact on chemical composition of subsoil water. Occasional and non-ubiquitous increase of dry residue amount is lower than that in the subsoil water – up to 200-300 mg/dm^3.

3.3 Control of ground water chemical and radiation status

In the locations of sludge collector and construction and industrial waste landfill of SS "Rivne NPP", the analysis is conducted by the ecological and chemical laboratory of EPS, which is certified to measure chemical composition of ground water (wells). Average indicators of ground water status in wells around waste disposal locations are given in Table 3.4.

Table 3.4. Average indicators of ground water status in wells around waste disposal locations.

2017рік	Well of the sludge collector		Well of the landfill	
	Background 38H	25H	Background 140H	1H
Temperature, ^0C	7.2	7.0	7.0	7.5
pH	7.92	6.08	8.01	8.24
Dry residue, mg/dm^3	201.50	150.00	1771.50	238.50
Ca, $mg·eq/dm^3$	2.813	1.746	2.425	1.067
Mg, $mg·eq/dm^3$	10.616	3.593	8.257	8.257
N NH4+, mg/dm^3	0.200	0.600	0.900	2.600
NO_2-, mg/dm^3	0.091	0.012	0.463	0.019
NO_3-мг/$дм^3$	0.392	0.102	28.095	9.770
Iron, mg/dm^3	0.500	0.475	2.000	0.800
Copper, mg/dm^3	0.000	0.000	0.002	0.000
Zinc	0.544	0.071	0.045	0.003
Chlorides	21.272	11.345	13.472	11.699
Anionic surfactants	0.028	0.019	0.024	0.021
Sulphates	22.350	22.200	32.950	29.867
Petroleum products	0.055	0.052	0.114	0.041

Heat and Underground Utilities Department and Environment Protection Service of SS "Rivne NPP" monitor status of ground water at water intake in the Village of Ostriv up to a schedule. Average indicators of ground water status are given in Table 3.5.

Table 3.5. Average indicators of ground water status

Sampling data	Well No.	units of pH	Dry residue. mg/dm^3	Total hardness. $mg·eq/dm^3$	Aniones. mg/dm^3			Cationes. mg/dm^3			
					CL^-	SO_4^{2-}	HCO^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
24.10.17	4	7.37	309.60	3.25	60.60	18.50	164.70	61.20	2.43	29.00	8.00
24.10.17	9	9.00	281.00	0.23	46.46	12.20	158.60	3.00	0.91	90.00	1.20
07.11.17	10	8.22	321.00	0.17	85.68	9.60	146.40	1.80	0.97	112.00	0.45
Under repair	11	-	-	-	-	-	-	-	-	-	-
18.10.17	12	8.90	292.60	0.35	52.23	10.50	164.70	5.21	1.09	91.00	0.50
18.10.17	13	6.94	304.40	0.12	48.48	10.50	176.90	1.60	0.42	100.00	0.60
24.10.17	14	9.10	306.00	0.20	52.52	19.96	164.70	2.20	1.09	98.00	1.90
18.10.17	15	8.50	610.40	0.50	191.90	11.45	251.93	9.01	0.60	211.00	2.60

Sampling data	Well No.	units of pH	Dry residue. mg/dm^3	Total hardness. mg·eq/dm^3	Aniones. mg/dm^3			Cationes. mg/dm^3			
					CL^-	SO_4^{2-}	HCO^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
18.10.17	16	8.40	304.60	0.30	50.50	13.20	170.80	3.90	1.27	98.00	0.90
18.10.17	II stage pump house	8.3	375.40	0.75	80.80	17.50	189.1	12.00	1.82	114.00	2.00

Main aquifer systems in the NPP location point and on the site of SS "Rivne NPP" are subsoil water (the Quaternary aquifer). aquifer system of Paleogene deposits. aquifer system of Upper Cretaceous deposits and aquifer system of Upper Proterozoic (Vendian and Riphaean) deposits.

Two centralized ground water intakes in the Region of Rivne are exploited in the controlled area of SS "Rivne NPP". while ground water reserves are approved for six water intakes. Exploited water intakes of utility and drinking water supply are Rafalivskyi-I and Chudlynskyi. the consumers are SS "Rivne NPP" and the Town of Varash. In addition. there are many water intakes and individual wells in the CA that exploit different aquifers with unapproved ground water reserves. They are exploited by different consumers under permissions for special water use.

Radiation status of ground water has been continuously controlled on the site since 1983.

Monitoring wells are used to control water of the first water-bearing layer located at a depth of 10...14 m from the surface. Water of deeper layers is controlled from piezometer wells.

Periodicity of sampling is quarterly from the monitoring wells and semi-annually from the piezometer wells. The type of control is measurement of $\sum\beta$ activity.

For this control. a 1 litre sample is withdrawn and boiled down. followed by measurement of total β-activity of radionuclides using a α/β radiometer MPC-9604 (USA). Duration of measurement is 10000 s. Control of tritium content in ground water was initiated in 2008. Volumetric activity of tritium samples is measured using a liquid scintillation radiometer Tri-Carb 3170 TR/SL. duration of measurement is 3600 s. MDA≅5·103 Bq/m3.

During the period under consideration. a new well No. 11316H was added in 2009. and well No. 269 ceased to exist in 2005.

Samples from monitoring wells are combined by facilities. and samples of piezometer wells are combined by layers. i.e. the Quarternary and Cretaceous aquifers. The combined samples undergo γ-spectrometric analysis.

Total β-activity over the entire monitoring period. except for May-August 1986. was way below the rated value – permissible concentration PCB=3.00E+11 Ci/l (1.11E+03 Bq/m3). In 1986. status of ground water in the upper part of lithosphere was affected by "Chernobyl trace". while concentration of ruthenium-103. caesium-134. caesium-137. lanthanum-140. zirconium-95. niobium-95 and silver-110m still was several orders below the permissible value.

Radiation status of ground water is satisfactory. content of ^{226}Ra. ^{137}Cs and ^{90}Sr are way below the values rated by NRBU-97 [45] and DR-2006 [30].

Tables 3.1 and 3.2 show average total β-activity of water in the monitoring wells during the period from 2004 through 2016 and average total β-activity of water in the monitoring wells during the period from 2004 through 2014.

During routine review of Radiation control regulation of Rivne NPP 132-1-Р-ЦРБ. monitoring of piezometric wells was excluded from the scope of radiation control and was performed up to the first half of year 2014.

Monitoring point	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
241 RC of unit No. 3	1.24E+02	9.33E+01	9.39E+01	8.33E+01	9.87E+01	1.48E+02	1.24E+02	1.40E+02	1.39E+02	1.11E+02	1.42E+02	2.58E+02	8.10E+01
242 RC of unit No. 3	1.14E+02	8.54E+01	6.30E+01	7.99E+01	9.54E+01	1.31E+02	8.58E+01	1.20E+02	1.46E+02	1.43E+02	1.39E+02	1.25E+02	8.30E+01
243 RC of unit No. 3	1.58E+02	1.19E+02	8.19E+01	1.07E+02	1.31E+02	1.52E+02	1.84E+02	1.61E+02	1.25E+02	1.21E+02	1.67E+02	2.04E+02	1.70E+02
244 RC of unit No. 3	1.86E+02	1.10E+02	1.05E+02	1.00E+02	1.32E+02	1.45E+02	1.36E+02	1.78E+02	1.61E+02	1.31E+02	1.46E+02	1.73E+02	1.59E+02
245 RC of unit No. 3	1.81E+02	1.12E+02	1.80E+02	1.18E+02	9.21E+01	1.55E+02	1.45E+02	1.26E+02	2.13E+02	1.30E+02	1.40E+02	1.35E+02	1.17E+02
246 RC of unit No. 3	1.41E+02	7.60E+01	9.30E+01	1.21E+02	9.81E+01	1.37E+02	1.41E+02	1.33E+02	1.59E+02	1.15E+02	1.36E+02	1.03E+02	8.10E+01
247 RC of unit No. 3	1.12E+02	8.26E+01	9.74E+01	1.12E+02	1.13E+02	7.71E+01	1.30E+02	1.14E+02	1.17E+02	1.29E+02	1.30E+02	1.31E+02	8.40E+01
248 RC of unit No. 3	1.22E+02	6.47E+01	8.07E+01	1.25E+02	1.05E+02	1.33E+02	1.60E+02	1.86E+02	1.72E+02	1.49E+02	1.54E+02	2.01E+02	1.31E+02
249 RC of unit No. 3	1.09E+02	8.37E+01	8.39E+01	8.65E+01	1.29E+02	1.52E+02	1.22E+02	1.52E+02	2.28E+02	1.91E+02	4.05E+02	8.78E+02	4.14E+02
250 RC of unit No. 3	7.66E+01	5.93E+01	6.47E+01	8.22E+01	7.23E+01	1.57E+02	1.51E+02	1.98E+02	1.41E+02	1.72E+02	1.72E+02	3.63E+02	1.76E+02
251 RC of unit No. 3	8.40E+01	5.06E+01	7.20E+01	7.99E+01	9.41E+01	1.18E+02	9.58E+01	1.43E+02	1.31E+02	1.56E+02	2.21E+02	3.30E+02	1.42E+02
252 RC of unit No. 3	1.10E+02	9.60E+01	5.88E+01	7.79E+01	8.93E+01	1.01E+02	8.28E+01	1.26E+02	9.60E+01	7.20E+01	8.70E+01	2.02E+02	1.02E+02
253 RC of unit No. 3	9.59E+01	9.68E+01	8.76E+01	1.00E+02	8.50E+01	1.41E+02	1.19E+02	1.11E+02	1.52E+02	1.34E+02	9.10E+01	2.60E+02	1.76E+02
254 SB of unit No. 3	8.96E+01	6.05E+01	5.01E+01	1.44E+02	8.19E+01	1.15E+02	9.24E+01	8.90E+01	1.14E+02	1.18E+02	1.14E+02	1.67E+02	1.31E+02
261 SB of units No. 1-2	7.47E+01	6.03E+01	6.54E+01	7.31E+01	8.84E+01	1.02E+02	5.19E+01	1.07E+02	1.19E+02	1.08E+02	7.00E+01	1.13E+02	5.40E+01
262 SB of units No. 1-2	1.96E+02	1.53E+02	1.90E+02	1.76E+02	2.22E+02	2.96E+02	1.85E+02	1.39E+02	1.45E+02	1.44E+02	1.43E+02	1.99E+02	1.48E+02
263 SB of units No. 1-2	2.17E+02	1.34E+02	1.09E+02	1.16E+02	1.34E+02	1.47E+02	1.42E+02	1.14E+02	1.83E+02	1.48E+02	1.21E+02	1.49E+02	1.26E+02

Monitoring point	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
264 SB of units No. 1-2	1.84E+02	1.04E+02	9.54E+01	9.04E+01	5.13E+01	7.47E+01	6.91E+01	9.10E+01	9.90E+01	1.25E+02	1.20E+02	1.06E+02	7.40E+01
265 SB of units No. 1-2	6.12E+01	6.21E+01	5.06E+01	1.47E+02	1.69E+02	2.96E+02	3.87E+02	3.99E+02	3.87E+02	4.05E+02	3.41E+02	1.91E+02	1.28E+02
266 SB of units No. 1-2	8.82E+01	6.88E+01	5.01E+01	8.97E+01	8.89E+01	1.75E+02	6.57E+01	8.00E+01	8.20E+01	8.80E+01	7.60E+01	8.30E+01	1.12E+02
267 РО блока 1	1.97E+02	1.90E+02	8.93E+01	1.96E+02	1.27E+02	1.74E+02	1.29E+02	1.86E+02	1.12E+02	1.33E+02	1.24E+02	2.30E+02	3.94E+02
268 RC of unit No. 1	1.05E+02	9.60E+01	6.07E+01	6.95E+01	1.04E+02	1.19E+02	1.41E+02	1.53E+02	1.36E+02	1.51E+02	1.13E+02	1.71E+02	1.38E+02
269 SB of units No. 1-2	1.14E+02	-	-	-	-	-	-	-	-	-	-	-	-
270 RC of unit No. 2	1.51E+02	1.33E+02	1.37E+02	1.82E+02	2.00E+02	1.62E+02	1.37E+02	1.73E+02	1.25E+02	1.54E+02	1.58E+02	2.22E+02	1.62E+02
271 RC of unit No. 2	7.72E+01	1.10E+02	7.32E+01	6.50E+01	6.43E+01	6.52E+01	5.77E+01	8.60E+01	8.50E+01	9.90E+01	1.06E+02	1.48E+02	8.00E+01
272 RC of unit No. 2	4.64E+01	9.86E+01	8.14E+01	1.57E+02	8.39E+01	7.49E+01	8.12E+01	9.80E+01	6.50E+01	1.00E+02	8.70E+01	1.48E+02	8.60E+01
273 IWS	1.26E+02	1.07E+02	7.12E+01	1.01E+02	1.39E+02	7.72E+01	4.37E+01	5.10E+01	2.60E+01	4.90E+01	9.40E+01	1.77E+02	4.80E+01
274 IWS	2.31E+02	1.71E+02	1.85E+02	1.53E+02	2.20E+02	2.22E+02	1.80E+02	1.80E+02	1.50E+02	2.73E+02	1.79E+02	1.71E+02	1.16E+02
275 IWS	1.29E+02	1.26E+02	1.21E+02	8.96E+01	1.24E+02	1.80E+02	1.00E+02	1.43E+02	9.80E+01	1.38E+02	1.37E+02	1.59E+02	1.44E+02
49-Н SRWS	8.53E+01	8.48E+01	1.21E+02	4.98E+01	7.74E+01	7.60E+01	6.41E+01	1.03E+02	7.90E+01	7.20E+01	1.04E+02	2.05E+02	2.08E+02
50-Н SRWS	1.01E+02	5.80E+01	8.36E+01	1.53E+02	8.46E+01	1.04E+02	8.50E+01	3.49E+02	5.40E+01	6.40E+01	8.40E+01	2.01E+02	1.35E+02
Пс-1 RC of unit No. 4	1.22E+02	1.02E+02	9.79E+01	1.02E+02	9.27E+01	1.11E+02	1.20E+02	8.40E+01	2.24E+02	1.12E+02	9.70E+01	1.09E+02	9.00E+01
Пс-2 RC of unit No. 4	1.27E+02	1.21E+02	7.87E+01	9.80E+01	9.83E+01	1.18E+02	2.28E+02	1.39E+02	1.02E+02	9.90E+01	1.67E+02	1.64E+02	1.09E+02
Пс-3 RC of unit No. 4	1.41E+02	9.49E+01	9.58E+01	1.37E+02	6.43E+01	9.57E+01	6.52E+01	6.80E+01	8.40E+01	6.00E+01	4.60E+01	1.41E+02	4.50E+01
Пс-4 RC of unit No. 4	8.93E+01	1.03E+02	6.67E+01	1.08E+02	5.91E+01	7.04E+01	6.18E+01	8.60E+01	3.70E+01	5.30E+01	2.50E+01	1.98E+02	4.30E+01
11316н SB of units No. 1-2	-	-	-	-	-	7.28E+01	8.45E+01	9.10E+01	1.09E+02	6.20E+01	6.40E+01	2.26E+02	7.50E+01

Table 3.7. Average Σβ activity of water in the piezometer wells, Bq/m^3.

Monitoring point	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
4H	9.28E+01	8.46E+01	1.27E+02	1.37E+02	6.99E+01	8.72E+01	5.25E+01	7.60E+01	7.30E+01	9.40E+01	3.70E+01
8H	2.62E+02	1.68E+02	1.41E+02	9.23E+01	1.07E+02	1.46E+02	4.30E+02	2.90E+02	1.56E+02	1.95E+02	1.77E+02
40H	1.45E+02	1.37E+02	7.65E+01	1.83E+02	1.08E+02	8.73E+01	1.37E+02	6.01E+02	8.00E+01	6.50E+01	5.00E+01
11H	6.80E+01	9.52E+01	2.83E+02	1.47E+02	2.75E+02	2.30E+02	2.43E+02	2.95E+02	1.67E+02	2.10E+02	2.00E+02
9H	1.34E+02	1.56E+02	1.76E+03	1.12E+02	1.15E+02	1.29E+02	1.36E+02	1.40E+02	1.17E+02	1.35E+02	1.01E+02
9H-M	8.00E+01	7.70E+01	8.61E+01	2.44E+02	2.41E+02	2.87E+02	3.19E+02	3.64E+02	1.65E+02	1.37E+02	6.90E+01
7H	1.11E+02	2.33E+02	6.48E+012	1.25E+02	1.34E+02	1.38E+02	1.61E+02	2.00E+02	1.48E+02	1.74E+02	5.90E+01
127H	1.44E+02	1.14E+02	1.60E+03	1.13E+02	1.18E+02	1.50E+02	1.66E+02	1.69E+02	1.67E+02	1.60E+02	1.54E+02
21M	5.98E+01	5.53E+01	1.53E+03	6.64E+01	3.67E+01	4.32E+01	1.09E+02	1.22E+02	5.20E+01	1.01E+02	6.10E+01
130H	7.92E+01	6.70E+01	9.40E+01	1.15E+02	5.66E+01	1.09E+02	1.10E+02	1.58E+02	1.45E+02	1.55E+02	1.15E+02
22H	1.12E+02	7.16E+01	1.25E+02	1.64E+02	6.61E+01	8.99E+01	2.66E+02	9.67E+02	1.25E+02	1.77E+02	8.28E+02
22H-M	1.67E+02	2.47E+02	4.06E+02	7.72E+01	2.28E+02	1.86E+02	4.31E+02	2.18E+02	1.41E+02	4.69E+02	2.23E+02
131M	6.14E+01	5.83E+01	5.51E+01	1.08E+02	7.78E+01	4.31E+01	5.12E+01	8.00E+01	2.55E+02	6.30E+01	6.10E+01
239H	9.61E+01	6.28E+01	1.64E+03	1.41E+02	8.02E+01	7.32E+01	8.06E+01	8.00E+01	6.80E+01	6.80E+01	3.30E+01
240H	9.95E+01	7.74E+01	9.69E+01	7.39E+01	8.05E+01	8.74E+01	4.08E+02	1.03E+02	7.70E+01	5.10E+01	1.23E+02
236H	1.41E+02	1.17E+02	1.13E+02	8.26E+01	1.18E+02	8.68E+01	9.63E+01	3.64E+02	8.50E+01	1.01E+02	1.20E+02
237H	1.17E+02	9.09E+01	1.49E+02	1.30E+02	1.17E+02	1.12E+02	9.36E+01	1.61E+02	1.25E+02	1.35E+02	8.90E+01
131H	5.63E+021	9.74E+01	1.18E+02	2.38E+02	1.23E+02	1.12E+02	3.86E+02	3.66E+02	1.07E+02	1.43E+02	8.50E+01
1H	1.31E+02	1.23E+02	1.41E+02	1.09E+02	1.39E+02	1.39E+02	1.45E+02	3.12E+02	8.50E+01	6.00E+01	9.20E+01
1H-M	<4.4E+01	1.39E+02	1.65E+03	7.24E+01	5.41E+01	5.41E+01	3.75E+02	7.70E+01	4.00E+01	3.00E+01	4.40E+01

4 CALCULATION OF DOSES FOR CRITICAL POPULATION GROUPS IN THE CONTROLLED AREA OF SS "RIVNE NPP" UNDER REGULAR EMISSIONS AND DISCHARGES

Rivne NPP operates a software package designed for control of doses received by critical population groups in the controlled area of RNPP under regular emissions and discharges (RNPP_Doses). This software package was developed in order to meet the requirements of NRBU-97, pt. 5.5.1 [45, 46].

RNPP_Doses is designed for calculation of effective doses that are exerted during calendar year by regular gaseous and aerosol emissions and liquid discharge of Rivne NPP on the critical population group living within the CA "Rivne NPP".

Methods and models of radiation dose calculation that are implemented in the software package are set forth in a document "Control of doses for critical population groups in the controlled area of Rivne NPP (under regular emissions and discharges). Methodology guidelines" [41-44] and agreed with the Ministry of Health of Ukraine.

As input data for calculation of effective doses over year 2017, the software package used input data files of five types, that have been specially prepared by Meteostat application:

- data files with daily meteorological parameters, that contain statistics of recurrence of atmosphere stability categories (Pasquill), by 16 wind direction sectors and 10 wind speed bins;
- data files with daily meteorological parameters, that contain statistics of relative precipitation rate;
- files that contain total daily values of gaseous and aerosol emission of IRG and iodine isotopes;
- files that contain total monthly values of gaseous and aerosol emission of the following radionuclides: ^{3}H, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{110m}Ag, ^{134}Cs, ^{137}Cs;
- files that contain total monthly values of discharge of the following radionuclides: ^{3}H, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{110m}Ag, ^{131}I, ^{134}Cs, ^{137}Cs, ^{144}Ce.

Files on daily emissions are received from databases of Radmon package, Files with meteorological data and monthly data on radionuclides emission and discharge are received from Atom package.

Input meteorological parameters for the software package RNPP_Doses are the following:

- wind speed and direction;
- atmosphere stability category by Pasquill;
- relative precipitation rate.

The program gets the input parameter by processing output data of automatic weather station ARSMS of SS "Rivne NPP" (certificate of registration No. 02/15 ГМ-11 dated October 28, 2015). This document is in the list of permissions granted to SS "Rivne NPP", which is given in Appendix B to this book.

The results of weather observations are presented in the "Annual report on the results of weather observations in 2007 within the area of Rivne NPP", 132-09-ЗВ-18-ЦРБ [40].

Table 4.1. Annual dose exerted on the critical population group due to gaseous and aerosol emissions of SS "Rivne NPP", µSv.

Year	External radiation from clouds	External radiation from ground surface	Inhalation	Ingestion	Total effective dose	Ratio to quota. %
2008	8.5E-02	1.3E-02	2.8E-02	1.9E-02	1.5E-01	0.36
2009	8.9E-02	1.2E-02	1.5E-02	5.8E-03	1.2E-01	0.30
2010	7.3E-02	1.1E-02	5.7E-03	2.6E-02	1.2E-01	0.29
2011	9.7E-02	1.1E-02	3.6E-02	4.1E-03	1.5E-01	0.37
2012	8.1E-02	1.1E-02	4.0E-02	3.8E-02	1.7E-01	0.43
2013	7.8E-02	1.1E-02	6.0E-02	3.7E-03	1.5E-01	0.38
2014	7.0E-02	1.0E-02	4.1E-02	2.5E-03	1.2E-01	0.31
2015	6.0E-02	8.9E-03	5.1E-02	2.4E-03	1.2E-01	0.30
2016	4.2E-02	9.0E-03	4.8E-02	1.4E-03	1.0E-01	0.25
2017	5.4E-02	3.1E-05	5.5E-02	7.4E-04	1.1E-01	0.28

Table 4.2. Annual dose exerted on the critical population group due to liquid discharges of SS "Rivne NPP", µSv.

Year	Recreation	Drinking water supply	Consumpt ion of fish	Irrigation	Watering of livestock	Total effective dose	Ratio to quota, %
2008	2.9E-02	7.1E-02	7.1E-02	1.5E-01	1.8E-03	2.8E-01	0.70
2009	2.0E-02	9.3E-02	8.7E-02	1.4E-01	4.0E-03	3.3E-01	0.83
2010	3.0E-03	9.9E-03	1.3E-02	1.3E-01	4.8E-04	1.5E-01	0.38
2011	5.7E-03	4.0E-02	5.0E-02	1.2E-01	8.8E-04	2.0E-01	0.50
2012	6.7E-03	6.9E-02	5.4E-02	1.2E-01	7.6E-04	2.2E-01	0.55
2013	3.9E-03	6.2E-02	2.5E-02	1.1E-01	4.2E-04	1.9E-01	0.48
2014	4.4E-03	7.0E-02	2.3E-02	1.1E-01	4.1E-04	1.9E-01	0.48
2015	2.7E-03	8.4E-02	2.4E-02	1.0E-01	3.3E-04	2.0E-01	0.50
2016	2.3E-03	6.4E-02	1.9E-02	1.0E-01	3.0E-04	1.7E-01	0.43
2017	4.6E-03	7.8E-02	3.5E-02	1.0E-01	4.9E-04	2.0E-01	0.50

Table 4.3. Total annual effective dose exerted on the critical population group due to emissions and discharges of SS "Rivne NPP", µSv.

Year	Dose, µSv	Ratio to dose limit quota, %
2008	0.42	0.52
2009	0.45	0.57
2010	0.26	0.32
2011	0.35	0.44
2012	0.37	0.46
2013	0.34	0.42
2014	0.31	0.39
2015	0.31	0.39
2016	0.27	0.34
2017	0.30	0.38

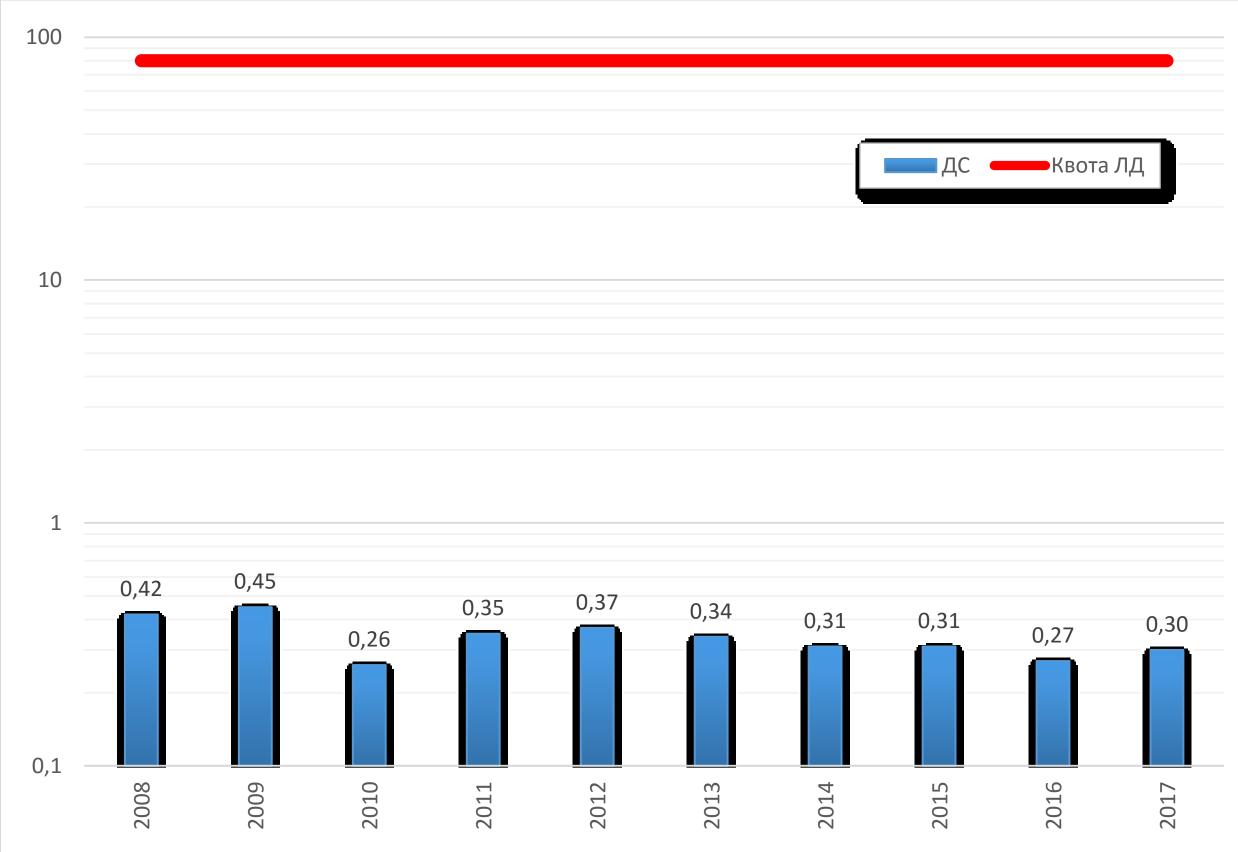

Fig. 4.1. Total annual effective dose exerted on the critical population group due to emissions and discharges of SS "Rivne NPP", μSv.

Total effective dose exerted on the critical population group in 2017 due to regular emissions and discharges of SS "Rivne NPP" was 0.30 μSv (0.38% of the dose limit quota).

CONCLUSIONS

In terms of non-radiation environmental impact during production and utility activities, SS "Rivne NPP" emits pollutants into the atmosphere, discharges return water into water bodies, stores, recycles and buries waste, as well as uses land plots.

Emissions of pollutants into the atmospheric air are released under conditions of permissions and do not exceed the permissible values.

Amounts of raw stock and materials used in 2017 did not exceed the values established by the justifications.

Water use at the enterprise is effected according to the established limits and rates of MPD that are specified in the permission for special water use. Analysis of qualitative indicators controlled by ecological and chemical laboratory of EPS shows that operation of Rivne NPP does not cause any significant changes in quality of surface water of the Styr River. During the period under review, limits of discharged into water bodies have never been exceeded.

Waste management at the enterprise is carried out in accordance with requirements of regulatory documents and production instructions. During the year, waste of spent luminescent lamps, accumulator batteries, engine, turbine and transformer lubricants, oil sludge and household waste were handed over to other enterprises for the purpose of further recycling or burial.

In 2017, design and predicted amounts of waste generation and allocation have not been exceeded. Environmental tax in 2017 was 890737.22 UAH.

Analysis of the controlled indicators shows that operation of Rivne NPP does not cause any significant changes in surface water quality. In 2017, water status in the Styr River (reference cross section) was preserved on the level of previous years' indicators. Dynamics of surface water status change in the Styr River (downstream of the NPP) in terms of chemical pollutants content was taken into account for the last 5 years.

Scheduled environmental measures are performed (rescheduled) within the prescribed time limits, a constant performance control system is established. In general, production activities of SS "Rivne NPP" in 2016 did not cause any changes in the natural environment that would indicate its deterioration. List of approval documents in the field of natiral environment protection, that served a basis for production activities of SS "Rivne NPP" during the period under review, is given in the appendix.

Hydrogeographic network in the 30-km zone of SS "Rivne NPP" is formed by rivers of Styr, Horyn and Veselukha basins, as well as lakes, ponds and a reclamation channels network. Within the 30-km zone, the Styr River has 12 tributaries more than 10 km long and 94 tributaries less than 10 km long falling into it. The river crosses the area of SS "Rivne NPP" in the South-North direction. The East part of the SS "Rivne NPP" area is occupied by left-bank tributaries of the Horyn Riven, and the North-West part hosts the Veselukha River basin. Within th 30-km zone of SS "Rivne NPP", there are 85 lakes with total water surface area of 16.57 km^2, including 15 lakes with water surface area more than 0.10 km^2. There are no storage reservoirs in the 30-km zone of SS "Rivne NPP". Beyond the controlled area of RNPP on the Styr River, 212 km upstream of the water intake, Khrinnytske storage reservoir is situated: it was restored in 1998 with its normal headwater level (NHL) 1 meter below the design level and water volume of 22.6 million m^3.

Impact of Rivne NPP on surface water can show up in places where process elements and structures of SS "Rivne NPP" communicated directly with public water bodies. The Styr River is such a water body for SS "Rivne NPP". SS "Rivne NPP" communicates with the river via intake facilities of the NPP service water supply and water discharge facilities of the NPP and the Town of Varash.

Water is drawn from the river for make-up of the NPP service water supply and cooling system for compensation of irreversible water losses in the NPP process cycle. Water is drawn from the river by the means of intake facility of the auxiliary water pump station (AWPS). Maximum design value of irreversible water consumption by the NPP providing for operation of all 4 power units is 2.2 m^3/s. At the same time, during the summer low-water period with account of successive power units shutdown scheduled preventive maintenance, design value of irreversible water consumption by the NPP does not exceed 2.0 m^3/s.

Process effluents of the NPP, purified sanitary waste water of the NPP and the Town of Varash, as well as storm runoff of Varash, are discharged into the Styr River.

Process effluents of the NPP consist mainly of blowdown water from the main cooling system. Blowdown water is auxiliary (river) water that has been boiled down in the cooling system. Therefore, it contains the same dissolved substances that flow into the cooling system with make-up water from the Styr River.

Neutralized reclaimed water from CWT and condensate purification plant (CPP) filters, which also contains substances specific to river water, is discharged into the Styr River together with blowdown water. The rest of process waste water of the NPP is disposed of in production cycles of the NPP.

Sanitary waste water of SS "Rivne NPP" and the Town of Varash are purified at complete biological treatment facilities and discharged into the Styr River downstream of the Town of Varash. Storm runoff of the Town of Varash is purified at local treatment facilities.

Comparison of sanitary and natural runoff to the Styr River shows that the business has almost no impact on the runoff.

Average multi-year value of natural runoff varies between 10.5 m^3/s (331.4 million m^3/year) at gauging station Shchurovtsi and 41.7 m^3/s (1316.0 million m^3/year) at gauging station Mlynok. In cross section of SS "Rivne NPP", this value makes 40.5 m^3/s (1278.2 million m^3/year).

Water economy balance has been calculated for low water years with water availability of 75, 95 and 97% in 9 balance areas, provided that three and four power units are operating.

Values of annual runoff for design water availabilities in balance cross sections have been determined based on monitoring data collected at gauging stations. In cases when balance cross section did not match the gauging station, runoff characteristics were determined by interpolation. Runoff in cross section of SS "Rivne NPP" in years with 75, 95 and 97% water availability are, respectively: 32.0 m3/s (1009.9 million m3/year), 26.1 m3/s (823.7 million m^3/year) and 24.8 m^3/s (782.7 million m^3/year).

Spring flood flow makes 40-50% in annual distribution, while part of the spring flow increases from the years of 75% availability towards those of 97% availability. The lowest runoff values are observed in summer. It is worth noting, that annual flow distribution has become more uniform over the past decades due to changes in temperature regime – a tendency towards increase of winter temperatures and decrease of summer ones. As a result, the values in March and April have become more similar.

The considered part of water basin hosts three storage reservoirs with total available capacity of 25.3 million m^3 and water surface area of 21.7 km^2. The largest storage reservoir is Khrinnytske storage reservoir in the Region of Rivne. Currently, available capacity of the storage reservoir is equal to 20.46 million m^3, and water surface area is 16.4 km^2; it is intended for recreation. The storage reservoir can not be used for water supply of SS "Rivne NPP" due to its remoteness. In addition, there are 353 ponds in the basin, with water surface area of 57.3 km^2 and available capacity of 58.7 million m^3.

Estimated amount of predicted ground water resources in this part of basin is 918.8 million m^3/year, including proven and approved resources of 112.2 million m^3/year. Most of ground water is reserved in Cretaceous, Devonian and Proterozoic deposits. Currently, 62.2 million m^3/year, or 7% of predicted ground water resources, are used for water supply of population and industry. In order to meet the household and drinking water demand on the current level, water supply must be 62.2-75.0 million m^3/year.

The largest ground water consumer is the City of Lutsk with a demand of 33.8-34.5 million m^3/year.

Total current water consumption by all branches of economy in the Styr River basin on the current level reaches 182.6 million m^3/year. Consequently, total water discharge is up to 73 million m3/year.

In the structure of irreversible water consumption, the main part is comprised, on the current level, by agriculture (reclamation) and, on a level of years 2016-2017, industry.

Rates of evaporation from water surface of ponds and storage reservoirs are calculated with differentiation and make 8.2, 14.2 and 16.0 million m^3/year in years of the calculated availabilities in the Styr River basin.

Values of sanitary flow rates have been determined based on the minimum average monthly flow rates for 95% availability from the monitoring series in each cross section. In cases when balance cross section did not match cross section of the gauging station, the method of linear interpolation was used. Sanitary flow rates in cross section of SS "Rivne NPP" have been determined by interpolation of average monthly flow rates for 95% availability in cross sections of Lutsk and Mlynok, making about 14.0 m^3/s. At that, data for the gauging station Mlynok have been adjusted to a multi-year period, since the multi-decade series of monitoring describes a high water period on the Styr River and gives over-estimated values. Sanitary flow rates in cross section of SS "Rivne NPP" have been determined by interpolation of average monthly flow rates for 95% availability in cross sections of Lutsk and Mlynok, making 11.0 m^3/s.

During approval of basic design of SS "Rivne NPP" in 1983, the essential requirement of the Ministry of Water was to preserve the flow rate of 9 m^3/s in the river, which corresponded to the minimum average monthly flow rate for 95% availability in cross section of SS "Rivne NPP" before 1980 and described the low-water phase of runoff. The new value of sanitary flow rate adopted in calculations of water economy balance (WEB) reflects changes in runoff characteristics of the Styr River over the past decades.

Based on the drawn WEB assuming operation of four units at SS "Rivne NPP", excessive runoff has been identified in all cross sections of the Styr River.

In a year with 97% availability in cross section of SS "Rivne NPP" on the current level, during the limiting period (summer – autumn – winter), the income part of the balance is up to 50.0 million m^3/month, water consumption is up to 6.0 million m3/month, sanitary flow rates are up to 30 million m^3/month, runoff excess is up to 15 million m3/month.

During operation of 4 units at SS "Rivne NPP", there is no deficit on the downstream sections of the river.

Upon condition of significant economic growth in the region with subsequent increase of water consumption for quite low-water years (95 and 97% availability), it will be necessary to develop additional measures on improvement of water economy status in the Styr River basin.

The following measures are envisaged according to data on water quality in cross sections of the Styr River that are located in settlements of Kolky and Staryi Chartoryisk of the District of Manevychi, near the municipal beach in the Town of Varash, in the Village of Stara Rafalivka, downstream of purified sanitary waste water discharge (in the Villages of Babka and Sopachiv), as well as in other surface water bodies, including Lake Bile, and sanitary status of surface water bodies in the monitored districts (the District of Rokytne – Stvyha, Lva and Bunev Rivers, in the District of

Kostopil – the Zamchysko River).

In order to reduce environmental pressure on the Styr River, blowdown water at SS "Rivne NPP" will be discharged from pressure conduits of unit pump stations, i.e. the discharge will comprise cooled water with a temperature of maximum 30-33 ^{0}C in summer. It is also envisaged that SS "Rivne NPP" will stop discharging rainwater runoff from its site into the river. Rainwater runoff will be purified and used for the cooling system make-up.

Concentration of ^{90}Sr in water of the Styr River in 1978 varied in a narrow range and was 0.007 Bq/dm^3 on average. Concentration of ^{137}Cs was 0.01 Bq/dm^3 on average, and its minor variations have also been recorded.

Average values of ^{90}Sr and ^{137}Cs during 1980-1985 (before the CNPP disaster) were 0.017 Bq/dm^3 and 0.026 Bq/dm^3. After 1986, in 1988, concentration of ^{90}Sr and ^{137}Cs in water of the Styr River increased by a factor of 2.4 and 2.3 respectively due to impact of the "West trace" of CNPP accidental release on the natural environment. Concentrations ^{90}Sr and ^{137}Cs started to reduce in 1989 and stabilized in 1993. Their average values over the years of 1988-1995 were 0.021 and 0.044 Bq/dm^3 respectively.

When comparing concentrations of radionuclides in the periods of authorization and operation of SS "Rivne NPP", it can be seen that differ insignificantly (except for several years after the CNPP disaster) and are several orders below the rated indicators of these radionuclides concentration in drinking water PCBingest for category B as per NRBU-97 (water is not used for drinking in the 30-km zone). Therefore, during operation of SS "Rivne NPP" there have not been any significant increase of indicators representing radionuclides concentration in water of the Styr River.

To control hydrological regime and hydrochemical composition of water in the Styr River within the 30-km zone of SS "Rivne NPP", a state and institutional monitoring system has been established.

Institutional control is effected by National Nuclear Energy Generating Company (NNEGC) "Energoatom" and its enterprise – SS "Rivne NPP". Hydrological and hydrochemical monitoring is carried out by ecological and chemical laboratory within Environmental Protection Service of SS "Rivne NPP".

Impact of industrial and sanitary discharges on content of sulphates was observed within an average of 9-15%. However, impact of industrial and sanitary discharges on other main ions and dry residue has not been observed, which is evidenced by comparison of both average and maximum values measured in the points near the Town of Polonne and the Village of Sopachiv.

There is a tendency towards some increase in concentrations of biogenic and organic substances in the Styr River downstream of industrial and sanitary waste water discharges. This increase, although it is minor, is mainly caused by discharge of sanitary waste water by the Town of Varash. However, in cross section of UTS of Zarichne, 4 km from the Belarusian border, content of these substances, as well as other hydrochemical indicators, is almost not different from the values observed in water of the Styr River upstream of SS "Rivne NPP"

The same is observed even for heavy metals – Mn, Cu, Zn. In all points, where water of the Styr River was sampled, including the area of SS "Rivne NPP" and the Town of Varash, both average and maximum values of their content was almost on the same level and way below the MPC.

During the summer low-water period, which is the most pressurized in terms of water economy, average and maximum values of water quality indicators for the Styr River were not notably different from the average annual values.

Numeric values of water pollution indexes (WPI) show that environmental impacts of SS "Rivne NPP" and the Town of Varash on quality of water in the Styr River are minor. Within the Region of Rivne, water of the Styr River generally belongs to class III – moderately polluted water.

At that, industrial discharges of SS "Rivne NPP" and the Town of Varash affect only numeric values of WPI, without changing the water pollution class. Even maximum values of hydrochemical indicators are way below the MPC. As for indicator of organic substance content, it exceeds the MPC, but this excessive value is observed in all sampling points and is not associated with discharges of SS "Rivne NPP". The same tendency towards excess of MPC is observed in other rivers and gives evidence of water pollution in the rivers due to natural and anthropogenic factors.

Prior to start-up of power unit No. 4 of SS "Rivne NPP", a predictive assessment of impact of water discharges from SS "Rivne NPP" with 4 power units in operation was carried out, and hydrochemical characteristics were calculated in the reference cross section after discharge and after complete mixing. Predictive environmental calculations have been performed based on the following conservative assumptions:

- hydrochemical characteristics of treated auxiliary water have been selected as per design materials calculated for the worst hydrochemical indicators of natural water;

- hydrochemical characteristics of natural water in predictive environmental calculations have been adopted as the worst values of summer months based on the results of water analyses for years 1982-1983. Hydrochemical characteristics of water, that are based on data of the past years' analyses, are less conservative.

The following conditions have also been taken into account in the calculations:

- process waste water of SS "Rivne NPP" that was being discharged into the Styr River was composed of blowdown water of the main NPP cooling system (94% of the volume) and neutralized reclaimed water from CWT and CPP filters;

- blowdown water of the main NPP cooling system contains the same dissolved substances that flow into the cooling system from the Styr River together with auxiliary water (with account for softening at the auxiliary water treatment facility (AWTF);

- waste water temperature does not exceed 33^0C in summer (maximum permissible process temperature of water cooled in the cooling towers) and 10-20^0C in winter.

Quantitative and qualitative characteristics of process effluents from water treatment plants are described in this EIA.

According to requirements of the Rules of Surface Water Protection from Pollution by Waste Water, the calculation has been performed for the minimum value of average monthly water flow rates in the river for a year with 95% availability.

Based on the analysis of predicted water quality indicators for the Styr River in the coverage area of NPP, the following conclusion can be made: quality of water in the Styr River after discharge of process waste water of NPP meets the requirements of effective regulatory documents in terms of all indicators.

Current status of hydrobiocenoses in the area of SS "Rivne NPP" has been investigated at a number of stations on the Styr River (downstream and upstream of the blowdown water discharge, downstream and upstream of water discharge from the treatment facilities), in the silt-detention basin of water intake of SS "Rivne NPP", open channels of the NPP, as well in Lake Bile – that is, the investigation has covered the main water bodies of the NPP area.

During investigations, prevailing ions in the river water were ions of calcium and hydrocarbonates. No significant changes have been detected in ion and salt composition of the Styr River water due to impact of blowdown water discharge.

Indicators of bacterial plankton growth in the Styr River were up to 6 millions cells/cm^3 in summer and up to 7 million cells/cm3 in autumn (average values). Increase of total bacterial count has been detected downstream of the blowdown water discharge, in the area of discharge from the treatment facilities, in open channels of SS "Rivne NPP".

Phytoplankton of the investigated water bodies and water courses in the area of SS "Rivne NPP" included 102 species of algae (106 subspecies and forms) in summer and 84 species (87 subspecies and forms) in autumn. Maximum indicators of phytoplankton count in summer were recorded in the area of ISSS discharge and in the open take-off channel of the NPP. Phytoplankton count in the NPP take-off channel was 14.0 million cells/dm^3, represented mainly by blue-green algae. Count of blue-green algae in the river was 0.9-4.0 million cells/dm3 in the area of ISSS discharge and varied within 0.38-0.89 million cells/dm3 in other areas.

According to all investigation of the water bodies, microphytal benthos is represented by 79 species of algae in summer and 63 species in autumn. Maximum numbers of benthos algae in summer has been recorded in the vicinity of the Village of Krymno, as well as downstream of the ISSS discharge – 7.5 million cells/10 cm^2 and 1.02 million cells/10 cm^2 respectively. In general, morphometry of the river bed does not encourage growth of phytobenthos.

Higher aquatic plants do not achieve significant growth in the Styr River and do not play any significant role in formation of hydrobiocenoses.

Zooplankton of the Styr River and open channels within the territory of SS "Rivne NPP" is characterized by its scarcity. Only 19 species and forms of invertebrates have been found here in summer and 33 species in autumn. In summer, zooplankton numbers in the area of blowdown water discharge were 200 specimen/m3, while average numbers for the river and cooling system were 760 specimen/m^3. Zooplankton was characterized by significant fluctuations towards large numbers on different sections of the river. In autumn, increase of zooplankton numbers has been detected in the area of blowdown water discharge.

114 species and forms of invertebrates have been found in summer in zoobenthos of the investigated water bodies in the area of SS "Rivne NPP", and 55 of them have been detected in autumn. Reduction of zoobenthos numbers and biomass has been observed in the area of blowdown water discharge. Numbers of the only group of invertebrates found here (oligochaetes) was 1300 specimen/m^2, while their total numbers in other sections of the river varied between 4500 and 42313 specimen/m^2. As opposed to summer, in autumn diversity indicators were higher in the area of blowdown water discharge than on other stations.

Periphytic algae have reached their maximum growth in the open take-off channel, mainly due to growth of blue-green algae. Periphytic invertebrates were represented by macroforms, such as colonies of sponges and bryozoa, gastropods, large insect larvae, as well as small forms – insect larvae and worms. In total, 72 species and forms of invertebrates have been found in summer and 64 in autumn. In biotopes, they are most affected by SS "Rivne NPP" (open take-off channel) – their numbers an biomass were dozens of times lower than at other stations. This phenomena was less distinct in autumn.

Primary phytoplankton production has been determined as 1.49 mg $O_2/dm^3 \cdot day$ in the area of NPP water intake, while downstream of blowdown water discharge it was 3 times lower (0.55 mg $O_2/dm^3 \cdot day$). Destruction indicators in these areas were similar. These primary phytoplankton production levels lie within the range of this indicator fluctuations in water bodies of Ukraine. Production to destruction ratio was above one, being the evidence of self-pollution processes that are more distinct in the Styr River upstream of ISSS discharge with decrease of primary production level. In autumn, no significant changes of primary production indicators have been detected in individual areas.

Analysis of data on environmental water quality assessment for water bodies under investigation has shown that the water can be placed mainly into class II – clean water – based on average indexes of water quality categories. In terms of average indexes of quality categories in summer and autumn, only water of the take-off channel is placed into the class of pollute water.

However, in terms of such indicators as bioplankton count, nitrites content and pH, water belonged to classes IV and V – dirty water an very dirty water.

Probability of biological obstacles to operation of pumping an heat exchange equipment can be currently estimated as minor. However, there are species among the hydrobionts that can be potential sources of biological obstacles – zebra mussels, bryozoa, sponges and submersed higher aquatic plants.

In terms of biological indicators, impact of discharges from SS "Rivne NPP" on hydrobiocenoses of the Styr River on the river section, where process waste water is discharged, is feebly marked and quite local.

Ichthyofauna of the Styr River includes 25 species of fish that belong to 7 families, and ichthyofauna of Lake Bile includes species of 6 families, among which the following species have been recorded and are rarely encountered: barbel, undermouth, eel, burbot, unicornfish.

Distribution of whitebaits species by river sections depends on characteristics of spawning grounds, and their quantitative indicators depend on food reserves.

Water bodies in the area of SS "Rivne NPP" are of interest only for small private fishery an fishing enthusiasts.

Fish food reserves are poorly developed but sufficient for feeding of fishes that inhabit the water bodies (taking into account their quantitative composition and diversity of species).

Based on investigations performed and analysis of EIA materials, it can be claimed that operation of four power units of SS "Rivne NPP" will not lead to impact on water quality in the Styr River over permitted standards and will not affect the living environment of fish. Lake Bile has no direct connection with the Styr River; therefore, adverse impact that could be caused by SS "Rivne NPP" have not been detected.

Structures and technologies used in design and construction of all power units of SS "Rivne NPP" and their sites have been envisaged with account of measures aimed at mitigation of the NPP impact on surface water, and have been introduced at all operating power units of the NPP:

- cooling towers are equipped with water catchers, that allow for significant reduction of water losses due to droplet carryover;
- spray cooling ponds of group A and B consumers cooling system have double water proofing that allows almost full elimination of filtration losses;
- rainwater runoff from the entire area of the NPP will be purified and used for make-up of main cooling system of the NPP. This will exclude the possibility of pollutants transfer into the Styr River after being washed off from the NPP area by rainfall runoff;
- there are provisions for discharge of main cooling system blowdown water from pressure pipelines of unit pump stations, i.e. after water cooling in cooling towers. This will reduce temperature of process effluents that are discharged into the Styr River by 9-10 ºC and, consequently, reduce their impact on the river;
- auxiliary water treatment facilities (AWTF) intended for elimination of scale forming properties of cooling water. Treatment at AWTF reduces total salt content in the auxiliary water by more than 1.5. As a result, discharge of salts into the Styr River together with process waste water can also be reduced approximately by 1.5.
- in order to reduce impact of purified sanitary waste water discharge on the Styr River, sanitary effluents treatment facilities will be expanded by 10000 m^3/day, i.e. their total productive capacity will be 30000 m^3/day. The second stage of treatment facilities is designed to reduce concentration of pollutants to 15 mg/dm3 in terms of BODfull and 15 mg/dm3 in terms of suspended matter. Expansion of sanitary effluents treatment facilities and increase of their operational efficiency will minimize the impact of purified sanitary waste water discharge on the Styr River.

Investigations performed within the scope of this EIA and analysis of materials on hydrochemical and radiation water monitoring in the Styr River with four power units operating confirm that there is no impact of process waste water of the NPP on the Styr River over permitted standards. Based on the calculations performed,it can be claimed that operation of four power units also has no impact over permitted standards on the Styr River. Concentration of radionuclides in water of the Styr River is thousands times lower than permissible concentration of radionuclides in drinking water. Maximum indicators of specific tritium activity are hundreds times lower than permissible concentration of this radionuclide in drinking water.

Bottom sediments, algae and fish of the Styr River are sampled annually in August. The samples were subjected to gamma-spectrometric analysis. There are no technogenic radionuclides in water bodies of the Styr River, except for ^{137}Cs of "Chernobyl" origin. Specific activity of ^{137}Cs in fresh fish is hundreds times below the established permissible level.

Sanitary protection zones of the first belt of artesian wells in the Village of Ostriv are marked and fenced. Activity of technogenic isotopes in ground water is thousands times lower than their permissible concentration in drinking water. There are no isotopes of technogenic origin in 9 wells of the artesian wells network. In the locations of sludge collector and construction and industrial waste landfill of SS "Rivne NPP", the analysis is conducted by the ecological and chemical laboratory, which is certified to measure chemical composition of ground water (wells). Analysis of the controlled characteristics shows that impact of the SS "Rivne NPP" site does not cause any significant changes in ground water quality.

REFERENCES

1. Енергетична стратегія України на період до 2030 року, схвалена розпорядженням Кабінету Міністрів України від 24.07.2013 р. № 1071-р.

2. Стратегічний план розвитку Державного підприємства «Національна атомна енергогенеруюча компанія «Енергоатом» на 2017-2021 роки.

3. Конвенція щодо оцінки впливу на навколишнє середовище в транскордонному контексті, ратифікована Законом України № 534 – XIV від 19.03.1999 р.

4. Протокол засідання міжвідомчої координаційної ради (МКР) з питань реалізації в Україні Конвенції про оцінку впливу на навколишнє середовище у транскордонному контексті (Конвенція ЕСПО) від 15 грудня 2016 року.

5. Закон України «Про оцінку впливу на довкілля» (Відомості Верховної Ради (ВВР), 2017, № 29, ст.315).

6. Директива 2001/42/ЄС Європейського Парламенту та Ради від 27 червня 2001 року «Про оцінку впливу окремих планів та програм на навколишнє середовище» (Офіційний вісник ЄС, L 197, 21 липня 2001 р.).

7. Договір від «27» березня 2018 р. № 347 «Проведення оцінки впливу на довкілля майданчика ВП «Рівненська АЕС» що було укладено між «ДП «НАЕК «Енергоатом» його відокремленим підрозділом – «Рівненською АЕС» та НТ – Інжиніринг.

8. Технічні вимоги на виконання послуги: «Проведення оцінки впливу на довкілля майданчика ВП «Рівненська АЕС». 083-01-ТВ-СОНС, затверджені головним інженером-першим заступником генерального директора ВП «Рівненська АЕС» від 06.02.2018 р.

9. Закон України «Про оцінку впливу на довкілля» (Відомості Верховної Ради (ВВР), 2017, № 29, ст.315).

10. Закон України «Про охорону навколишнього природного середовища» від 25.07.1991 р № 1264-XII.

11. Закон України «Про поводження з радіоактивними відходами» № 256/95-ВР від 30.06.95 р.

12. Закон України «Про дозвільну діяльність у сфері використання ядерної енергії» від 11.01.2000 р. № 1370-XIV.

13. Закон України «Про використання ядерної енергії та радіаційну безпеку» від 08.02.1995 р. № 39/95-ВР.

14. Закон України «Про основні засади (стратегію) державної екологічної політики України на період до 2020 року» від 21.12.2010 № 2818-VI.

15. Закон України «Про об'єкти підвищеної небезпеки» від 18.01.2001 р.

16. ДСТУ ISO 14001:2006 Системи екологічного керування. Вимоги і керівні принципи.

17. Рекомендації щодо змісту матеріалів впливів діючих об’єктів на навколишнє середовище.

18. ДБН А.2.2-1-2003 «Склад і зміст матеріалів оцінки впливів на навколишнє середовище (ОВНС)».

19. Посібника до розроблення матеріалів оцінки впливів на навколишнє середовище (до ДБН А.2.2-1-2003).

20. Закон України «Про охорону атмосферного повітря» від 16.10.1992 р. № 2707.

21. Закон України «Про інформацію» від 02.10.1992 р. № 2657.

22. Конвенція про доступ до інформації, участь громадськості в процесі прийняття рішень та доступ до правосуддя з питань, що стосуються довкілля від 06.07.1999 р. № 832-14 .

23. Закон України «Про охорону земель» від 19.06.2003 р. № 0962.

24. Закон України «Про природно-заповідний фонд України» від 16.06.1992 р. № 2456.

25. Закон України «Про рослинний світ» від 09.04.1999 р. № 0591.

26. Закон України «Про тваринний світ» від 03.03.1993 р. № 3041 і від 13.12.2001 р. № 2894 .

27. Земельний кодекс України від 25.10.2001 р. № 2768-14.

28. Постанова Кабінету Міністрів України от 27.07.95 р. № 554. Перелік видів діяльності та об'єктів, що становлять підвищену екологічну небезпеку.

29. Наказ Міністерства охорони навколишнього природного середовища України від 18.12.2003 N168 про затвердження Положення про участь громадськості у прийнятті рішень у сфері охорони довкілля.

30. Постанова Кабінету Міністрів України від 29.06.2011р. №771 «Про затвердження Порядку залучення громадськості до обговорення питань щодо прийняття рішень, які можуть впливати на стан довкілля.

31. Доповідь про стан навколишнього природного середовища в Рівненській області у 2016 році./Департамент екології та природних ресурсів Рівненської облдержадміністрації, Рівне, 2017 р. – 224 с.

32. Ривненская АЕС. Энергоблоки № 3,4. Отчет по периодичнской переоценке безопасности. Фактор безопасности 14. Глава 5. Влияние на окружающую среду. 22.3,4.133.ОППБ.05. АТ03-14.564.ОД.1, 2018 г. – 84 с.

33. Нетехнічне резюме. Матеріали з обґрунтування безпеки продовження терміну експлуатації енергоблоку № 3 ВП «Рівненська АЕС» у понадпроектний термін./Міністерство енергетики та вугільної промисловості України, Державне підприємство «Національна атомна енергогенеруюча компанія «Енергоатом», ВП «Рівненська АЕС», 2018 р. -58 с.

34. Звіт про оцінку впливу нерадіаційних факторів ВП «Рівненська АЕС» ДП «НАЕК «Енергоатом» на оточуюче природне середовище за 2017 рік./ Міністерство енергетики та вугільної промисловості України, ДП «Національна атомна енергогенеруюча компанія «Енергоатом», ВП «Рівненська АЕС», 2018 р. -25 с.

35. Наставления гидрометеорологическим станциям и постам. Выпуск 2. Часть 2 Ленинград 1975 г., Выпуск 6. Часть 1. Ленинград 1978 г.

36. «Положення про виконання спостережень за гідрологічним режимом р. Стир на гідрологічному посту ГТЦ 172-2-П-ГТЦ».

37. Регламент радіаційного контролю ВП «Рівненська АЕС», 132-1-Р-ЦРБ.

38. Допустимі рівні вмісту радіонуклідів ^{137}Cs та ^{90}Sr у продуктах харчування та питній воді (Державні гігієнічні нормативи ДР-2006).

39. Річний звіт з оцінки радіаційного впливу ВП «Рівненська АЕС» на навколишнє середовище та населення у 2017 році. 132-12-ЗВ-18-ЦРБ / Міністерство енергетики та вугільної промисловості України, ДП «Національна атомна енергогенеруюча компанія «Енергоатом», ВП «Рівненська АЕС», 2018 р., -63 с.

40. Річному звіті про результати метеорологічних спостережень в 2017 році в районі розташування Рівненської АЕС, 132-09-ЗВ-18-ЦРБ.

41. Допустимый водный сброс радиоактивных веществ Ривненской АЭС. НИИ радиационной защиты АТН Украины, Научный центр радиационной медицины АМН Украины о ОП «Ровенская АЕС», Кузнецовск, 2001 г.

42. 132-DY.C-2006. Допустимый водный сброс радиоактивных веществ Ривненской АЭС. (радиационно-гигиенический регламент первой группы).

43. 132-2013-КУ-ЦРБ. Контрольные уровни газо-аэрозольного выброса и водного сброса ОП «Ровенская АЭС» (радиационно-гигиенический регламент первой группы).

44. 132-2011-ДС-ЦРБ. Допустимый водный сброс радиоактивных веществ Ривненской АЭС (Радиационно – гигиенический регламент первой группы).

45. ДГН 6.6.1. – 6.5.061-98 «Норми радіаційної безпеки України (НРБУ-97)», МОЗ України, м. Київ, 1998 р.

46. ДСП 6.177 2005-09-02. Основні санітарні правила забезпечення радіаційної безпеки України (ОСПУ-2005), м. Київ, 2005 р.

Appendix A

HYDROGRAPHIC CHARACTERISTICS OF RIVERS IN THE 30-KM ZONE OF SS "RIVNE NPP"

Name of water course or cross section	Where it falls in and from which bank	Distance to confluence of the water course or cross section along the main river. km		Length of water course. km		Water catchment area. km^2		Elevation. m abs.		River fall. m/km	Valley		Width		Number of tributaries in the zone with length km	
		From the source	From the mouth	Total	In the NPP area	Total	In the NPP area	Source	mouth (of reference cross section)		Width. km	Height of slopes. m	Beds. m	Floodplains. km	< 10	> 10
1 Basin of the Styr River																
1 Styr River	Prypiat, right bank	–	491	494	113	12900	1850	230	129.3	0.21	2-4	10–15	30-60	2.0–3.0	94	12
Cross section of entrance into the zone (the UTS of Kolky)	–	268	226	268	–	9050	–	230	170	0.23	2.0	10	30	1.0–1.2	–	–
1.2 P Rudka	Styr, right bank	268	226	25	0*	186	0	191	170	0.89	1–3	10–15	2.0	0.2–0.3	9	–
1.3 Zheleznytsia	Styr, left bank	302	192	22	16	94.0	61	172	163.5	0.53	2.0	4–5	2.0	1.0–1.5	1	–
1.4 Okinka	Styr, left bank	312	182	25	25	286	286	173	163	0.40	3–4	8–10	6–10	1.0–1.5	5	2
1.5 Pidhorets	Okinka, right bank	11	14	14	14	48.3	48.3	177	169	0.57	1–2	4–5	1.5	1.0	–	–
1.6 Cherniavka	Okinka, left bank	18.7	6.3	18	18	96.2	96.2	182	165.5	0.92	2–4	12–15	2.0	2.0–3.0	7	–
1.7 Unnamed	Styr, right	314	180	7.5	7.5	16.4	16.4	172.	163.0	1.3	0.8–	4–5	1.0–	1.0	–	–

Name of water course or cross section	Where it falls in and from which bank	Distance to confluence of the water course or cross section along the main river. km		Length of water course. km		Water catchment area. km^2		Elevation. m abs.		River fall. m/km	Valley		Width		Number of tributaries in the zone with length km	
		From the source	From the mouth	Total	In the NPP area	Total	In the NPP area	Source	mouth (of reference cross section)		Width. km	Height of slopes. m	Beds. m	Floodplains. km	< 10	> 10
	bank							8			1.0		1.5			
1.8 Kormyn	Styr, right bank	317	177	53	27	824	284	188	162.8	0.48	3–4	8–10	4–5	0.2	25	2
1.9 Krosokha	Kormyn, left bank	41	12	12	12	90.4	45.5	172	166.8	0.43	2.0	8–10	2.0	0.2–0.3	5	–
1.10 Pischanka	Styr, left bank	322	172	10	10	44.0	44.0	172.5	161	1.1	1.0	4–5	1.5	0.2–0.3	–	–
1.11 RNPP water intake	–	326.7	167.3	326.7	78*	10400	1350*	230	162	0.20	2–3	10	40–60	2–3	41	6
1.12 Horbakh	Styr, left bank	340	154	17	17	72.4	72.4	171	159	0.7	1.5–1.8	5–15	6	0.3–0.5	6	–
1.13 Rov	Styr, right bank	349	145	14	14	102	102	170	156.5	0.92	–	–	10	–	5	–
1.14 Cross section of egress from the RNPP zone (the Village of Mlynok))	–	381	113	381	113**	10900	1850**	230	158	0.20	4–5	5–10	40–60	2–3	62	8
1.15 Vyrok	Richytsia,	7	10	19	9	316	296	152	144	0.42	3.0	5	5–8	0.5	11	2

Name of water course or cross section	Where it falls in and from which bank	Distance to confluence of the water course or cross section along the main river. km		Length of water course. km		Water catchment area. km²		Elevation. m abs.		River fall. m/km	Valley		Width		Number of tributaries in the zone with length km	
		From the source	From the mouth	Total	In the NPP area	Total	In the NPP area	Source	mouth (of reference cross section)		Width. km	Height of slopes. m	Beds. m	Floodplains. km	< 10	> 10
	left bank															
1.16 Lotok	Vyrok, left bank	2	17	12	12	72	72	156	151	0.46	–	–	–	–	4	–
1.17 Berezyno	Lotok, left bank	7	5	28	28	224	224	179	153	0.93	3	5	5–8	0.8–1.0	6	–
1.18 Stubla	Styr, right bank	419	75	70	30	593	241	154	138	0.29	3	10–15	10	2.0	7	–
1.19 Bezimianka	Stubla, right bank	37	33	20	7	163	117	156	150	0.46	3.5	10	2	2.0	3	–
2 Basin of the Horyn River																
2.1 Melnytsia	Horyn, left bank	477	182	39	8	432	217	191	152.6	0.98	3.5	10	5	0.3	20	3
2.2 Holubytsia	Melnytsia, left bank	25	14	17	17	72.8	72.8	181	164	1.00	2.0	10	2	0.2	3	–
2.3 Chopelka	Melnytsia, left bank	30	9.1	25	25	101	101	172	162	0.40	2.5	5	2	0.3	7	-
2.4 Vyrka	Horyn, left bank	489	170	27	24	261	250	166	152	0.53	3.0	10	5	0.4	13	5
2.5 Verkhnii	Vyrka, left bank	12	15	12	12	91.8	91.8	169	157	1.0	3.0	10	2	1.0	5	–

Name of water course or cross section	Where it falls in and from which bank	Distance to confluence of the water course or cross section along the main river. km		Length of water course. km		Water catchment area. km^2		Elevation. m abs.		River fall. m/km	Valley		Width		Number of tributaries in the zone with length km	
		From the source	From the mouth	Total	In the NPP area	Total	In the NPP area	Source	mouth (of reference cross section)		Width. km	Height of slopes. m	Beds. m	Floodplains. km	< 10	> 10
2.6 Smuha	Vyrka, left bank	20	6.7	11	11	59.5	59.5	163	154	0.82	2.5	10	2	0.5	3	–
2.7 Berezhanka	Horyn, left bank	527	132	34	12	253	135	162	145	0.50	4.0	15	5	0.5	5	4
2.8 Chakva	Horyn, left bank	493	166	9	9	51	51	167	153	1.50	–	–	–	–	–	–
3 Basin of the Veselukha River																
3.1 Veselukha	Prypiat, right bank	–	587	69	29	940	189	160	138	0.32	2.5	10	5	2.0	5	3
3.2 The Bihuchyi Stream	Veselukha, left bank	7	62	19	19	133	133	180	157	0.42	2.0	5	2	1.0	9	–

* – from the entrance cross section of the 30-km zone of SS "Rivne NPP" water intake and water catchment area within these boundaries;

** – river length from the entrance cross section of the 30-km zone of SS "Rivne NPP" to river egress from the zone and water catchment area within these boundaries.

Appendix B

HYDROGRAPHIC CHARACTERISTICS OF LAKES AND PONDS IN THE 30-KM ZONE OF SS "RIVNE NPP"

Name of water course or cross section	Lakes in the catchment area		Ponds on rivers in the 30-km zone		Largest lakes in the basin	
	Quantity	Total area, km²	Quantity	Total area, km²	Name of lake	Area, km²
1 Basin of the Styr River						
1.1 The Styr River	5	0.94	-	-	Zaprudske	0.14
					Ostrovatske	0.54
					Zakhvatske	0.10
1.2 The Okinka River	11	0.87	5	0.56	-	-
1.3 The Cherniavka River	5	0.25	-	-	Lisovske	0.13
1.4 The Kormyn River	7	0.92	-	-	-	-
1.5 The Horbakh River	1	0.37	2	-	Unnamed near the Village of Kostiukhnivka	0.37
1.6 The Vyrok River	18	4.60	-	-	Liubenske	0.26
1.7 The Lotok River	4	4.44	-	-	Bile	4.11
					Stav	0.10
1.8 8 The Berezyne River	6	0.13	-	-	-	-
1.9 The Stubla River	7	0.51	-	-	Voronky	0.23
1.10 The Bezimianka River	1	0.20	-	-	Unnamed near the Village of Ozero	0.20
2 Basin of the Horyn River						
2.1 The Melnytsia River	2	0.04	-	-	-	-
2.2 The Berezhanka River	-	-	1	0.18	-	-
3 Basin of the Veselukha River						
3.1 The Veselukha River	6	1.6	-	-	Redychi	0.16
					Velyke	0.26
					Male	0.10
3.2 The Bihuchyi Stream	12	1.7	9	0.48	Dovhe	0.12
					Okhnych	0.40
Total	85	16.57	17	1.22	15	7.22

Appendix C

List of Licenses, Permits of SS Rivne NPP in the Field of Environmental Protection (Non-Radiation Umpact)

No.	Document title	Date of issue	Term of validity	Issuer of the permit, license
Protection of atmospheric air				
1	Permit No. 5610700000-8 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (TrTs RNPP)	23/09/2013	23/09/2018	DENR* of the Rivne Regional State Administration DENR Letter No. 2754/04/1-09/16 06/12/2016
2	Permit No. 5610700000-11 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (the industrial zone)	27/12/2013	27/12/2018	
3	Permit No. 5610700000-12 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (vocational school No. 12, Sports Complex, Community Center)	24/10/2014	unlimited	
4	Permit No. 5610700000-13 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (URP, ASKRO, TsGO)	24/10/2014	unlimited	
5	Permit No. 5610700000-14 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (asphalt-bitumen plant, TsSR)	24/10/2014	24/10/2024	
6	Permit No. 5610700000-16 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (sewage treatment facilities for household faecal waste from the industrial site of SS RNPP)	24/10/2014	unlimited	
7	Permit No. 5620881201-1 for emissions of pollutants into the atmosphere by stationary sources of ROK “Bile Ozero” of SS Rivne NPP	28/11/2011	unlimited	
Protection of water resources				
8	Permit Ukr No. 1/RVN for special water use by SS Rivne NPP	06/08/2015	06/08/2020	DENR of the Rivne Regional State Administration
9	Permit Ukr No. 454/RVN for special water use by ROK “Bile Ozero” of SS Rivne NPP (continued)	15/01/2014	Continued perpetual	
10	License No. 458 on the management of hazardous waste as determined by the Cabinet of Ministers of Ukraine	02/12/2015	perpetual	The Ministry of Ecology and Natural Resources of Ukraine
Protection of land and subsoil				
11	Special permit for the use of subsoil No. 2263 (Rafalivske-1 deposit)	09/10/2000	20 years	The Ministry of Ecology and Natural Resources of Ukraine

APPROVED

Director of NT Engineering

_______________R. V. Maraikin

"__" ____ 2018

REPORT
ON
SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 3 Volume 5

Soils. Flora and Fauna, Protected objects

Version 2

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ABSTRACT

Book 3, Part 5 of this report consists of 155 pages of text, 22 figures, 34 tables.

The operating power units, buildings and constructions that form part of the complex of RNPP site of NNEGC Energoatom, as well as their impact on the environment in the area of RNPP location are the subject of consideration in this book.

The object of research is the environment of RNPP zone of influence.

Purpose: identify natural and man-made threats in RNPP zone of influence, assess its ecological, nuclear and radiation safety and impact on soils, flora and fauna, as well as on protected objects.

Nuclear power is a reliable source of energy supply and it plays a leading role in ensuring the energy needs of Ukraine. The priority of protecting a human being and the environment against the negative effects of radiation and ensuring the safety of nuclear energy is one of the main principles of state policy in the field of nuclear energy and radiation protection in Ukraine. RNPP is the first nuclear power plant with four power units (two VVER-440 and two VVER-1000).

The report is developed in compliance with the requirements for the scope and content of the documents on environmental impact assessment.

The outcome of this report is environmental justification to accept the economic activities by the operating facilities on RNPP site and identification of safety conditions during future activities.

At carrying out research work, the data of topical research efforts and monitoring conducted in RNPP zone of influence by different institutions were collected and analyzed, the state of the ecological, nuclear and radiation safety was determined.

KEY WORDS: RNPP, NPP, SOILS, RADIATION SAFETY, ENVIRONMENTAL SAFETY, MONITORING, PROTECTED OBJECTS, FLORA, FAUNA.

Conditions of the report distribution: according to the contract.

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SCOPE OF REPORT

Rivne NPP Environmental Impact Assessment

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4		Assessment of impact on the surrounding social and anthropogenic environment	
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6		Non-technical summary of SS Rivne NPP site environmental assessment	
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LIST OF DESIGNATIONS, SYMBOLS, UNITS, ABBREVIATIONS AND TERMS

Denotation	Denomination
AEWA	Agreement on Preservation of Afro-Eurasian Migratory Waterbirds
Alneta glutinosae	Black Alder Forests
ARMS	Automated Radiation Monitoring System
Betuleta pendulae	Silver Birch Forests
Betuleta pubescentis	Downy Birchy Forests
BSR	Building Standards and Regulations
CA	Control Area
CCP	Central Control Point
ChNPP	Chornobyl Nuclear Power Plant
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CP	Checkpoint
DD	Data Deficient
DL	Doze Limit
E	East
EIA	Environmental Impact Assessment
EN	Is Under Threat
Energoatom	National Nuclear Energy Generating Company “Energoatom”
EUROBATs	European Coordinating Body for the Monitoring and Protection of Bats
HD	Head Department
ICC	Interdepartmental Coordination Council
IRG	Inert Radioactive Gases
ISSS	Industrial Stormwater Sewer System
IUCN	International Union for the Conservation of Nature
IUCN Red List of Threatened Species	European Red List
KhNPP	Khmelnitsky Nuclear Power Plant
LC	Is Under Large Threat
LLR	Long-Lived Radionuclides
LR	Low Risk of Disappearance
LSRIRH	Leningrad Scientific Research Institute of Radiation Hygiene
MDA	Minimum Detected Activity
MHU	Ministry of Health of Ukraine
MPC	Maximum Permissible Concentration
N	North
NN	Close to the Threat of Disappearance
NNP	National Nature Park
NPP	Nuclear Power Plant
NT-Engineering	Limited Liability Company “NT-Engineering”
OA	Observation Area
OSG	Open Switchgear

Denotation	Denomination
PE	Permissible Emission (Limit Emission)
PED	Power of Exposure Doze
Piceeta abietis	Small Spruce Forests
Pineta sylvestris	Pine Forests
Querceta roboris	Oak Forests
RBU	Red Book of Ukraine
RNPP	Rivne Nuclear Power Plant
RRPCE	Rivne Regional Production Communal Enterprise
RS	Radiation Source
RSSU-97	Radiation Safety Standards of Ukraine, 1997
S	South
SE	State Enterprise
SI	State Institution
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SRA	State Regional Administration
TS	Technical Specifications
VU	Vulnerable
VVER-1000	Water-Cooled Water-Moderated Power Reactor with Rated Capacity of 1000 MW
VVER-440	Water-Cooled Water-Moderated Power Reactor with Rated Capacity of 440 MW
W	West
WWF	Wild World Fund
WWS	Water and Wastewater Services
A_{mid}	Average Activity Value
pH	Acidity Index

INTRODUCTION

“Environmental Impact Assessment of Rivne NPP Production Site. Soils. Flora and Fauna, Protected Objects” is made within topic “Environmental Impact Assessment of Rivne NPP Production Site”.

The assessment is done within the observation area (OA): 30 kilometers around RNPP, that is marked in Figure 1.1.

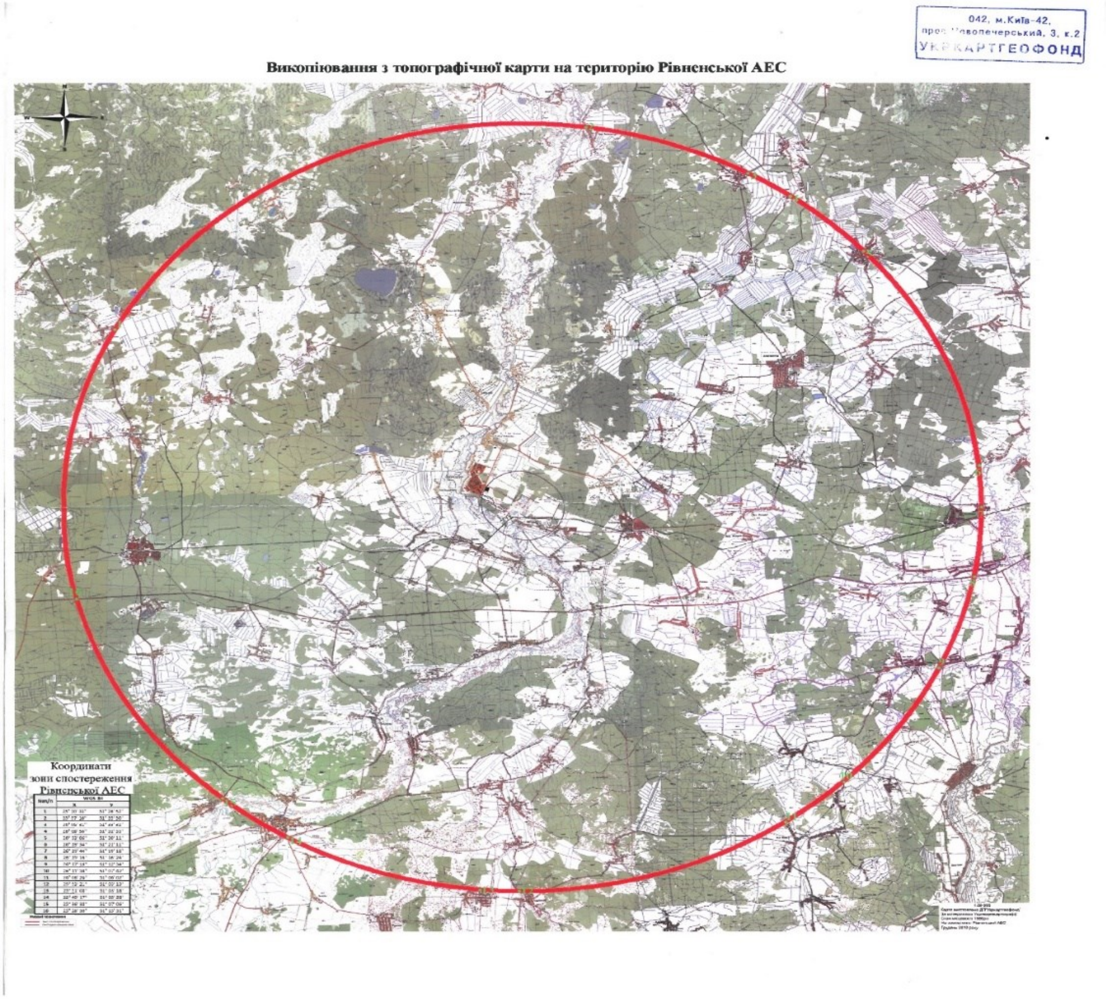

Figure1.1. RNPP observation area

The service under topic “Environmental Impact Assessment of Rivne NPP Production Site” is provided under agreement No. 347 of 27 March 2018 concluded between the State Enterprise National Nuclear Energy Generating Company Energoatom (Energoatom), its Separated Subdivision Rivne Nuclear Power Plant and Limited Liability Company NT-Engineering.

The basis for “Environmental Impact Assessment of Rivne NPP Site” is:

- Energy Strategy of Ukraine until 2030 approved by Cabinet Order No. 1071-p. of 24 July 2013[1];

- Strategic Plan for the Development of the State Enterprise National Nuclear Energy Generating Company Energoatom for 2017-2021 [2];

- Convention on Environmental Impact Assessment in a Transboundary Context ratified by the Law of Ukraine No. 534-XIV of 19.03.1999 [3];
- Minutes of the Meeting of the Interdepartmental Coordination Council (ICR) on Implementing the Convention on Environmental Impact Assessment in a Transboundary Context (the ECPO Convention) of 15 December 2016 [4];
- Law of Ukraine “On Environmental Impact Assessment” (Official Gazette of the Verkhovna Rada of Ukraine, 2017, No. 29, p.315) [5];
- Directive 2001/42/EC of the European Parliament and the Council of 27 June 2001 on the Assessment of the Effects of Certain Plans and Programs on the Environment (Official Journal of the EU, L 197, July 21, 2001) [6].
- Agreement of 27 March 2018 No. 347 “Environmental Impact Assessment of the RNPP Site” concluded between the Energoatom, RNPP and LLC NT-Engineering [7].
- Technical specifications for the performance of service: “Environmental Impact Assessment of the RNPP Site”. 083-01-TV-SOS approved by Chief Engineer, First Deputy General Director of RNPP dated 06.02.2018 [8].
- Law of Ukraine “On Environmental Impact Assessment” (Bulletin of the Verkhovna Rada (BBP), 2017, No. 29, p.315) [9].
- Law of Ukraine “On Environmental Protection” No. 1264-XII of 25 July 1991 [10].
- Law of Ukraine “On Environmental Expertise” No. 45/95-VR of 09 September 1995 [11].
- Law of Ukraine “On Authorizing Activities in Nuclear Energy Use” No. 1370-XIV of 11.01.2000, [12].
- Law of Ukraine “On Nuclear Energy Use and Radiation Safety” No. 39/95-VR of 08 February 1995 [13].
- Law of Ukraine “On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine till 2020” No. 2818-VI of 21 December 2010 [14].
- Law of Ukraine “On Hazardous Objects” of 18 January 2001 [15].
- DSTU ISO 14001: 2006 Ecological Management Systems. Requirements and Guidelines. [16].

The purpose of the development of materials for environmental impact assessment (EIA) is to assess environmental impact of RNPP operation on the results of implementing environmental protection measures, long-term results of environmental monitoring and comparison of environment condition around the NPP before its commissioning and during its operation.

The EIA is executed in accordance with the “Recommendations for the content of materials of the existing object effects on the environment” [17], DBN A.2.2-1-2003 “Composition and content of environmental impact assessment materials (EIA)” [18] and the Manual on Developing Materials for Assessing Environmental Impacts (to DBN A.2.2-1-2003) [19].

As well as:

1. The Law of Ukraine “On the Protection of Atmospheric Air” No. 2707 of 16 October 1992 [20];
2. The Law of Ukraine “On Environmental Protection” No. 1264 of 25 June 1991 [21];
3. The Law of Ukraine “On Information” No. 2657 of 02 October 1992 [22];
4. Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters dated No. 832-14 06 July 1999 [23];
5. The Law of Ukraine “On the Protection of Land” No. 0962 of 19 June 2003 [24];
6. The Law of Ukraine “On the Nature Reserve Fund of Ukraine” No. 2456 of 16 June 1992 [25];

7. The Law of Ukraine “On the Flora” No. 0591 of 09 April 1999 [26];

8. The Law of Ukraine “On the Fauna” No. 3041 of 3 March 1993 and No. 2894 of 13 December 2001 [27];

9. Land Code of Ukraine No. 2768-14 of 25 October 2001 [28];

10. Cabinet Resolution No. 554 of 27 July 1995. List of Activities and Objects that Constitute an Increased Ecological Hazard [29];

11. Order of the Ministry of Environmental Protection of Ukraine on the Approval of the Regulation on Public Participation in Environmental Decision-Making No.168 of 18 December 2003 [30].

12. Cabinet Resolution “On the Approval of the Procedure for Involving the Public in Decision-Making Issues that May Affect the State of the Environment” No. 771 of 29 June 2011 [31].

Performance of the environmental impact assessment of RNPP site is stipulated in 7 books.

Book 3, “Environmental Impact Assessment of RNPP Site”, Part 5, “Soils. Flora and Fauna, Protected Objects” provides the information on soil characteristics, as well as on the impact on the flora and fauna, protected objects in implementing the planned activities of RNPP, and its impact on the public and the environment.

1 SOILS

In the use of RNPP, there are 418.1533 hectares located in Varash and 62.06 hectares in Volodymyrets district. [32].

Table 1.1. Lands used by RNPP

Land	**Hectares**
Total	480.2761
Land under construction	468.7507
of them:	
Land for construction and maintenance of residence buildings	12.0312
Public lands	3.9162
Land for commercial use	0.3455
Land used for technical infrastructure	433.8881
Lands used for recreation and other open lands	30.0951

The areas outside the city allocated to RNPP for the points of the automatic radiation monitoring system (ARMS) in the village councils of the Volodymyrets district are presented in Table 1.2.

Table 1.2. Areas reserved for RNPP outside the city

No.	Name	Total area, hectares	Permanent use	Entered according to the document
1.	Lozkya village council	0.0700	0.0700	State certificate YaYaYa No. 272079 of 29 June 2006
2.	Polytsi village council	0.0400	0.0400	State certificate II-RV No. 001898 of 20 November 2000
3.	Velykyi Zholudsk village council	0.1100	0.1100	State certificate II-RV No. 001899 of 20 November 2000
4.	Lyubakhy village council	0.0770	0.0770	State certificate II-RV No. 001900 of 20 November 2000
5.	Bilska Volia village council	0.0500	0.0500	State certificate YaYaYa No. 272073 of 29 June 2006
6.	Sopachiv village council	0.0520	0.0520	State certificate II-PB No. 001901 of 20 November 2000
Total		0.3990	0.3990	

1.1 Land fund structure

The ecological basis of the reproduction of soil fertility is the biogeochemical cycle of organic substances, among which humus has a leading role. Organic substances actively influence the processes of soil formation, determine the harvesting capacity, buffering, create water-physical, physico-chemical properties favorable to biota, soil-ecological regimes, etc. Therefore, the introduction of agricultural systems aimed at preserving and constantly replenishing organic matter of the soil guarantees sustainable development of agrarian production, food and ecological safety of the state. Humus soil condition is related to monitoring not only through nutritional status, but also characterizes their ecological status and biosphere functions.

Light gray and gray podzolic soils are poor in humus in their properties. Its amount is only 1.6-2.2%. They have all the characteristics of little saturated bases and few structural soils. They are characterized by rapid precipitation after cultivation. The depth of the humus alluvial horizon is 25-30 cm.

The average and high content of humus is predominantly black soil and blacksoil-meadow soils. The deep humus horizon of these soils with a granular-laced structure gives rise to favorable water-air properties: they have good permeability, high moisture content and aeration. They are also characterized by a high level of ability. Blacksoil-meadow soils differ from black soils by the presence of gelling in the humus layer and in the rock. According to granulometric composition, they are from sandy to clay differences. The humus horizon is quite deep: 50-80 cm, humus content: 3.4-6.5 %.

According to the results of agrochemical certification of agricultural lands in the region, the soils with low (<2 %) content of humus are distributed in all climatic zones and make up 48.1 % of the surveyed areas of the region conducted by the Rivne branch of the State Soil Protection Agency.

In the Polissia region (Dubrovytsia, Kostopil and Volodymyrets districts), low humus content is typical for 59.3, 63.6, 67.8 % of the surveyed areas, while in the forest-steppe zone, the largest areas with low humus content are observed in Rivne (52.7 %), Zdolbuniv (51.3 %), Dubno (44.3%) districts. The content of humus in the region is within the range of 2.02-2.66 %, with an average of 2.2 %. The area of soils with high and very high content is 1.1% of the surveyed area. The overwhelming majority of them was concentrated in the forest-steppe part of the region. The areas with medium and high humus content make up 50.7 %.

The dynamics of total humus content in the arable land of the forest-steppe indicates a tendency to decrease it from 2.42 % to 2.26 %.

One of the important characteristics that causes soil fertility is the reaction of soil solution. Increased acidity reduces the activity of microbiological processes, which adversely affects the content of phosphorus, potassium and trace elements available in soil.

Soil acidity is influenced by many factors: natural factors of reclamation, indiscriminate (excluding physical and chemical properties of soil) introduction of mineral fertilizers and their forms and lime making (or its absence).

The acidic reaction of the soil solution suppresses the vital activities of bacteria, which expose the most of organic residues and contribute to the synthesis of humus acids. It is equally important that the humic substances formed in the intermediate products of the decomposition of organic substances are not fixed in acidic soil due to the lack of calcium and magnesium and washed out in the lower soil layers.

In the Polissia districts of the region, the average weighted index of acidity of rNsol is observed within 4.87-5.59 units, in the forest-steppe regions: 5.98-7.01 units.

In the area of Polissia, 73 % of the investigated areas of acid (with pH = 5.5) of arable land are concentrated with 19% of the acidic soils being composed of slightly acidic (pH = 5.1-5.5), 27% of the average acid (pH <5.0) and 27 % - from strongly acid (pH <4.5). The largest areas of acid soils in the Polissia zone are concentrated in Volodymyrets and Rokytne districts: 83 % and 80% respectively, and the smallest are in the Kostopil district: 52%.

In the forest-steppe zone, the most of acid soils are observed in the Korets, Goshcha, Zdolbuniv districts: 32 %, 30 %, 30 % of the surveyed areas respectively, and the least in Radyvyliv and Rivne districts: 7, 12 % respectively.

Soil acidity of the Polissia area during the last 20 years has increased to 5.11 units, the share of areas with acidic reaction of the soil solution (pHsol less than 5.0) increased from 32 % to 54 %. The situation with soils, where the reaction of the soil solution is very acidic (pHsol less than 4.5), deteriorated - their area increased from 9 to 27 % or 3 times.

Nitrogen accumulation in soil is possible only in organic form, therefore its content in soil depends on the content of organic matter and, above all, humus. Consequently, the more humus is contained in soil, the more nitrogen will be in it. The total nitrogen content in an arable layer of different soils ranges from 0.05 % to 0.3 % and is directly related to the presence of organic substances in them. Most of it is contained in typical black soils and ordinary black soils. The least is in the sod-podsolic soils of Polissia.

The weighted average content of alkaline hydrolyzed nitrogen in the region is 115.2 mg/kg of soil, with the distribution of areas within 96-156 mg/kg of soil, which corresponds to the levels of very low to medium availability.

The distribution of the areas of the Polissia and forest-steppe arable land in the content of alkaline-hydrolyzed nitrogen shows that a part of the areas with very low content (less than 100 mg/kg) is respectively 58.2 % and 37 % of the surveyed area.

The phosphate regime of the soil depends, first of all on the parent rock, degree of its weathering and nature of soil forming process. Phosphorus content in soils depends on their granulometric composition, humus content, as well as the presence of phosphorus-containing minerals. Poor sod-podzolic and sandy soils are poor in total phosphorus content. More general phosphorus is contained in the upper soil layers, which is associated with plant activity, active absorption of soil and introduction of fertilizers. In most soils, mineral content of phosphorus predominates over organic matter.

By the level of mobile phosphorus supply, soils of the forest-steppe zone differ significantly from the soil of the Polissia area. Mobile phosphorus content is observed in forest-steppe soils 104-176 mg/kg, Polissia: 75-101 mg/kg of soil.

The highest average weighted content of mobile phosphorus in the forest-steppe zone is observed in Goshcha, Mlyniv, Dubno districts: 176, 174 and 160 mg/kg, the least: in 104, 104, 133 mg/kg of soil respectively in the Ostroh, Radyvil, Korets districts. Mobile phosphorus content in the forest-steppe soils during the period from the VIth to IXth agrochemical passport fell by 10%. Among the areas of the forest-steppe zone, the largest soil areas with very low phosphorous content are observed in Ostroh and Korets districts: 16.7 and 17.4% respectively.

Among the areas of the Polissia zone, the highest content of phosphorus is in Rokytne, Kostopil, Sarny districts: 101, 91, 91 mg/kg of soil, and the smallest is in Zarichne, Berezno, Volodymyrets districts: 75, 77, 78 mg/kg of soil respectively. The largest areas of soil in the Polissia area of the region with very low and low content of mobile phosphorus are concentrated in Volodymyrets (41.9%) and Berezno (39.9%) districts. The content of mobile phosphorus in the soil of Polissia for the period of VIth to IXth round of agrochemical certification generally decreased by 24%.

In spite of the fact that potassium is extracted from soil by crop yields continuously and in large quantities, it is rarely possible to find soil where the lack of this element can limit yields. In most cases, this is due to the fact that potassium content in most soils is much higher than nitrogen and phosphorus content, which significantly limits receiving of high yields. Potassium content in soils is determined by the mineralogical composition of soil forming rocks, their granulometric composition, as well as zonal conditions and the nature of land use.

Unlike phosphorus, the area of the region may be characterized as scarce by the level of supply with exchangeable potassium requiring the use of potassium fertilizers. The largest amount of potassium contains heavy granulometric soils: clay and loamy. In these soils, its amount can reach 2-3% of soil mass. Significantly less potassium is in soils of light granulometric composition: 0.1-0.2%. Often, soil erosion results in significant loss of exchangeable potassium.

The highest content of exchangeable potassium is observed in the soil of forest-steppe: 74-132 mg/kg of soil. The most scarce content of this element is in the soil of Polissia: 37-59 mg/kg of soil.

There are 57.4 % of soils with very low and low content of exchangeable potassium in the forest-steppe region. Among the areas of the forest-steppe zone, the highest potassium content is in Goshcha, Demydivka and Rivne districts: 132, 111, 106 mg/kg of soil, and the lowest is in Radyvyliv and Korets districts: 72, 83 mg/kg of soil, respectively. The content of exchangeable potassium in the soils of the forest-steppe region for the period VI-to-IX round of agrochemical certification decreased from 123, 9 mg/kg to 89.0 mg/kg of soil, or by 28 %.

In the Polissia zone, there are 90.8 % of arable land with very low and low content of exchangeable potassium. In the Polissia zone, the highest potassium content is in Rokytne, Zarichne districts: 59.47 mg/kg of soil and the lowest is in Volodymyrets and Dubrovytsia districts: 37, 41 mg/kg of soil respectively. The largest areas with very low and low content of exchangeable potassium are observed in Volodymyrets (95.4 %), Berezno (93.5 %) and Dubrovytsia (91.8%) districts. The content of exchangeable potassium in soil of the Polissia zone for the period VI-to-IX round of agrochemical certification decreased from 90.9 mg/kg to 42.8 mg/kg of soil, or 2.1 times.

The uneven intensity of depletion by mobile phosphates and exchangeable potassium over the zones of the region may be explained by different soil cover. The most intense depletion of mobile compounds occurs in Polissia areas, where soil has weak buffering capacity; react quickly to the level of economic activities with regard to preservation or loss of their fertility.

Besides macroelements, the optimum mode of plant nutrition is provided as well with the trace elements. The content of trace elements depends on the quantity and quality of soil organic matter, human economic activities, etc. Their mobility and availability for plants are influenced by: the reaction of the soil solution, humus content, capacity of cation exchange, content of other elements.

It was established that soil of the Polissia zone is significantly poorer in the moving forms of trace elements. Mobile copper content in arable lands between zones varied by 2.2 times, and manganese content: by 1.5 times. In recent years the areas with low content of moving forms of trace elements in the Polissia area have significantly increased.

Rivne hydrogeologically-meliorative expedition carried out research on the factors that influence soil fertility and their water-physical properties, in particular soil acidity on drainage lands has been determined.

Table 1.3. Distribution of drainage lands according to the degree of soil acidity

No.	District	Area of acidity measurement, hectares	Level of acidity, hectares						
			Alka-line	Neutral	Acid				
					Total	Including			
						Low-acid	Middle-acid	High-acid	
1	Berezno	6478	407	2025	4046	1634	1230	1182	
2	Volodymyrets	5006	-	642	4364	957	1828	1579	
3	Goshcha	2583	2355	228	-	-	-	-	
4	Demydivka	522	522	-	-	-	-	-	
5	Dubno	570	570	-	-	-	-	-	
6	Dubrovytsia	3329	-	143	3186	615	1377	1149	
7	Zarichne	9988	498	2546	6944	2128	2102	2714	
8	Zdolbuniv	1329	1329	-	-	-	-	-	
9	Korets	4840	406	726	3708	726	1329	1653	
10	Kostopil	6600	317	1519	3764	1448	1563	753	
11	Mlyniv	603	529	74	-	-	-	-	
12	Ostroh	1201	1016	66	119	12	89	18	
13	Rivne	1499	660	325	514	295	219	-	
14	Rokytne	10937	356	2330	8251	3013	3201	2037	
15	Sarny	8749	1226	743	6780	1095	3429	2292	
Total in the region		64234	10191	12367	41676	11887	16367	13422	

Acid soils occupy the largest areas in the following districts: Berezno (4046 ha), Volodymyrets (4364 ha), Dubrovytsia (3186 ha), Zarichne (6944 ha), Rokytne (8251 ha), and Sarny (6780 ha). Limestone is required for medium and high acid soils with a total area of 29,789 ha.

In recent years, the area with acid soils has increased significantly. Moreover, this growth occurs due to the increase of medium, high acid and very acid soil. The reasons for the growth of these areas are man-made soil contamination, use of physiologically acidic mineral fertilizers, as well as prolonged neglecting measures of chemical melioration, which, in turn causes the transformation of slightly acid soil in medium and high acid. The growth of these areas is confirmed by the non-fulfillment by agricultural producers of measures on liming soils and selection of crop rotation.

1.2 Land and soil structure and conditions

The soil cover of RNPP 30-km zone is quite diverse. A considerable proportion in its structure belongs to sod-podzolic, sod, alluvial, meadow, meadow-swamp, peat and peatland-swamp soils, as well as peatlands of varying degrees of capacity (a total of about 280 soil varieties).

Due to the different soil-forming rocks, different degrees of gluing, waterlogging, washing and peating of soil cover, RNPP 30-km zone is rich both in species and in their habitats.

The largest areas in the soil structure of RNPP 30-km zone are occupied by sod-podzolic soils confined to inter-river and ancient alluvial plains, and formed under mixed and pine forests in conditions of stagnant and flushing water regime in ancient alluvial and water-glacial deposits. Distributed almost throughout the territory, the largest areas are in the central, western, eastern and south-eastern parts of the zone.

The prevailed soils in RNPP are of light mechanical compositions: sand, clay-sand and sandy soils. Light-loamy soils have a small distribution, mostly in the floodplains of rivers; medium-loamy soils occur rarely.

Within RNPP 30-km zone, sod-podzolic soils with a low content of humus of 0.1-3 % predominate. They occupy an area of 1864.3 km^2. Humus-containing soils (3.1-5.0 %) are distributed on a territory of 205.7 km^2, and 5.1-7.0 % of humus are distributed on a territory of 152.5 km^2. Significant areas are occupied by soils of humus with 7.1-8.0 % and more than 8.0 % - 524.6 km^2, which is due to the presence of meadows, meadow-swamp soils and peat of varying capacity on these territories.

The whole range of gleyed soils (area 1382.8 km^2) is presented in the studied area.

The most common soils in RNPP are with a weak acidic reaction (an area of 1269.9 km^2), the smaller territories are occupied with soils with acid and neutral reaction (604.9 km^2 and 702.1 km^2). Alkaline and slightly alkaline soils are commonly distributed. Indicators of hydrolytic acidity (mg eq/100 g of soil) range from 1.33 to 45.6 mg eq/100 g.

Indicators of calcium and magnesium content in the soils of RNPP 30-km zone are generally homogeneous. The content of calcium for sod-podzolic soils does not exceed 4 mg eq/100 g, meadow grass, sod and peat - 10-17 mg eq/100 g, the highest indices in meadow gley sandy soils - 26 mg eq/100 g percentage of nitrogen content is quite low - 0.08-0.4 %.

The content of phosphorus in the soils of the studied area is low – 0.02-0.09 %, only in sod-concealed podzolic, sod-weakly developed and meadow soils it reaches 0.13-0.17 %. The percentage of potassium varies from 0.3 to 1.1 %. The smallest amount in peat-wetlands and peatlands is 0.3 %, sod-podzolic soils have 0.6 % of potassium, meadow-swamp soils – 0.7 %, sod soils – 0.9%.

The density of the studied soils is characterized by an almost stable value close to 2.5 g/cm^3. Exceptions are swamp, peat-swamp soils and peatlands - 1.5-1.7 g/cm^3. The values of the bulk mass vary somewhat, but the margins of variation are negligible - 1.2-1.6 g/cm^3. The volumetric mass of peat soils is 0.2-0.25 g/cm^3.

The greatest mobility of man-made substances, including ^{137}Cs, is observed in swamp and meadow soils, that is, in hydromorphic soils. As for automorphic soils, the indicators of the considered water-physical properties (spariability, moisture capacity, maximum hygroscopicity) are the largest in sod-podzolic, sandy-loam, loamy and turf soils, the smallest are in sod-podzolic sandy soils.

In analyzing the land use structure, the following categories were identified:

1) agricultural lands, which include agricultural fields, cultural plots within the settlements (agrophytocoenoses of settlements), perennial plantations (gardens, hunters, nurseries, etc.), pasture and grasslands;

2) forests;

3) swamps, land occupied by ponds, peatlands.

The land use structure of RNPP 30-km zone is dominated by forests (49.6 % of the whole zone territory), as well as agricultural lands (45.3 %). Among the agricultural lands, the largest part belongs to fields - 60.7 % and pastures with hayfields - 26.3 %.

The analysis of the landscape structure of the territory allowed the isolation of 18 individual landscapes, which are united into four types of landscapes. Since the entire study area is located in the zone of mixed forests, the main criterion for the allocation of types of landscapes were zonal differences, and especially the morphological structure.

Backgrounds in the landscape structure of the territory are inter-tribal plains, floodplain terraces, floodplains of rivers. Subdominant tracts are, first and foremost, numerous wet and swampy cavities, sand dunes and oases, separate morainic hills, as well as slopes, mostly gentle; proluvial-diluvial plumes; relatively poorly developed erosion grid (mostly hollows), drainage deprivation at its peaks, karst funnel. The main role in their formation is played by moraine-water-glacial deposits (mostly sandy with the inclusion of debris of crystalline rocks, gravel and pebbles, rarely - clay), ancient alluvial and alluvial sand and loam deposits.

The landscape-geochemical structure directly depends on the complexity of the landscape structure, which caused the originality of landscape-geochemical and biochemical processes. The geosystems of RNPP 30-km zone belong to six geochemical classes, distinguished by typomorphic elements: acid (H^+) - 22.6 %, acid gley (H^+, H^+ -Fe^{2+}) - 21.9 %, gley (H^+ -Fe^{2+}) – 50 %, calcium gley (Ca^{2+}|H^+-Fe^{2+}) – 2.5 %, calcium sulfate (H^+-Ca^{2+}) – 0.4 %, calcium acid-gley (Ca^{2+} H^+ ,H^+-Fe^{2+}) – 0.3 %.

Half of the territory of the geosystems within RNPP 30-km zone belongs to the gley-type class. RNPP had little influence on the change of water and physical properties of adjacent soils due to changes in the level of groundwater during its construction. It is possible to talk about the joint influence of RNPP and land use in case of RNPP emissions getting to agricultural land, when, as a result of agrochemical treatment, the contaminating agents penetrates down the profile of the soil to the depth of the plow sole and evenly shuffles. In fact, there is an acceleration of the migration process of those insignificant quantities of contaminating agents, which can settle on the ground due to emissions from the NPP.

Assessment of NPP impact on the environment is organized by monitoring the radiation parameters at the control points. A network of sedimentation posts has been adopted as the control points. This network is chosen taking into account the winds in the vicinity of RNPP. In accordance with the requirements stipulated in the "Recommendations on Dosimetric Control in the Vicinity of the Nuclear Power Plant", the check of soil and vegetation is conducted at these points as well.

The selection of grain, vegetables and milk is carried out at 12 base points. The doze control is done at Manevychi town.

The ingestion of radionuclides into a human body occurs in one of the food chains, in this case, the one associated with the soils.

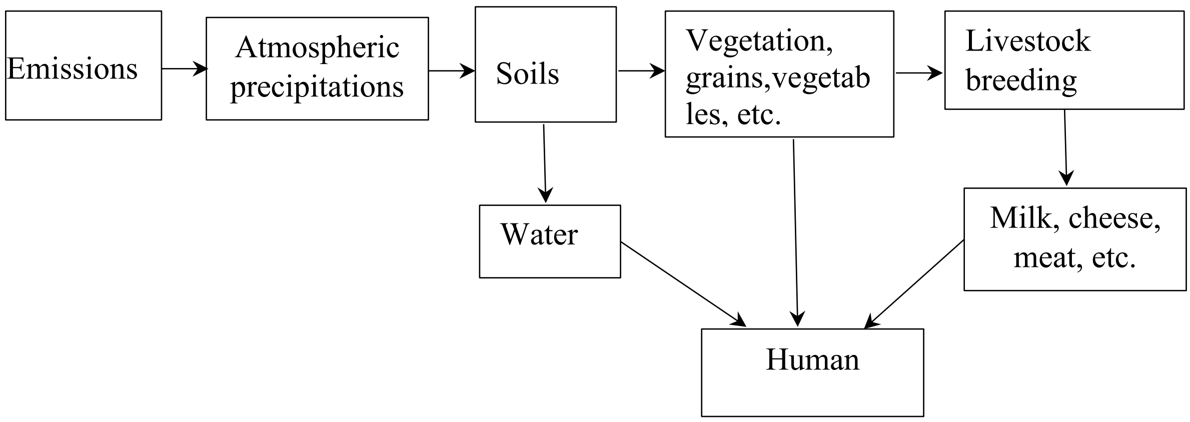

Fig.1.2. The food chain of radionuclide intake to the human body

In the period from 1976 to 1979, activities were carried out in the area of RNPP construction on the study of the radiation status of environmental objects before the commissioning of the nuclear power plant - the definition of the so-called "zero background". The results of these studies are used to assess the radiation exposure of RNPP units to the environment during the entire period of its operation.

According to the “zero background”:

- the specific activity of aerosols in the atmospheric air was in the range: ^{137}Cs – 1.11E-05÷5.92E-05 Bq/m^3; ^{90}Sr – 1.48E-05÷1.11E-04 Bq/m^3;
- the total beta activity of atmospheric leaks was in the range: 7.4E+00÷3.29E+02 (Bq/m^3)/month;
- the content of ^{137}Cs in the conifer was in the range: 7.2E+00÷1.7E+01 Bq/kg; ^{90}Sr – 2.96E+01÷1.05E+02 Bq/kg;
- the content of ^{137}Cs in vegetation was in the range: 2.55E + 00 ÷ 9.55E + 01 Bq/kg;
- surface contamination of soil by ^{137}Cs prior to RNPP commissioning was in the range: 4.44E+02÷5.07E+03 Bq/m^2; ^{90}Sr – 2.96E+01÷1.05E+02 Bq/m^2;
- the specific activity of ^{137}Cs in milk before RNPP commissioning was in the range: 6.3E-01÷6.6E+00 Bq/l;
- the specific activity of ^{137}Cs in vegetables before RNPP commissioning was in the range: 1.5E-02 ÷ 2.0E + 00 Bq/kg;
- the specific activity of ^{137}Cs in grain crops before RNPP commissioning was in the range: 8.1E-01÷1.18E+00 Bq/kg.

1.3 Landscape characteristics

The area is geomorphologically divided into three parts: Polissia, Volyn Forest Plateau and Male Polissia located in the south between the towns of Radyviliv and Ostroh, where the spit of the Podolsk Hill with its heights of about 300 meters above the sea-level is plunged into it.

The location of the Rivne Region on the border of the Eastern European Platform and the Carpathian Geosynclinal Region resulted in a stormy and ambiguous flow of geological history, which was reflected in the heterogeneity of the tectonic structure and the formation of a fairly difficult complex of geological deposits on the greater part of it.

The territory of the region is located within two major platform structures - the Ukrainian Shield and the Volyn-Podilsky Plate, and only a small area on the north-eastern outskirts of the Rivne Region lies within the Pripyat deflection [33].

RNPP OA is located within the Volyn Polissia, which occupies the western part of the Ukrainian Polissia. Geographical position of this territory contributed to the formation of a typical Polissian nature: the predominance of moraine-fluvioglacial sandy deposits, domination of sod-podzolic soils, high swampiness and forestry. Specific features of this territory include the geological structure - domination among the indigenous rocks of chalk and marls of the upper Cretaceous age, and in the southern part - occurrence of basaltic rocks [34].

In the geomorphological structure of the territory, a significant proportion has alluvial plains, widespread hilly moraine, moraine-shady forms of relief, present denudation forms on the chalk basis and karst forms [35].

The surface of the studied area is a flat, slightly wavy lowland tilted to the north. The dismemberment of the territory is weak. Heights fluctuate within 160-200 meters.

The entire area of the observation area crosses the Styr River from southwest to north. The river network is very thick (tributaries of Styr and Horyn). There are many lakes in the studied area, the largest of which is the Bile Lake. The territory is rather swampy. Swamps and wetlands occupy more than 15 % of the territory.

RNPP 30-km zone is characterized by considerable forest cover. Forests and shrubs occupy about 40 % of the territory here. Among the forests, large areas are occupied by pine-oak and oak-hornbeam forests [35].

Within the studied area, twelve physical-geographical areas were allocated on the basis of the data of landscape studies.

The Bilozersky physico-geographical area is located in the northwest of the studied area. In geomorphological respect, the area is the second floodplain terrace of the Prypiat River, on which the Styr terraces and the smaller rivers flowing into the Pripyat are laid. Within the area, the dominant position is occupied by the ancient alluvial plains (super-terraces) of different levels, composed of sand. The surface is complicated by moraine hills (kamis), formed by sandy deposits with layers of rocky sand with sod-podzolic soils. The soil cover of this territory is characterized by sod-weakly- and medium-podzolic sandy, non-gleyed and gley-like, as well as turf-poded sandy soils under fresh, moist and damp forests and sub-forests. Also, peat and swamp soils and peatlands of various capacities are found, among which there are upper and transitional, as well as meadow-swamp soils under black-greenwood forests and sedge-swamp meadows.

Lower-Styr physical-geographical region is the area of distribution of modern alluvial plains (floodplains of the Styr River) of high and intermediate level, as well as low swampy sections of floodplain, composed of loamy and sandy alluvium with turf and meadow, dusty sand, sandy loam and loam, meadow-swamp sandy loam and loamy soils under grain-grass and splinter wet-grass meadows, mostly meliorated.

Komarovsky physical-geographical area is the terraced valley of the Styr River with the valley of its tributary - the Okonki River, which in its lower reaches forms a common terrace with the Styr River. The dominant position in the region is occupied by relatively high and low levels of the ancient alluvial plains, sometimes transient to the swamplands, among which there are dunes. The territory of the district is composed mainly of sand with sod-podzolic, turf-podzolic and gleyed sandy soils under fresh, moist and damp coniferous forests.

Upper-Styr physical-geographical region is the area of the spread of modern alluvial plains in the middle and low levels of the Styr River floodplain, composed of loamy and sandy alluvium with turf and meadow dusty, sandy and loamy soils, meadow-swamp, swampy and peaty-swamp, sandy-loamy and loamy soils under the grain-grass and meadow-grass meadows, mostly meliorated.

Telchinsky physical-geographical area extends from the center of the studied area to its southern border. Within the region, the dominant position is occupied by the ancient alluvial plains (floodplain terraces) of different levels, composed mainly of sand, with turf-podzolic ungleyed and gleyed, turf-lined sandy soils under fresh, moist and damp forests and subforests. Fragmentarily, there are ancient alluvial plains composed of loam deposits. They are characterized by the richest turf and turf carbonate dust-sand and sandy soils, which are occupied by agrocoenoses. The subordinate position is occupied by areas of low marshy terraces and floodplains of small rivers and streams with meadow-marsh, peat-marsh soils and peatlands of varying power under black alder forests and sedge-bilberry-meadows. The proliferation of wetlands and dry basins, including karst origin is significant in the area.

Polytskyi physical-geographical area occupies the south-eastern part of RNPP 30-km zone. The landscapes are low among the annual plains within it, leveled and hilly, somewhat wetlands. They are composed of water-ice sands with sod-podzolic, mainly dust-sand and sandy soils, which are characterized by significant fertility and therefore largely plowed. The area is also characterized by the presence between the annual plains, sandy, near water-glacial and lake loam deposits, with turf-podzolic sandy and sub-sandy soils of varying degrees of gleying, which are characterized by rich conditions of habitat (sub-oakery and oakery). Here, as well as in the previous area, there is a significant spread of depressions with peat-gley soils and peat-swamp under the moisture-rich-bellied-forest vegetation and black alder.

1.4 Effect on soils. Soil monitoring

Contamination of RNPP OA consists of a superposition of global precipitation, falls due to the ChNPP accident and falls caused by the aerosol emissions of RNPP operating units. The last source of pollution is so insignificant that virtually its allocation from total pollution is impossible and the confirmation of this is the spatial distribution of radiocaesium contamination around the plant, which does not correlate at all with the average ratio of winds for a given region.

Substantial environmental damage to land resources is caused by soil contamination with industrial waste and during chemicalization in agriculture. Man-made contamination of soils depends on the type of soil, the amount of entering contaminants. The soils of the area are characterized by high acidity, low humus content.

Lowly buffered few humus sod-podzolic soils are subject to significant contamination (including radionuclide). Under acidic conditions, contaminating agents are transformed into more mobile compounds migrating to lower layers and groundwater.

Heavy metals and residual amounts of pesticides in the soil are the result of human economic activity in general and agricultural production in particular. An increase in the content of toxicants in the soil leads to an increase in their concentrations in crops. Since plant products are unaltered in a person’s diet, dangerous chemicals and radionuclides get into the human body together with it. Many toxicants can lead to morbidity in humans.

Soil contamination is determined by the hazard class of individual toxicants. The classes of harm include:

I grade - arsenic, cadmium, mercury, selenium, lead, zinc, fluorine, benz(a)pyrene;

II grade - boron, cobalt, nickel, copper, molybdenum, antimony, chrome;

III grade - barium, vanadium, tungsten, manganese, strontium.

Their content in soils can be estimated in both gross and moving forms of elements.

Soil is a specific element of the biosphere, it not only accumulates toxic substances, but acts as a natural barrier. The barrier function of the soil as an element of the landscape consists in the ability to transform metal compounds, bind them in less accessible forms, thereby reducing their inputs to plants, and also in the ability to self-purify.

The natural buffer properties of the soils to the action of the pollutants have a certain limit. Therefore, when the soil is saturated with chemical components, it can become a source of secondary pollution for water bodies, atmospheric air, for animal feed and human food. Unlike other agents in the soil, there is no possibility of their rapid purification, so chemical pollutants can be stored in it for many years and, included in the ecological chains, cause long-term exposure to toxicants. This increases the risk of chronic intoxication.

Ensuring the conditions for the normal development of agricultural crops in conditions of growing pollution of the environment becomes a priority task. Successful resolution depends, in particular, on the effectiveness of monitoring the flow of soil pollutants as the starting point of the food chain.

The functioning of the environmental monitoring system in the region is carried out in accordance with the Law of Ukraine “On Environmental Protection”, the Resolution of the Cabinet of Ministers of Ukraine No. 391 dated 30 March 1998 “On Approval of the Regulation on the State System for Environmental Monitoring” [10, 36].

Subjects of the environmental monitoring system in the region are specially authorized bodies of ministries and departments, regional state administration, enterprises, institutions and organizations that have appropriate laboratories with certificates for the measurement of environmental components, in particular:

1. State Ecological Inspection in the Rivne Region.
2. Rivne Complex Geological Party of the State Enterprise “Ukrainian Geological Company”.
3. Rivne Regional Department of Water Resources (Rivne Hydrogeological and Reclamation Expedition).
4. Rivne Regional Center for Hydrometeorology.
5. SE “Rivne Regional Laboratory Center of the Ministry of Health of Ukraine”.
6. Rivne branch of the State Farmland State Criminal Department.
7. Center for the Organization of Radiological Control in the Agro-Industrial Complex of the Regional State Administration.
8. Food Safety and Veterinary Health Directorate of the State Committee for Civil Service of Ukraine in the Rivne Region.
9. Main Directorate of the State Geocadastre in the Rivne Region.
10. Rivne Regional Department of Forestry and Hunting.
11. RRPCE WWS “Rivneoblvodokanal”.
12. RNPP (in NPP CA and OA).

Environmental monitoring of the territory in the region is implemented through independent departmental monitoring networks in accordance with its functional tasks for departmental programs and work plans. The monitoring entities monitor the state of the components of the environment, in particular [33]:

- State Ecological Inspection in Rivne Region:
- sources of industrial emissions in the atmosphere by regional enterprises and emissions of mobile sources (content of pollutants);
- sources of discharges in sewage of regional enterprises and their influence on the surface water objects of the region (hydrochemical indicators);
- soils (content from pollutants).

Rivne Complex Geological Party of the State Enterprise “Ukrainian Geological Company”:

- groundwater and interlayer water (hydrogeological, hydrochemical research);
- exogenous geological processes (species and spatial characteristics, activity of manifestation).

Rivne Regional Department of Water Resources (Rivne Hydrogeological and Reclamation Expedition):

- surface water in border sections, in KhNPP and RNPP zones of influence (radiological and hydrochemical observations);
- sources of discharges in RNPP sewage waters (radiological observations);
- lands reclaimed and adjoining to them (ecological and land reclamation observations).

Rivne Regional Center for Hydrometeorology:

- hydrometeorological conditions and phenomena, including natural;

- atmospheric air, atmospheric exits (radiological observations);
- surface waters of the Horyn, Ustia (hydrochemical observations) Rivers, in KhNPP and RNPP zones of influence (radiological observations);
- Soils in KhNPP and RNPP zones of influence (radiological observations).

State institution "Rivne Regional Laboratory Center of the Ministry of Health of Ukraine":

- atmospheric air in settlements and zones of industrial objects placement (underfactual observations);
- surface water of water bodies exposed to the greatest anthropogenic impact (sanitary-chemical, bacteriological and radiometric studies);
- underground sources and objects of centralized water supply (sanitary-chemical, bacteriological and radiometric studies);
- soils (sanitary-chemical bacteriological studies, heavy metal salts, pesticides).

Rivne branch of the State Institution "State Crop Protection":

- Soils of agricultural lands (toxicological and radiological studies).

Center for the Organization of Radiological Control in the Agro-Industrial Complex of the Region:

- livestock products at agricultural enterprises and private farms of the population of six radioactive contaminated areas of the region (radiological studies);
- plant production in agricultural enterprises and private farms of the region's population (radiological studies).

Food safety and veterinary safety department of the State Committee for Civil Service of Ukraine in the Rivne Region:

- products and raw materials of animal origin, feed, life-style animal diagnostics (radiological studies);
- food products and food raw materials (toxicological and radiological studies).

The Main Directorate of the State Geocadastre in the Rivne Region carries out the current accounting of land for the purpose of studying the structure of land use, the transformation of lands depending on their intended purpose, the state and quality of soils, the state of vegetation, the restoration of disturbed lands, the state and use of land resources, and the preparation of statistical reports on the availability of land and their distribution by owners, land users, lands and types of economic activity.

Rivne Regional Department of Forestry and Hunting:

- forest plantations of the region (forest-pathological surveys);
- soils in forests (radiological control);
- forestry products (radiological control).

RRPCE WWS "Rivneoblvodokanal":

- drinking water of centralized water supply networks (content of pollutants);
- surface water above and below the discharges of the treatment facilities of the enterprise and its sections (hydrochemical determinations);
- sewage from the treatment facilities of the enterprise and its sections (hydrochemical determinations).

The generalization of monitoring observation results (collection, processing, systematization and analysis of information) from entities of the state environmental monitoring system is carried out by the Department of Ecology and Natural Resources of the Rivne Regional State Administration.

Monthly, on the basis of data of environmental monitoring subjects, the information arrays of the computer bank of environmental data obtained from the information systems are updated to present operational and retrospective information on the state of the environment and natural resources.

The regional study system for the environment and the monitoring program in 2016 are presented in Tables 1.4 - 1.5.

Table 1.4. Environmental monitoring system

No.	Subjects of environmental monitoring	Quantity of control points, units								
		Atmospheric air	Stationary sources of emissions into the atmospheric air	Surface waters	Sources of discharges in surface water	Sea waters	Sources of discharges in sea water	Underground water	Sources of discharges into deep underground aquifers	Soils
Ministry of Environment and Natural Resources										
State Ecological Inspection										
1	State Ecological Inspection in the Rivne Region	-	49	69	36	-	-	-	-	20
State Agency of Water Resources										
2	Rivne Regional Department of Water Resources (Rivne Hydrogeological and Melioration Expedition)	-	-	17	-	-	-	54	-	2167
Ministry of Emergency - State Hydrometeorological Service of Ukraine										
3	Rivne Regional Center for Hydrometeorology	9	-	9	-	-	-	-	-	21
Ministry of Health										
4	SE “Rivne Regional Laboratory Center of the Ministry of Health of Ukraine”	68	-	66	-	-	-	782 wells	-	103
Ministry of Agrarian Policy										
5	Rivne affiliate of SE “State Soil Protection”	-	-	-	-	-	-	-	-	30
Ministry of Regional Development, Construction and Housing and Communal Services										
6	RRPCE WWS “Rivneoblvodokanal”	-	-	6	4	-	-	67 wells	-	-

Table 1.5. Environmental monitoring under regional programs

No.	Name of the regional (local) environmental monitoring program	Subjects of environmental monitoring involved in the implementation of programs	Key recommendations provided by the implementation of regional programs
1	Monitoring program for radioactive contamination of the environment in the area of operating nuclear power plants (on the network of the State Hydrometeorological Service of Ukraine within the Rivne and Khmelnitsky regions)	Rivne Regional Center for Hydrometeorology	Gamma-survey of terrain at sampling points of the soil (exposure dose rate of γ-radiation), sampling of soil and water (γ-emitting radionuclides ^{137}Cs, ^{40}K)
2	Quality improving program for basic monitoring of pollution and environmental monitoring on the base network of the State Hydrometeorological Service of Ukraine (within the Rivne region and under atmospheric conditions within the 8 western regions of Ukraine)	Rivne Regional Center for Hydrometeorology	Daily measurement of the exposure dose rate of γ - radiation; sampling of atmospheric precipitation (total β-activity once every two days); expeditionary surveys of the radiation situation in the NPP areas (γ-emitting radionuclides ^{137}Cs, ^{40}K in water samples, soil, atmospheric deposition)
3	State Hydrochemical and Radiological Monitoring Program of the Dnipro Basin	Rivne Hydrogeological and Melioration Expedition	Assessment of surface water quality by hydrochemical and radiological indices
4	Monitoring program for land reclamation and adjacent land	Rivne Hydrogeological and Melioration Expedition	Level mode forecast. Estimation of the land melioration state of dehydrated agricultural lands and technical condition. Assessment of soil fertility. Determination of soil acidity. Assessment of the quality of soil, drainage and surface water by hydrochemical parameters on drained lands
5	Ecological and agrochemical certification of agricultural lands	Rivne branch of SE “State Crop Protection”	Compilation of agrochemical certificates for assessing the land fertility; compilation of potatoes content of nutrients and different types of pollutants; development of design and estimate documentation of chemical melioration on liming of acid soils; development of recommendations for the use of fertilizers

No.	Name of the regional (local) environmental monitoring program	Subjects of environmental monitoring involved in the implementation of programs	Key recommendations provided by the implementation of regional programs
6	Dosimetric certification of settlements in the region	Rivne branch of SE “State Soil Protection”	The contamination of soil by radionuclides is identified to calculate radiation doses for the public

Rivne branch of SE “State Soil Protection” carried out the agrochemical certification of agricultural lands, the results of which showed that heavy metals significantly affect the sanitary and hygienic state of the soil cover. The analysis of the data on the content of roughly fixed forms of heavy metals indicates that their concentration varies within: cadmium – 0.13-0.48 mg/kg, lead – 5.43-100.0 mg/kg of soil. The content of heavy metals in the Polissia is slightly lower and is about: cadmium – 0.28 mg/kg of soil, lead – 5.43-6.25 mg/kg of soil.

The state Environmental Inspectorate in the Rivne Region analyzed 16 soil samples from 19 objects, including enterprises, agricultural lands and border posts with the Republic of Belarus for 26 indicators.

The sampling points are listed in Table 1.6.

Table 1.6. Sampling points in RNPP region

Sampling point	Distance, km	Azimuth, ⁰	Location radius	Atmospheric air	Atmospheric precipitations	Soils	Vegetation	Snow	Conifer	Grain	Vegetables	Milk
Units 3, 4 Checkpoint	0.4	140	A									
Units 1, 2 Checkpoint	0.7	270	A									
Polonne	1.2	172	A									
Makeup pumphouse	1.4	190	A									
Equipment dep.	1.6	200	A									
ARMS	3.3	298	B									
Zabolottia[1]	3.8	122	B									
Ostriv	3.9	140	B									
Airport	4.3	20	B									
Tsminy	4.6	218	B									
Sukhovolia	5.4	80	B									
Stara Rafalivka	5.6	342	B									
Velyka Vedmezhka	6.9	254	B									
Nova Rafalivka	8.7	108	B									
Kostiukhnivka	9.7	290	B									
Sopachiv	9.8	0	B									
Staryi Chartoryisk	10.5	180	C									
Liubakhy	10.9	57	C									

Sampling point	Distance, km	Azimuth, ^{0}	Location radius	Atmospheric air	Atmospheric precipitations	Soils	Vegetation	Snow	Conifer	Grain	Vegetables	Milk
Polytsi	13.8	118	C									
Velykyi Zheludsk	13.9	93	C									
Bilska Volia	14.0	340	C									
Manevychi	26.2	263	D									
Total of control points				16	22	22	22	22	20	12	12	12
Note[1]: Atmospheric air is sampled at OSG-750 (distance -1.4 km, azimuth-96^0, location radius “A” – from 0 to 3 km).												

1.4.1 Monitoring non-radioactive soil contamination

According to the Law of Ukraine “On Environmental Protection”, the composition and properties of the soil in RNPP region are being monitored.

RNPP performs the chemical control of soils in the NPP area and bottom sediments of the Styr River for the rational use of land resources, prevention of man-made pollution and contamination of land plots resulting from agricultural activities according to the legal requirements.

The current chemical control of soils is performed according to the chemical control schedule using standard measurement methodologies and qualification scope. The list of indicators of soil composition and properties is defined according to “GOST 17.4.2.01-81. Nature Conservation. Soils. Sanitary State” [37] taking into account production technology peculiarities.

Sampling is carried out twice a year: in spring after melting of snow cover and in autumn after fading of the vegetation.

RNPP performs analysis of soil composition and properties to ensure control over environmental contamination:

- control area;
- observation area;
- waste landfill;
- sludge storage pits;
- composition and peculiarities of bottom sediments (Styr River silt)

Results of chemical analysis are compared with MPC. The level of contamination by hazardous substances, for which MPCs are not currently established, is estimated in comparison with background values of these substances in soil, which makes it possible to properly assess soil contamination level in the area of RNPP industrial activities, and to take corrective measures if necessary.

The list of chemical parameters of soils and silts subject to control are presented in Table 1.7.

Table 1.7. Chemical parameters of soils and silts subject to control.

No.	Name	Measurement unit	MPC
1	Ammoniacal nitrogen	mg/kg	not regulated
2	Exchange aluminum	mg/kg	not regulated
3	Bicarbonate ion	mmol/100g of soil	not regulated
4	pH value	pH	not regulated
5	Iron (active forms)	mg/kg	not regulated
6	Potassium	mg/kg	not regulated
7	Calcium	mg/kg	not regulated
8	Cobalt (active forms)	mg/kg	5.00
9	Magnesium	mg/kg	not regulated
10	Manganese	mg/kg	1500.0
11	Copper (active forms)	mg/kg	3.0
12	Sodium	mg/kg	not regulated
13	Oil products	mg/kg	not regulated
14	Nickel (active forms)	mg/kg	4.0
15	Nitrates	mg/kg	130.0
16	Lead (active forms)	mg/kg	20.0
17	Sulfates	mg/kg	160.0
18	Specific electric conductivity	mS/cm	not regulated
19	Phosphorus (active forms)	mg/kg	not regulated
20	Chlorides	mg/kg	not regulated
21	Zinc	mg/kg	23.0

One of the areas of environmental monitoring at RNPP is to ensure laboratory control of soils in the area of sludge storage pits and waste sites at the waste landfills.

The results of environmental monitoring make it possible to properly evaluate the degree of impact of RNPP industrial activities on the state of soils within NPP location area. Analysis of long-term observations of the chemical composition and properties of soil showed that the MPCs were not exceeded by the active forms of the most environmentally significant chemical elements (responsible for the migration speed in food chains). If there are no MPCs for the substance, the comparison is being performed with background concentration.

1.4.2 Monitoring of radioactively contaminated soils and monitoring results

RNPP is located within the boundaries of the Ukraine-Belarus Polissia. In the sanitary and radiation plan, this area is characterized by the peat-bog soils and sod-podzolic soils formed on the sands, which facilitate the entry of ^{137}Cs from the atmosphere into the grass. The degree of ^{137}Cs transition into vegetation depends on the soil type and has the following schematic form: **sod-podzolic ⇒ red soil ⇒ alkaline and calcareous soil ⇒ grey soil.** As can be seen from the series, sod-podzolic soils least hold ^{137}Cs. The study of ^{137}Cs sorption and desorption processes demonstrated that sod-podzolic soils have the least ability to stable fixation of ^{137}Cs and have the ability to the highest mobility of this radionuclide in the “soil – solution” system. Acidic reaction, low content of humus, calcium, magnesium, iron, stable cesium and other elements are typical for such soils. The main fraction is large sand, which leads to a decrease in absorbing capacity. As a result, ^{137}Cs falling out of the atmosphere mainly enters ion-exchange reactions. As a consequence, it increases the likelihood of its transition into vegetation.

Soil samples were taken from the layer 0÷5 cm according to [38] to control surface contamination of soil by radionuclides within RNPP area. The samples were taken in the period April ÷ May in 22 control points and were measured by γ-spectrometers.

According to the zero background data [39], surface contamination of soil by ^{137}Cs before commissioning of RNPP was within the range of 0.44 ÷ 5.07 kBq/m^2; Sr-90 – 0.19 ÷ 2.92 kBq/m^2. According to the zero background data [40], contamination of soil by ^{137}Cs before commissioning of RNPP was within range (4.44-50.7)×10^2 Bq/m^2.

Soil samples were taken in accordance with requirements of the current radiation monitoring procedures to control the possible surface contamination of soils by radionuclides in the territories adjacent to RNPP.

The sampling is performed every year in April-May and studies are carried out using γ-spectrometers.

Table 1.8 presents data on specific soil contamination in the period from 2004 to 2016. The averaged values of activity are presented for each year.

The list of control points is presented in Section 2.5 “Environmental Radiation Monitoring” of Book 5 “Comprehensive Measures to Ensure Standard State of the Environment and Its Safety”.

Table 1.8. Specific soil contamination in the period from 2004 to 2016 [41].

Year	^{7}Be, Bq/m^2	^{40}K, Bq/m^2	^{60}Co, Bq/m^2	^{131}I, Bq/m^2	^{134}Cs, Bq/m^2	^{137}Cs, Bq/m^2
2004	4.11E+02	9.87E+03	<2.10E+01	<1.90E+02	4.96E+01	1.12E+04
2005	3.21E+02	9.97E+03	1.78E+01	<7.40E+02	3.53E+01	1.11E+04
2006	4.40E+02	9.20E+03	<2.50E+01	<1.90E+02	2.81E+01	7.99E+03
2007	2.00E+02	7.96E+03	<7.90E+00	<4.70E+01	1.47E+01	8.16E+03
2008	2.31E+02	8.98E+03	<9.60E+00	<7.90E+01	<1.40E+01	5.20E+03
2009	4.32E+02	1.06E+04	<2.10E+01	<1.0E+02	<3.20E+01	5.92E+03
2010	3.29E+02	9.53E+03	1.70E+01	<7.10E+01	<2.40E+01	4.95E+03
2011	1.56E+02	8.27E+03	<7.42E+00	<3.70E+01	<1.08E+01	3.47E+03
2012	2.02E+02	1.06E+04	<8.40E+00	<5.90E+01	<1.42E+01	5.72E+03
2013	2.62E+02	9.84E+03	<1.1E+01	<1.1E+02	<1.8E+01	4.67E+03
2014	1.48E+02	8.19E+03	<9.00E+00	<2.40E+01	<1.30E+01	4.19E+03
2015	9.20E+01	8.18E+03	<3.9E+00	<2.2E+01	<6.80E+00	3.43E+03
2016	1.!5E+02	8.91E+03	<4.2E+00	<2.4E+01	<7.20E+00	3.33E+03

During the reporting period, the maximum contribution to the specific activity of soil was caused by ^{137}Cs isotope that exceed the zero background over all reporting years, however such a contamination is explained by the consequences of the Chornobyl accident.

The ratio of the maximum activity of ^{137}Cs to the minimum activity observed within RNPP during the considered period reached several dozen times (21.2 in 2016), which indicates a significant heterogeneity of soil contamination.

Table 1.9 presents paired correlation coefficient and the ratio of ^{137}Cs and ^{134}Cs activities that are calculated for samples with ^{134}Cs activity higher than MDA. The age of mixture is defined taking into account the initial $^{137}Cs/^{134}Cs$ activity ratio of 1.6:1. The data of Table 1.7 indicate that soil contamination recorded in the observation area is due to the fallout of the fission products after the Chornobyl accident.

Table 1.9. Chornobyl ratio of $^{137}Cs/^{134}Cs$ activities in soil

Year	Paired correlation coefficient	Activity ratio	Estimated age of mixture
1994	0.98	21.1	8.2
1995	0.91	30.5	9.4
1996	0.96	42.8	10.5
1997	0.97	57.0	11.4
1998	0.96	74.1	12.2
1999	0.97	93.5	13.0
2000	0.98	128	14.0
2001	0.99	186	15.2
2002	0.89	180	15.1
2003	0.83	226	15.8
2004	0.74	267	16.4
2005	0.81	314	16.9
2006	0.54	284	16.5
2007	0.14	1280	21.4

Since 2002, there has been a change in the trend of the ratio of ^{137}Cs and ^{134}Cs activities related to decay of ^{134}Cs ($T_{1/2}$ = 2.064 years) and biochemical processes in soil.

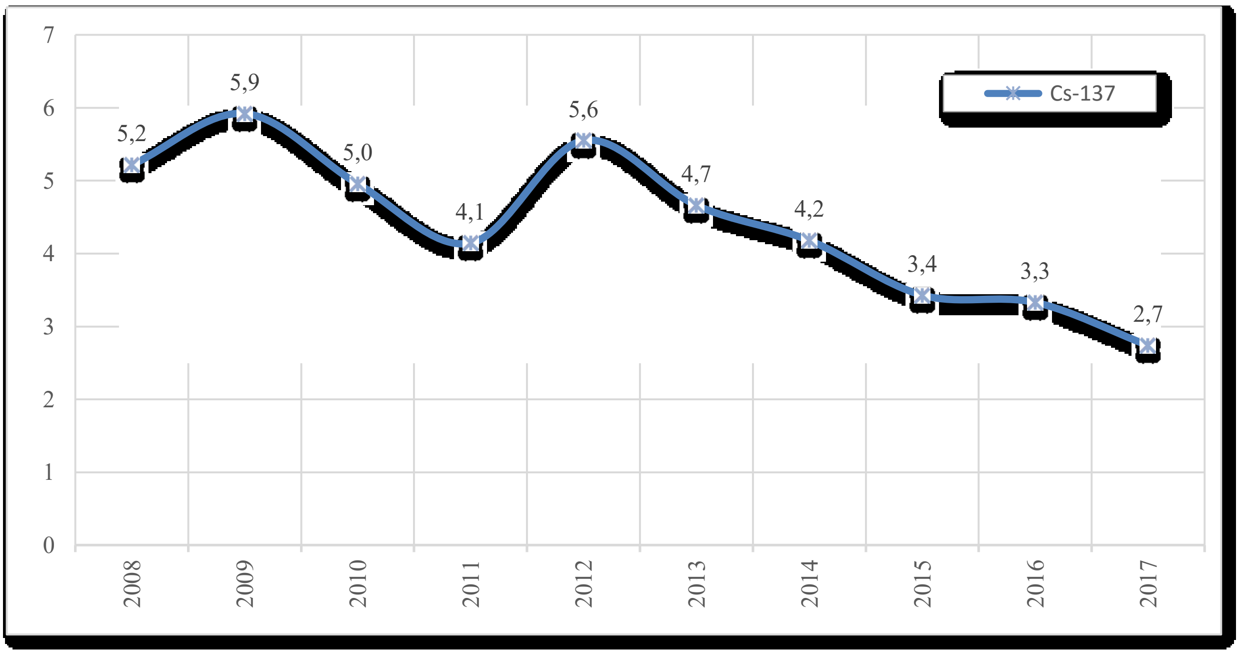

Figure 1.3 Surface activity of soil in the layer of 0÷5 cm within RNPP, kBq/m^2.

Table 1.10 presents information on the surface activity of different isotopes in soil samples.

Table 1.10. Surface activity of soil in the layer of 0÷5 cm, Bq/m^2 [42].

Sampling place	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<7.6E+01	1.11E+04	<3.4E+00	<5.7E+00	<1.6E+01	<6.2E+00	3.29E+03
Bilska Volia	<9.5E+01	7.57E+03	<3.1E+00	<5.7E+00	<1.7E+01	<5.9E+00	4.24E+03
Vel. Zheludsk	<1.4E+02	1.31E+04	<7.4E+00	<1.1E+01	<2.8E+01	<1.3E+01	5.41E+03
Vel. Vedmezhka	7.88E+01	7.97E+03	<3.0E+00	<4.6E+00	<1.2E+01	<5.1E+00	1.22E+03
Zabolottia	<1.0E+02	8.27E+03	<5.1E+00	<7.9E+00	<2.2E+01	<8.4E+00	4.59E+03
Varash	<1.2E+02	7.25E+03	<5.8E+00	<8.5E+00	<2.0E+01	<9.1E+00	6.27E+03
Kostiukhnivka	<1.1E+02	6.45E+03	<6.3E+00	<8.1E+00	<1.9E+01	<8.8E+00	4.17E+03
Liubakhy	<1.0E+02	9.19E+03	<3.7E+00	<6.2E+00	<2.0E+01	<6.3E+00	4.92E+03
Manevychi	<7.2E+01	7.71E+03	<3.2E+00	<6.3E+00	<1.2E+01	<5.9E+00	2.24E+03
N. Rafalivka	<1.0E+02	9.55E+03	<6.3E+00	<9.2E+00	<1.7E+01	<9.9E+00	3.85E+03
Equipment dep.	<7.4E+01	9.03E+03	<4.3E+00	<6.2E+00	<2.2E+01	<7.5E+00	6.09E+02
Polytsi	2.07E+02	1.05E+04	<7.1E+00	<9.0E+00	<2.3E+01	<1.1E+01	3.66E+03
Polonne	<8.4E+01	6.79E+03	<5.1E+00	<6.8E+00	<1.7E+01	<7.6E+00	2.36E+03
Rafalivka St.	1.27E+02	6.18E+03	<3.8E+00	<6.4E+00	<1.2E+01	<6.1E+00	1.39E+03
Sukhovolia	<8.7E+01	9.04E+03	<3.5E+00	<5.6E+00	<1.7E+01	<6.3E+00	3.22E+03
Sopachiv	<8.5E+01	6.51E+03	<6.1E+00	<8.0E+00	<1.8E+01	<8.4E+00	1.28E+03
Staryi Chartoryisk	<9.3E+01	1.01E+04	<3.8E+00	<6.4E+00	<1.9E+01	<6.9E+00	3.39E+03
Tsminy	<6.7E+01	7.33E+03	<3.3E+00	<5.7E+00	<1.1E+01	<5.9E+00	1.57E+03
Units 1, 2 Checkpoint	3.95E+01	9.16E+03	<2.3E+00	<3.2E+00	<6.2E+00	<3.5E+00	8.28E+02
Units 3, 4 Checkpoint	1.04E+02	9.97E+03	<4.0E+00	<6.3E+00	<1.3E+01	<7.3E+00	4.83E+02
Makeup pumphouse	7.75E+01	6.58E+03	<3.2E+00	<4.7E+00	<1.2E+01	<5.2E+00	7.06E+02
Airport	<6.3E+01	5.99E+03	<5.5E+00	<7.5E+00	<1.0E+01	<8.2E+00	4.95E+02
Amid, Bq/m^2	9.53E+01	8.42E+03	<4.5E+00	<6.8E+00	<1.7E+01	<7.4E+00	2.74E+03

The maximum value of ^{137}Cs surface activity was recorded in the sampling point "Varash" (A=6.27E+03 Bq/m^2), which is 1.2 times higher than the upper boundary of the range of data received in measuring the zero background. The ratio of the maximum value of ^{137}Cs surface activity to the minimum value was 13.0, which indicates the heterogeneity of soil contamination within RNPP area by this Chornobyl-origin radionuclide.

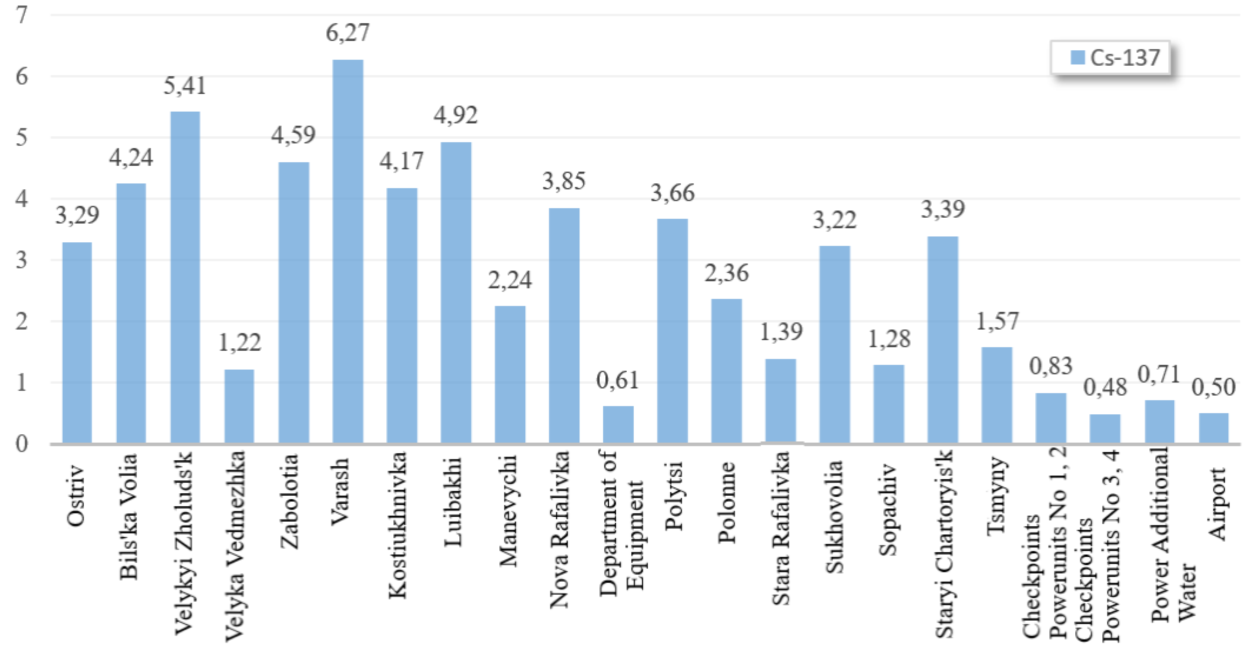

Figure 1.3. ^{137}Cs surface activity in soil of RNPP area in 2017, kBq/m^2.

1.4.3 Flora control

Natural vegetation has largely been preserved. The plowing in most of the territory is insignificant and varies from 10 % in the northern and eastern part to 20-25 % - in the western. Only in the central part, it reaches 43.5 %. Forests prevail in the vegetation, the average forest cover reaches 49.6 %. The swamps in the research area are numerous and differ in types of origin and in area.

Vegetation samples were taken in 22 control points at the beginning of the cattle grazing period. There was no ^{131}I recorded during the measurement of fresh vegetation samples.

According to the zero background data [39], the content of ^{137}Cs in vegetation before RNPP commissioning was within the range of 2.55E+00 ÷ 9.55E+01 Bq/kg.

Table 1.11. Specific activity of radionuclides in vegetation samples in 2017, Bq/kg

Point of control	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	8.03E+01	7.11E+02	<1.9E-01	<2.1E-01	<3.0E-01	<1.7E-01	2.12E+00
Bilska Volia	1.55E+02	9.02E+02	<7.4E-02	<1.0E-01	<2.2E-01	<1.1E-01	6.76E+00
Vel. Zheludsk	7.61E+01	6.67E+02	<2.0E-01	<2.2E-01	<6.4E-01	<1.9E-01	1.64E+00
Vel. Vedmezhka	9.90E+01	7.66E+02	<2.1E-01	<3.1E-01	<7.6E-01	<2.2E-01	4.36E+00
Zabolottia	7.85E+01	7.62E+02	<2.5E-01	<3.2E-01	<4.6E-01	<2.6E-01	4.84E+00
Varash	9.07E+01	6.74E+02	<2.5E-01	<3.2E-01	<4.1E-01	<2.5E-01	5.29E+00
Kostiukhnivka	1.03E+02	6.94E+02	<1.2E-01	<1.8E-01	<3.4E-01	<1.7E-01	2.70E+00
Liubakhy	1.45E+02	6.61E+02	<1.1E-01	<1.5E-01	<4.4E-01	<1.3E-01	3.28E+01
Manevychi	6.77E+01	8.18E+02	<3.9E-01	<4.9E-01	<8.9E-01	<3.6E-01	5.73E+00
N. Rafalivka	7.96E+01	5.01E+02	<2.3E-01	<3.2E-01	<8.4E-01	<2.7E-01	6.46E+00
Equipment dep.	4.07E+01	7.18E+02	<1.6E-01	<2.2E-01	<3.5E-01	<1.7E-01	5.77E-01

Point of control	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Polytsi	1.21E+02	8.57E+02	<3.2E-01	<4.5E-01	<1.3E+00	<3.6E-01	2.22E+00
Polonne	5.01E+01	6.56E+02	<3.2E-01	<4.2E-01	<4.5E-01	<3.0E-01	8.58E-01
Rafalivka St.	9.31E+01	5.53E+02	<1.8E-01	<2.5E-01	<4.7E-01	<2.5E-01	3.85E+00
Sukhovolia	9.92E+01	7.95E+02	<1.6E-01	<2.5E-01	<8.4E-01	<2.2E-01	2.58E+00
Sopachiv	5.47E+01	4.68E+02	<9.4E-02	<1.3E-01	<3.7E-01	<1.1E-01	8.18E+01
Staryi Chartoryisk	7.54E+01	6.63E+02	<2.2E-01	<3.4E-01	<9.3E-01	<2.6E-01	3.08E+00
Tsminy	6.26E+01	6.30E+02	<3.6E-01	<4.5E-01	<8.1E-01	<3.3E-01	1.29E+00
Units 1, 2 Checkpoint	8.42E+01	5.96E+02	<2.1E-01	<2.7E-01	<4.7E-01	<2.4E-01	9.04E-01
Units 3, 4 Checkpoint	8.83E+01	5.68E+02	<2.1E-01	<2.8E-01	<4.0E-01	<2.5E-01	2.40E+00
Makeup pumphouse	4.94E+01	7.95E+02	<2.1E-01	<2.7E-01	<3.5E-01	<2.1E-01	1.05E+00
Airport	9.75E+01	6.65E+02	<1.7E-01	<2.1E-01	<7.0E-01	<1.6E-01	2.91E+00
Amid	8.60E+01	6.87E+02	<2.1E-01	<2.8E-01	<5.8E-01	<2.3E-01	8.01E+00

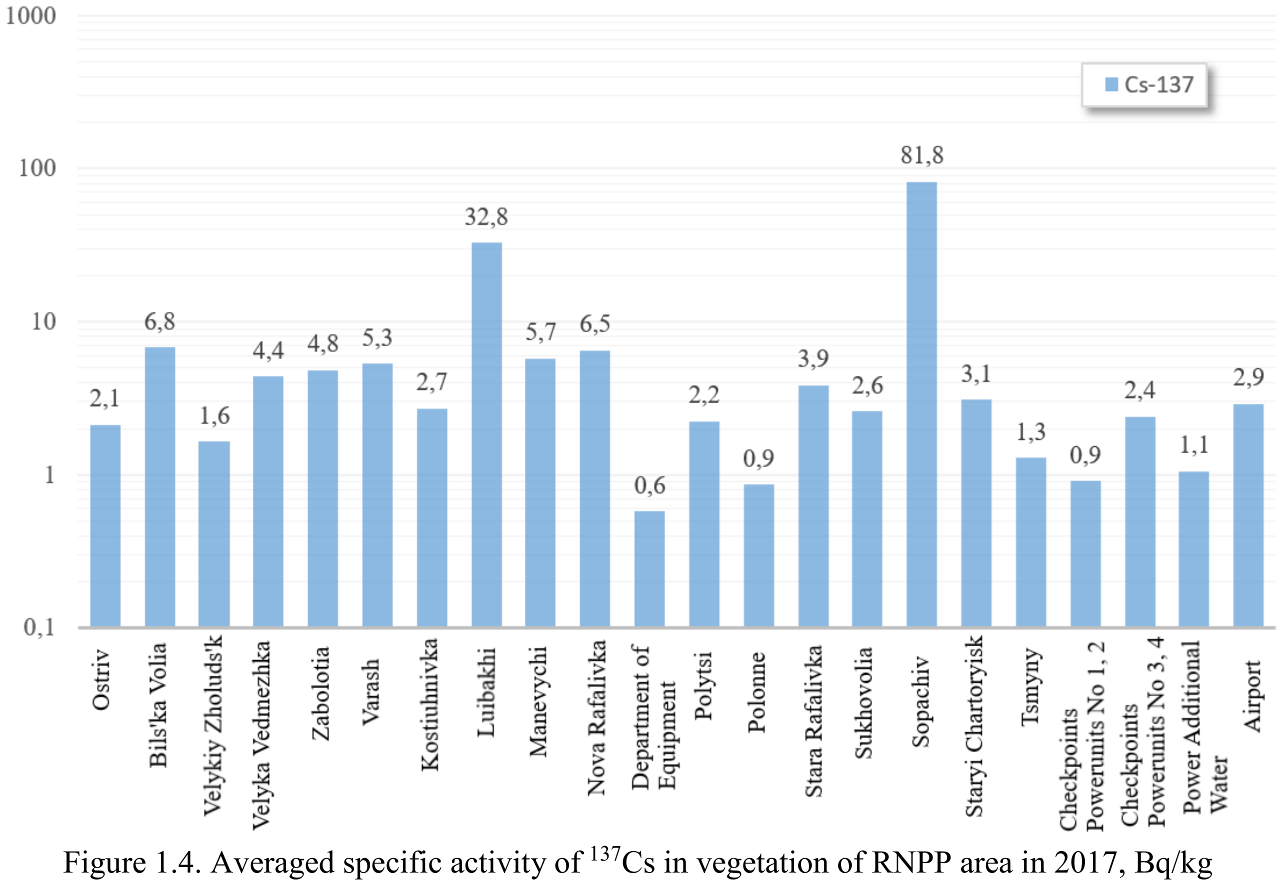

Figure 1.4. Averaged specific activity of ^{137}Cs in vegetation of RNPP area in 2017, Bq/kg

The averaged measurement results for all control points of the observation area demonstrate that the main contribution into the total specific activity of the vegetation belong to natural ^{40}K (A_{mid} = 687.0 Bq/kg) and cosmogenic ^{7}Be (A_{mid} = 86.0 Bq/kg) radionuclides. The average value of ^{137}Cs specific activity (A_{mid} = 8.0 Bq/kg) is 86 times lower than the value for ^{40}K. The maximum value of

^{137}Cs specific activity was recorded in “Sopachiv” control point – 81.8 Bq/kg that is less than the upper limit of specific activity received in the measuring of the zero background.

The ratio of the maximum value of ^{137}Cs specific activity to the minimum made 142, which indicates significant inhomogeneity of contamination. The activity of other man-made radionuclides in all vegetation samples in 2017 is less than MDA.

Many years of research have shown that emissions of radionuclides do not lead to increased activity of man-made isotopes. The accumulation of radionuclides in normal operation of the power plant in vegetation will not exceed the permissible standards and the contamination is currently due to Chornobyl-origin ^{137}Cs, which was studied in detail within the observation area. Speaking about the accumulation of radionuclides by plants, swamps are mostly contaminated as of today, and the highest concentration of radionuclides is found in moss, fungi and lower concentration is found in cranberries, blueberries.

People should be very careful when using forest and swamp products, in particular, fungi. Given that blueberries have a wider ecologic amplitude, the magnitude of its contamination with radionuclides can vary greatly depending on local conditions. Blueberries are collected and purchased quite intensively, so it is necessary to monitor them thoroughly for the content of radionuclides.

In recent years of control, the specific activity of fresh berries and mushrooms was as follows: cranberries 24.0 – 42.0 Bq/kg; blueberries 14.0 – 1400.0 Bq/kg (average activity 248.0 Bq/kg); mushrooms 11 – 780.0 Bq/kg (average activity 315 Bq/kg) at a permissible level for fresh forest berries and mushrooms 500 Bq/kg.

In general, based on the analysis of changes in the concentration of radionuclides with the distance from RNPP Units, it may be concluded that the radiation regime of NPP at its normal operation does not affect the vegetation, does not cause any changes at the level of individual plant species.

1.4.4 Conifer control

The conifer control is carried out annually in February at 20 points: CA – 3; OA – 16; background control (Manevychi) – 1. Since the conifer is a biological indicator, its samples show rather a high content of ^{137}Cs. The activity of this radionuclide is unevenly distributed over the control points, which indicates the presence of heterogeneous contamination of the surface layer of ^{137}Cs of the Chornobyl origin.

According to zero background data [39], the content of ^{137}Cs in the conifer before RNPP commissioning was within the range of 7.2E+00 ÷ 1.7E+01 Bq/kg; ^{90}Sr – 2.96E+01 ÷ 1.05E+02 Bq/kg.

Table 1.12. Specific activity of radionuclides in the conifer in 2017, Bq/kg

Point of control	^{7}Be	^{40}K	^{58}Co	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	2.55E+01	6.57E+01	<4.6E-02	<3.8E-02	<8.0E-02	<2.1E-01	<4.9E-02	3.62E+00
Bilska Volia	1.64E+01	5.97E+01	<1.5E-02	<1.3E-02	<2.5E-02	<9.4E-02	<1.6E-02	3.34E+01
Vel. Zheludsk	1.87E+01	5.18E+01	<1.4E-02	<1.3E-02	<1.9E-02	<6.0E-02	<1.6E-02	1.58E+00
Vel. Vedmezhka	1.97E+01	6.04E+01	<1.8E-02	<2.1E-02	<2.4E-02	<5.2E-02	<2.0E-02	2.11E+00

Point of control	^{7}Be	^{40}K	^{58}Co	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Zabolottia	3.15E+01	8.58E+01	<4.8E-02	<4.5E-02	<7.2E-02	<2.2E-01	<5.0E-02	4.88E+00
Varash	1.82E+01	6.87E+01	<3.8E-02	<3.1E-02	<6.3E-02	<1.0E-01	<4.0E-02	4.77E-01
Kostiukhnivka	2.36E+01	6.05E+01	<9.2E-03	<8.2E-03	<1.2E-02	<3.8E-02	<1.0E-02	2.14E+00
Liubakhy	2.63E+01	7.52E+01	<1.5E-02	<1.4E-02	<2.2E-02	<8.3E-02	<1.6E-02	7.89E+00
Manevychi	2.13E+01	5.80E+01	<2.5E-02	<2.3E-02	<2.9E-02	<1.4E-01	<3.1E-02	1.62E+01
N. Rafalivka	2.54E+01	6.84E+01	<1.0E-02	<9.6E-03	<1.3E-02	<4.7E-02	<1.1E-02	1.11E+00
Equipment dep.	3.18E+01	9.18E+01	<9.1E-03	<8.3E-03	<1.1E-02	<4.1E-02	<1.2E-02	3.31E+00
Polytsi	2.44E+01	7.86E+01	<5.6E-02	<5.9E-02	<1.1E-01	<1.5E-01	<6.0E-02	9.10E-01
Polonne	2.17E+01	6.79E+01	<1.1E-02	<9.5E-03	<1.6E-02	<5.5E-02	<1.1E-02	7.08E+00
Rafalivka St.	1.68E+01	4.36E+01	<3.4E-02	<3.3E-02	<6.5E-02	<1.7E-01	<3.7E-02	7.92E+00
Sukhovolia	1.78E+01	5.23E+01	<4.0E-02	<3.2E-02	<6.8E-02	<1.7E-01	<4.0E-02	2.13E+00
Sopachiv	1.85E+01	6.21E+01	<2.1E-02	<1.9E-02	<3.0E-02	<9.2E-02	<2.7E-02	4.49E+00
Staryi Chartoryisk	1.74E+01	4.95E+01	<3.5E-02	<3.2E-02	<4.5E-02	<1.2E-01	<3.7E-02	1.56E+00
Tsminy	2.53E+01	6.40E+01	<3.8E-02	<3.9E-02	<5.3E-02	<1.7E-01	<4.1E-02	9.50E+00
Units 1, 2 Checkpoint	1.99E+01	6.08E+01	<3.5E-02	<3.6E-02	<4.1E-02	<1.1E-01	<4.1E-02	9.40E-01
Units 3, 4 Checkpoint	2.06E+01	6.86E+01	<2.7E-02	<2.1E-02	<3.0E-02	<9.4E-02	<2.6E-02	6.52E-01
Makeup pumphouse	2.20E+01	6.47E+01	<2.7E-02	<2.5E-02	<4.1E-02	<1.1E-01	<3.0E-02	5.60E+00

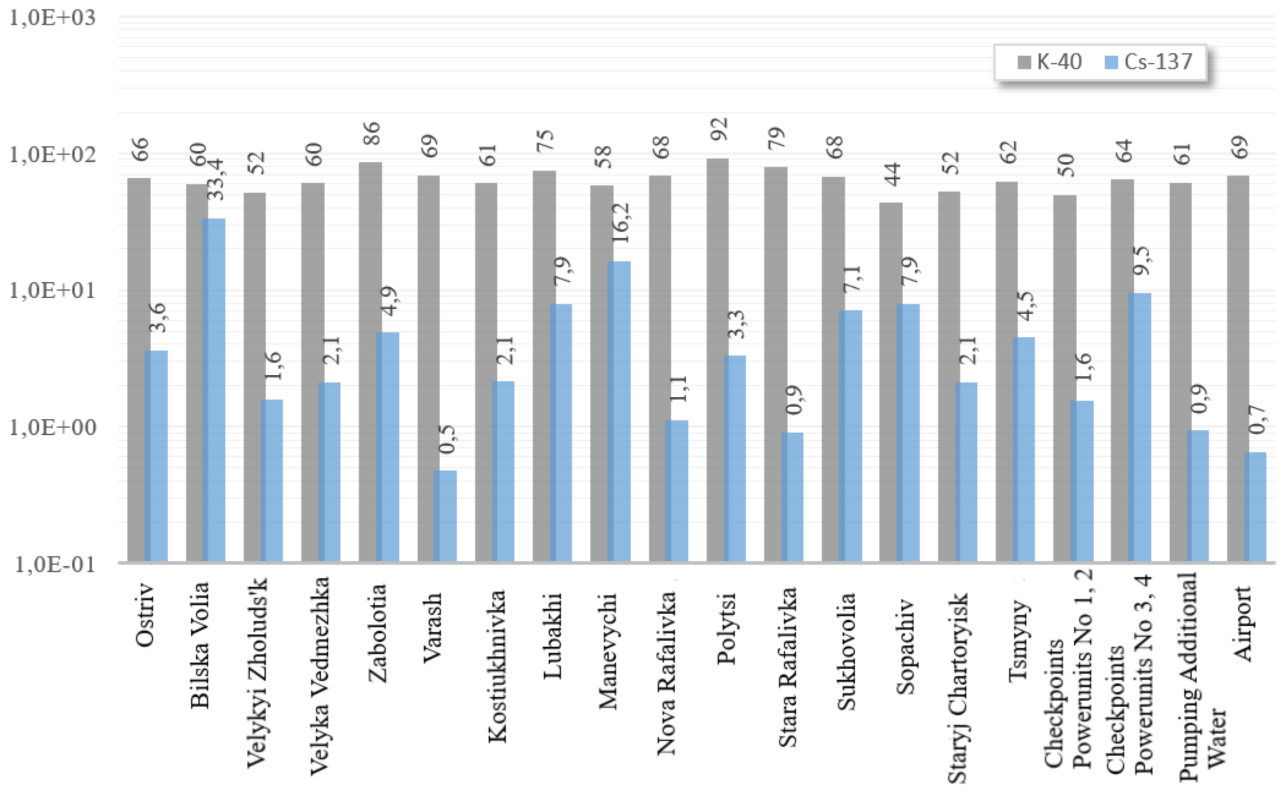

Figure 1.5. Averaged specific activity of ^{137}Cs and ^{40}K in the conifer of RNPP in 2017, Bq/kg

During the reporting period, the maximum specific activity of ^{137}Cs recorded in conifer samples taken in “Bilska Volia” point was 33.4 Bq/kg that is two times higher than values received in the period of measuring the zero background. The average value of ^{137}Cs specific activity of 5.6 Bq/kg complies with the range of zero background values.

The ratio of the maximum specific activity of ^{137}Cs to the minimum activity is 70.0 Bq/kg, which indicates a significant heterogeneity of contamination.

The conifer samples do not show the dependence of ^{137}Cs activity on the distance to RNPP, which confirms the Chornobyl origin of this radionuclide.

The activity of man-made radionuclides in all conifer samples in 2017 is less than MDA level.

1.4.5 Control of agricultural products

The main food products of the local population living near RNPP were under control: milk, vegetables and cereals. Samples were taken during the ripening period.

The samples were subject to γ-spectrometry analysis with the aim to detect man-made radionuclides, especially ^{131}I.

^{131}I was not detected in agricultural products in 2017. No other man-made radionuclides, except Chornobyl-origin ^{137}Cs, were detected. The increased content of this radionuclide in food is due to the higher value of the transition coefficient in the chain “soil-solution-plant”.

1.4.5.1 Milk control

Samples were taken in 12 settlements in private farms. The sample volume varies from 2.5 ÷ 3 l.

All milk samples were subject to γ-spectrometry analysis without radiochemical preparation. According to the zero background data, the activity concentration of ^{137}Cs in milk before RNPP commissioning was within the range of 6.3E-01 ÷ 6.6E+00 Bq/l.

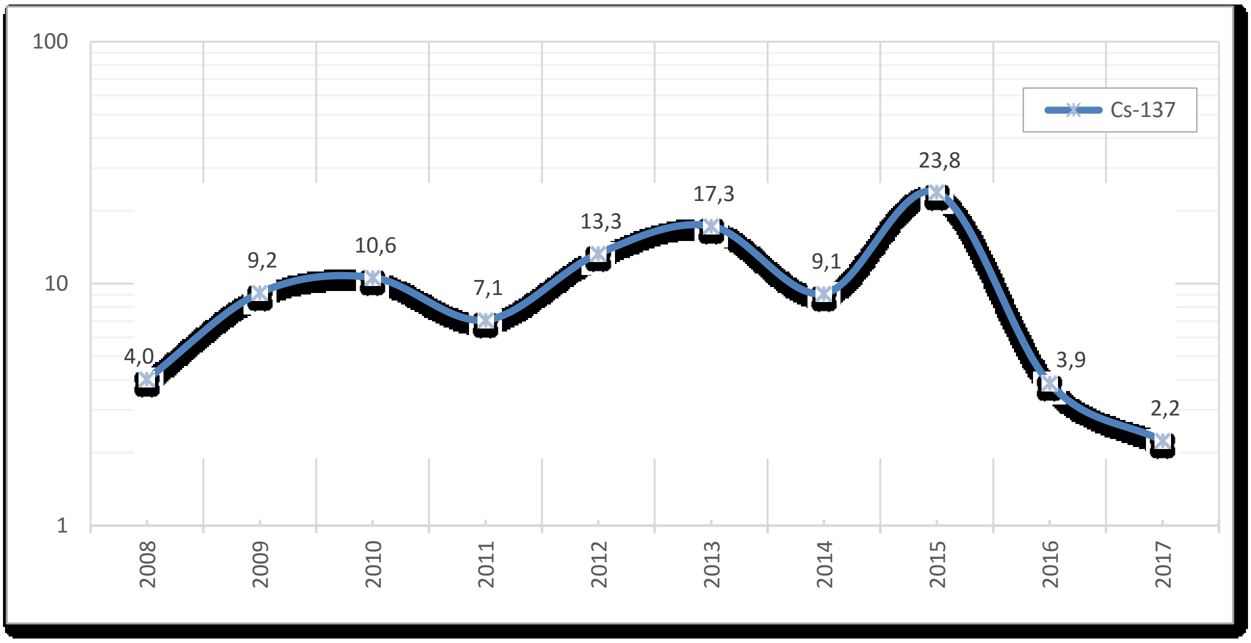

Figure 1.6. Averaged values of milk contamination in RNPP area, Bq/l

Table 1.13. Activity concentration of radionuclides in milk in 2017, Bq/l

Sampling point	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<8.7E-01	4.88E+01	<8.1E-02	<9.5E-02	<1.2E-01	<1.3E-01	3.74E-01
Bilska Volia	<6.4E-01	5.42E+01	<6.0E-02	<6.7E-02	<8.5E-02	<6.0E-02	3.85E+00
Velyka Vedmezhka	<6.7E-01	5.07E+01	<6.1E-02	<9.4E-02	<9.8E-02	<7.5E-02	1.21E-01
Zabolottia	<7.8E-01	5.24E+01	<8.0E-02	<1.3E-01	<9.8E-02	<1.0E-01	1.59E+00
Kostiukhnivka	<1.2E+00	5.10E+01	<1.4E-01	<1.5E-01	<1.5E-01	<1.3E-01	2.46E+00
Liubakhy	<4.7E-01	3.82E+01	<3.4E-02	<5.4E-02	<6.4E-02	<4.5E-02	2.94E+00
Manevychi	<8.4E-01	4.73E+01	<6.4E-02	<1.1E-01	<1.1E-01	<8.8E-02	4.95E+00
Polytsi	<1.2E+00	4.29E+01	<1.2E-01	<1.6E-01	<1.4E-01	<1.3E-01	2.96E+00
Stara Rafalivka	<5.8E-01	5.20E+01	<3.9E-02	<6.1E-02	<7.6E-02	<6.5E-02	2.29E+00
Sopachiv	<8.2E-01	4.27E+01	<6.0E-02	<9.3E-02	<1.2E-01	<9.4E-02	1.68E+00
St. Chartoryisk	<5.2E-01	5.25E+01	<4.8E-02	<7.7E-02	<8.2E-02	<6.0E-02	3.96E-01
Tsminy	<5.5E-01	4.06E+01	<4.3E-02	<6.7E-02	<8.2E-02	<6.0E-02	3.30E+00
Amid	<7.6E-01	4.78E+01	<6.9E-02	<9.6E-02	<1.0E-01	<8.6E-02	2.24E+00

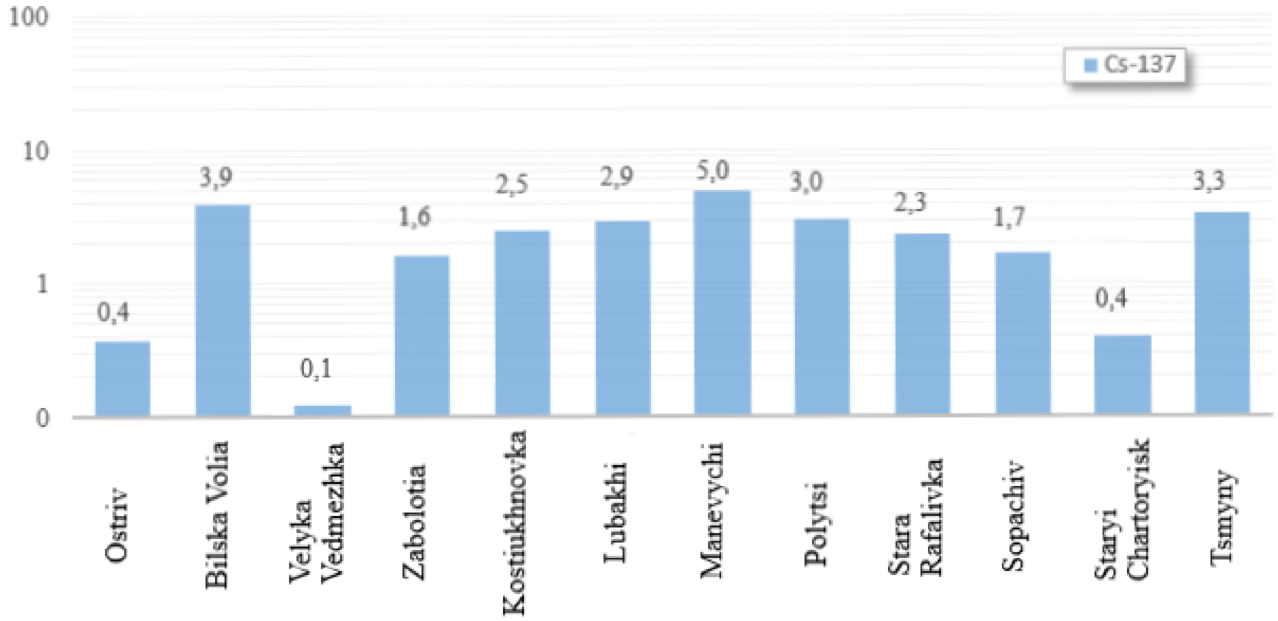

Figure 1.7. Activity concentration of ^{137}Cs in milk in RNPP area in 2017, Bq/l

The maximum content of ^{137}Cs was recorded in “Manevychi” control point and it was 4.95 Bq/l. The permissible content of ^{137}Cs in milk according to [43] is 100 Bq/l. The upper limit of the zero background for ^{137}Cs was not exceeded.

1.4.5.2 Vegetable control

Samples were taken in 12 settlements. The total weight of sampled potatoes reached 3 kg. According to the zero background data [39], specific activity of ^{137}Cs in vegetables before RNPP commissioning was within the range of 1.5E-02 ÷ 2.0E+00 Bq/kg.

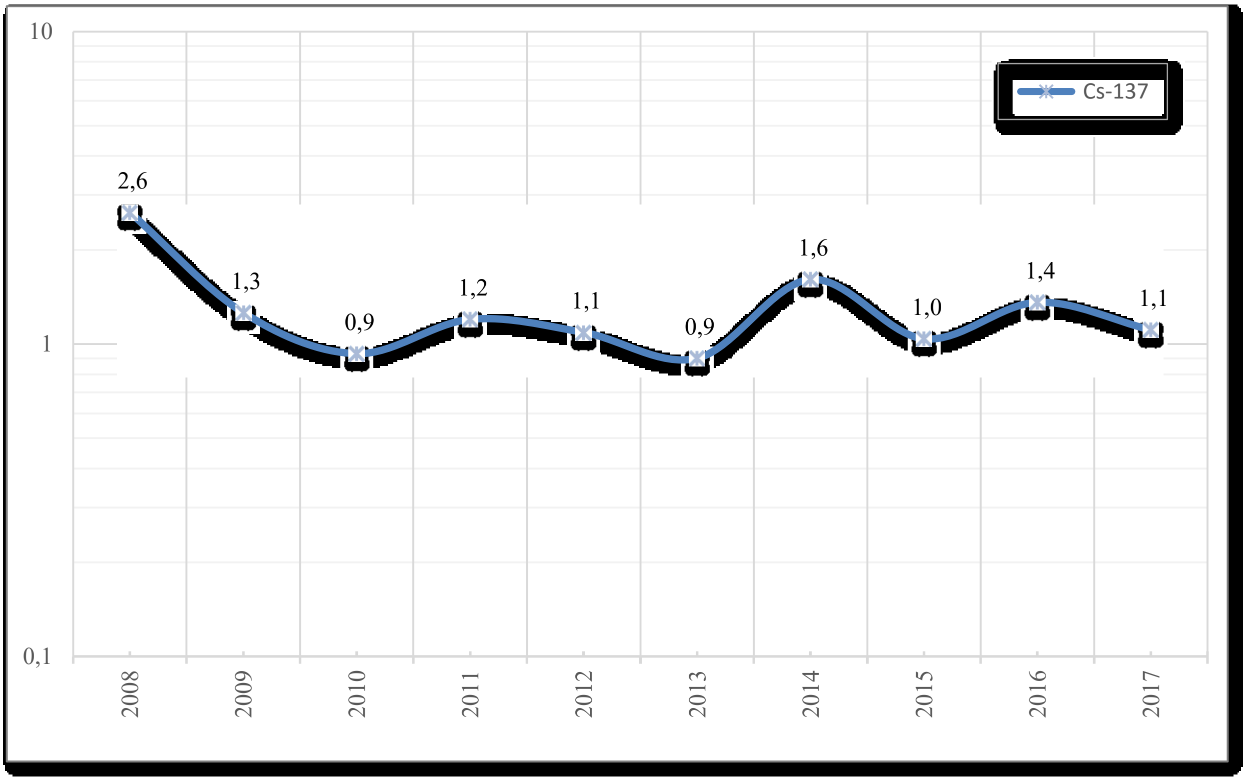

Figure 1.8. Averaged value of the specific activity of radionuclides in potatoes in RNPP area, Bq/kg

Table 1.14. Specific activity of potatoes in RNPP area in 2017, Bq/kg

Sampling point	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<2.1E-01	9.42E+01	<4.9E-02	<4.9E-02	<2.5E-02	<3.5E-02	4.41E-01
Bilska Volia	<4.0E-01	1.41E+02	<4.0E-02	<5.2E-02	<5.7E-02	<4.5E-02	2.78E+00
Velyka Vedmezhka	<2.5E-01	1.36E+02	<6.1E-02	<6.2E-02	<2.6E-02	<4.4E-02	1.90E-01
Zabolottia	<2.7E-01	1.10E+02	<2.7E-02	<3.4E-02	<4.5E-02	<3.1E-02	1.12E+00
Kostiukhnivka	<3.9E-01	1.19E+02	<4.0E-02	<6.4E-02	<5.3E-02	<4.3E-02	7.85E-01
Liubakhy	<2.8E-01	1.11E+02	<2.6E-02	<3.4E-02	<5.2E-02	<2.7E-02	4.00E+00
Manevychi	<2.3E-01	8.26E+01	<2.4E-02	<3.2E-02	<4.6E-02	<2.7E-02	8.12E-01
Polytsi	<3.5E-01	1.23E+02	<3.6E-02	<5.5E-02	<5.6E-02	<3.7E-02	1.28E+00
Stara Rafalivka	<2.7E-01	1.17E+02	<2.5E-02	<3.3E-02	<4.5E-02	<2.6E-02	4.87E-01
Sopachiv	<2.1E-01	9.87E+01	<2.4E-02	<3.1E-02	<4.4E-02	<2.5E-02	6.37E-01
Staryi Chartoryisk	<2.2E-01	9.93E+01	<4.9E-02	<5.2E-02	<2.5E-02	<3.6E-02	4.89E-01
Tsminy	<1.9E-01	1.26E+02	<4.0E-02	<4.2E-02	<2.0E-02	<2.9E-02	2.57E-01
Amid	<2.7E-01	1.13E+02	<3.7E-02	<4.5E-02	<4.1E-02	<3.4E-02	1.11E+00

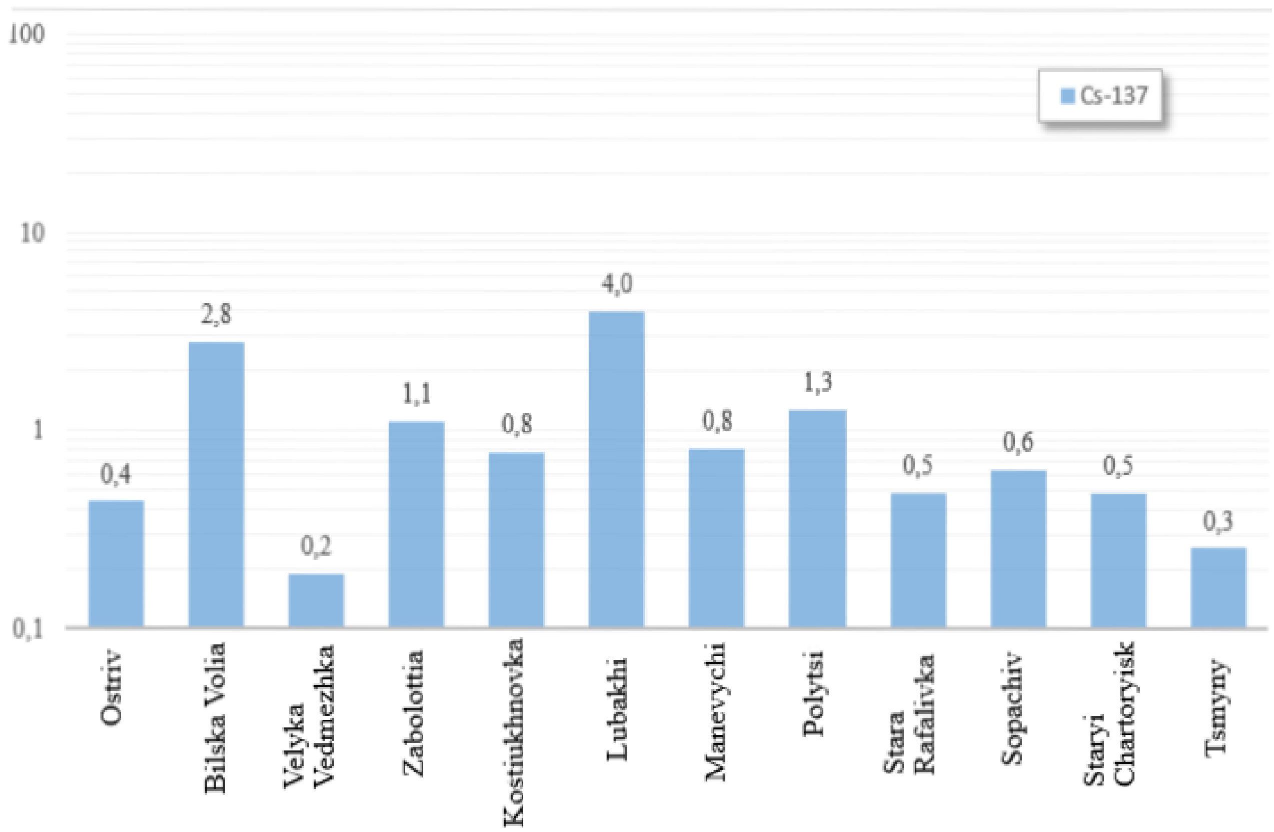

Figure 1.9. Specific activity of ^{137}Cs in samples of potatoes in RNPP area in 2017, Bq/kg

The maximum content of ^{137}Cs in potatoes in 2017 was recorded in "Liubakhy" control point – 4.0 Bq/kg. The permissible content of ^{137}Cs in fresh potatoes according to [43] is 60.0 Bq/kg. The exceeding of the upper limit of the zero background was recorded in two control points.

1.4.5.3 Control of grain crops

The samples were taken in 12 settlements of RNPP area. The weight of taken samples of each type of grain crops was 3 kg. The samples were subject to γ-spectrometry analysis without radiochemical preparation.

According to the zero background data [39], the specific activity of ^{137}Cs in grain crops before RNPP commissioning was within the range of 8.1E-01 ÷ 1.18E+00 Bq/kg.

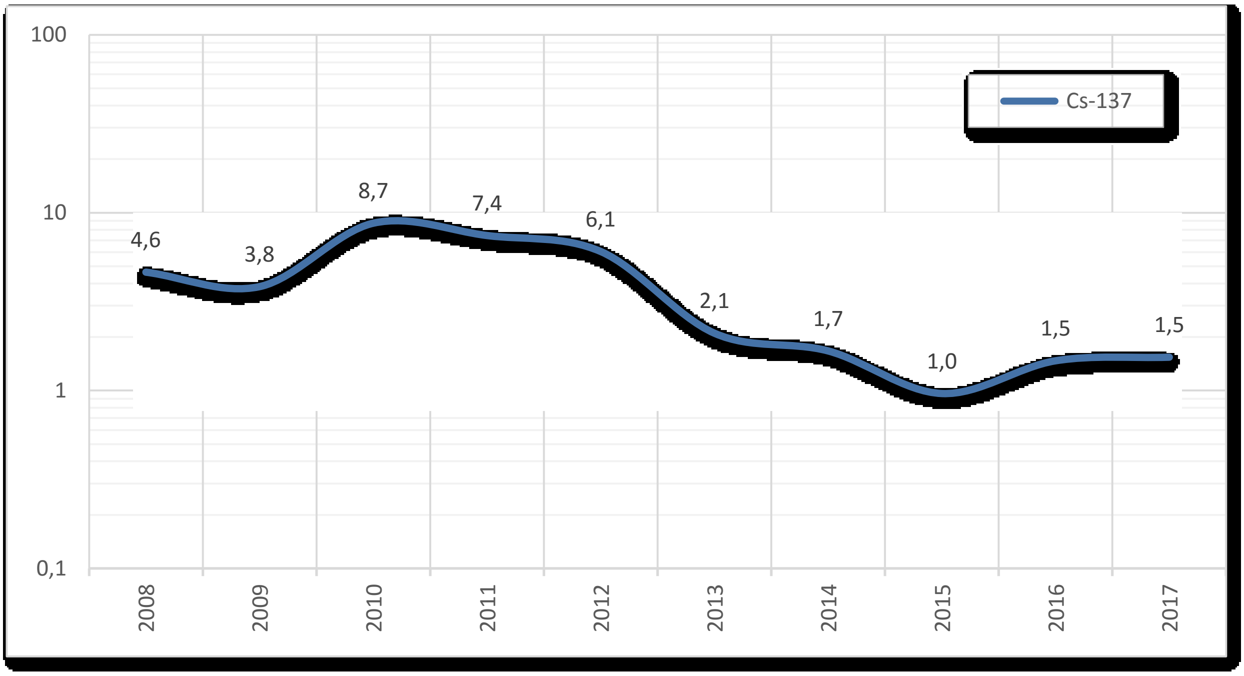

Figure 1.10. Averaged specific activity of ^{137}Cs in grain crops in RNPP area, Bq/kg

Table 1.15. Averaged specific activity in grain crops in 2017, Bq/kg

Point of control	Subspecies	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	134Cs	^{137}Cs
Ostriv	Wheat	4.33E+00	1.11E+02	<8.5E-02	<1.2E-01	<1.4E-01	<1.0E-01	2.69E-01
Bilska Volia	Wheat	2.64E+00	1.18E+02	<5.1E-02	<8.6E-02	<7.9E-02	<6.9E-02	1.69E-01
Velyka Vedmezhka	Wheat	5.31E+00	1.24E+02	<6.2E-02	<1.1E-01	<1.0E-01	<8.8E-02	2.83E-01
Zabolottia	Wheat	2.61E+00	1.31E+02	<8.1E-02	<1.2E-01	<1.4E-01	<1.0E-01	1.31E+00
Kostiukhnivka	Oat	1.07E+01	8.91E+01	<1.9E-01	<2.3E-01	<1.8E-01	<2.1E-01	4.07E+00
Liubakhy	Rye	8.75E+00	1.43E+02	<7.4E-02	<1.1E-01	<1.2E-01	<9.4E-02	6.43E+00
Manevychi	Wheat	2.17E+00	1.41E+02	<6.2E-02	<9.0E-02	<9.4E-02	<7.2E-02	2.71E-01
Polytsi	Oat	8.35E+00	1.46E+02	<9.7E-02	<1.3E-01	<1.5E-01	<1.3E-01	7.37E-01
Stara Rafalivka	Oat	5.36E+00	1.30E+02	<1.2E-01	<1.6E-01	<1.8E-01	<1.5E-01	1.86E+00
Sopachiv	Wheat	1.67E+00	1.08E+02	<8.5E-02	<1.0E-01	<1.5E-01	<1.0E-01	1.50E+00
Staryi Chartoryisk	Oat	1.60E+01	1.05E+02	<8.3E-02	<1.2E-01	<1.6E-01	<1.2E-01	1.44E+00
Tsminy	Wheat	1.3E+00	1.28E+02	<9.6E-02	<1.4E-01	<1.4E-01	<1.2E-01	1.97E-01
Amid		5.76E+00	1.23E+02	<9.1E-02	<1.3E-01	<1.4E-01	<1.1E-01	1.54E+00

Specific activity of ^{134}Cs is lower than MDA for all points of control. The ratio of the maximum specific activity of ^{137}Cs (“Liubakhy” control point – 6.43 Bq/kg) to the minimum activity was 38.0 and this indicates heterogeneous contamination of RNPP territory by this radionuclide.

Table 1.15 shows that activity of ^{137}Cs does not depend on the distance to RNPP, which means that ^{137}Cs has Chornobyl origin.

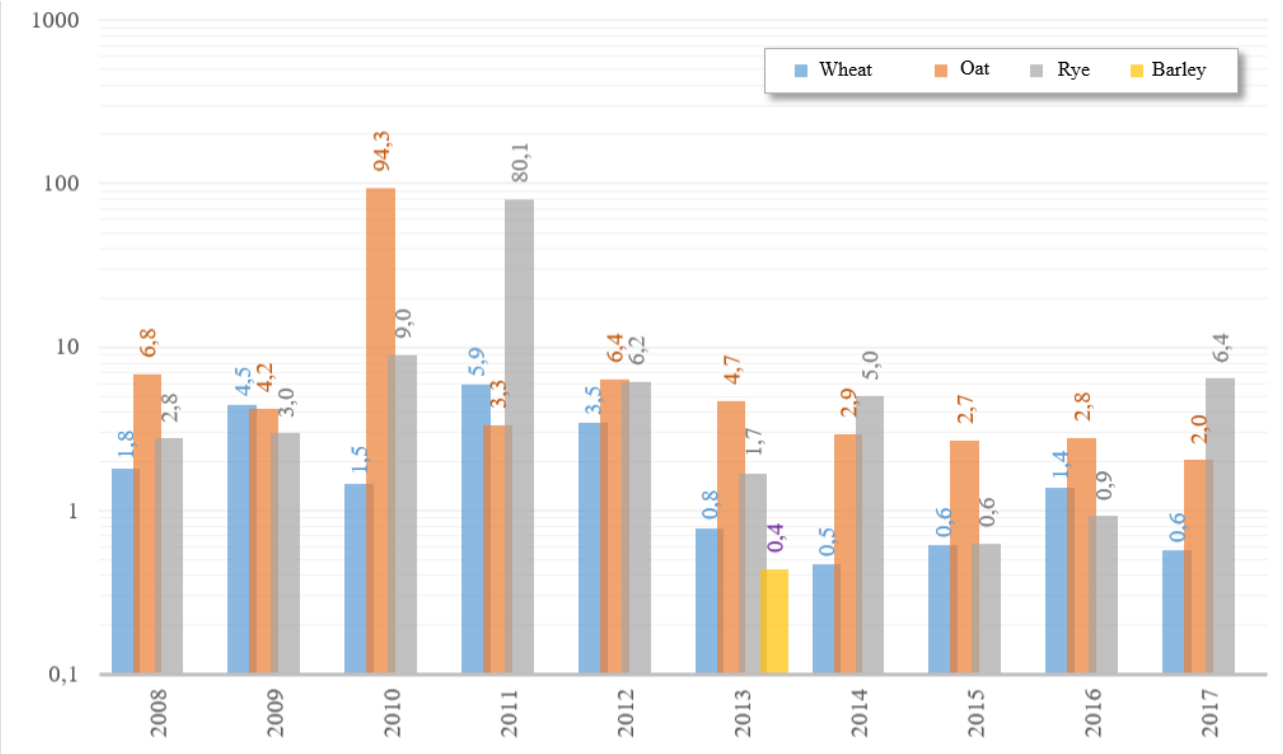

Figure 1.11. Averaged specific activity of ^{137}Cs in grain crops in RNPP area, Bq/kg

Figure 1.12. Averaged specific activity of ^{137}Cs in grain crops in RNPP in 2017, Bq/kg

For the majority of objects of the environment, the activity of radionuclides is within the range of zero background measurements.

There is heterogeneous contamination of environmental objects by Chornobyl-origin ^{137}Cs radionuclide observed in RNPP area.

In all taken soil samples in the layer of 0÷5 cm in 2017, the activity of ^{134}Cs is lower than MDA. The ratio of the maximum surface activity of ^{137}Cs to the minimum activity in RNPP area on virgin lands is 13.0, which indicates the heterogeneity of the contamination of soil surface level.

In 2017, the average value of ^{137}Cs specific activity in milk is 44.6 times less and in potatoes 54.1 times less than the permissible values established in the document “Permissible Levels of ^{137}Cs and ^{90}Sr Radionuclides in Food and Drinking Water. DR-2006” [43].

2 FLORA AND FAUNA. NATURE RESERVE OBJECTS

2.1 General characteristics of the natural system in the region

Geographical position of Rivne Region, its physical and geographical conditions contributed to the formation of a rich flora and fauna. The flora of the region has more than 1600 species of higher plants [44]. The flora is represented mainly by pine and oak-pine forests. Oak-hornbeam and oak forests are rarer. Alder forests are typical for the most humid places. The forest area of the region covers 36 %. The area of meadowlands concentrated in the floodplains of rivers is rather significant. The swamps occur mostly in floodplains and heads of small and medium-sized rivers, and in relict valleys. The area of open waterlogged lands is 5.3 % of the total area of the region. The swamps are a kind of natural systems, in the formation of which surface water and groundwater play an important role. They have original soils, vegetation and microclimatic conditions. They contribute to feeding of rivers and lakes with water. Lowland (autrophic) swamps fed by the surface runoff and groundwater. They are developed in lower relief on floodplains, old river areas, shores of lakes. They are waterlogged by organic and mineral substances. Swamp ecosystems are important places for the conservation of many species of plants and animals, including those in the Red Book of Ukraine. Highland (oligotrophic) swamps are much less often. They are fed mainly by the atmospheric precipitations, and therefore are poor in mineral substances. Among them, the most waterlogged massif of Ukraine is Kreminne located in the valley of the Lva River with a total area of more than 35 thousand hectares. The Rivne Region has a significant potential for biodiversity and can be considered as one of the most powerful reserves for the restoration of Ukraine's biodiversity. In order to preserve typical and unique natural complexes with all the combination of their components, including biological and landscape diversity, there are natural fund reserves created in the region.

The main threats to biodiversity are related to human activities. They consist in the destruction of natural habitats of animals and plant growth sites, their fragmentation and degradation (including contamination), to global climate change, environmentally unbalanced exploitation of species by human, the spread of alien species, the spread of diseases, etc.

The structure of land plots in Ukraine in general, and the Rivne Region in particular has undergone some changes in recent years, but generally preserved all the main features and, above all, the excessive ecologically unjustified agricultural development of the territory. The agricultural lands occupy 46.2 % of the region area and are mainly represented by arable lands for 71 %, and pastures and hayfields occupy only 24 % of agricultural lands, perennial plantings – 1.3 %, old lands – 0.4 %.

The destruction of natural habitats of animals and plant growth sites results due to plowing, deforestation, drainage or flooding of the territories, industrial, residential and suburban house construction, etc. There is a catastrophic decrease of wetland areas, grassland ecosystems, natural forest ecosystems, which are the basis for biodiversity conservation. Coastal areas and water protection zones of the rivers are environmentally vulnerable.

The territories and objects of the nature reserve fund suffer from significant anthropogenic pressure. In particular, one of the main causes of the impact of anthropogenic factors on the natural systems of the Rivne nature reserve is the close location of settlements and other places that are actively used by people. For the majority of reserve territory, activities are compensated by the protection zone of adjacent users (mainly forestries, whose territories adjacent to the reserve have a special regime and serve as a peculiar buffer), while a part of Biloozersk forestry is deprived of such a possibility. This territory is directly adjacent to the settlements Bilska Volia, Rudka, Ozirtsi and the local people have the free opportunity to enter the nature reserve territory, some domestic animals may enter the nature reserve, there is noise impact, etc. The recreation area at the Bile Ozero (the territory of the rescue station; RNPP lands with the tourist base; lands of the Volodymyrets state forestry), which also directly borders with the territory of the Biloozersk forestry of the Rivne nature reserve, permanently suffers from the anthropogenic impact.

In 2016, the active construction activities took place in the coastal area (fences, piers, caravans, amusement rides), as well as the arrangement of entertainment events because of new land users.

2.2 Flora

Forest resources are unevenly distributed in the region and are mainly concentrated in the northern part. In the forest cover, coniferous species of trees make 68 %, softwood trees make 21 % and hardwood trees make 11 % [44].

Pine (69 % of forested area), oak (10 %), birch (10 %) and black alder (8 %) dominate in the natural composition of forest tree species. Other breeds (hornbeam, aspen, ash tree, spruce, etc.) occupy small areas.

Spruce forests make a peculiar group of coniferous forests in the Rivne Region (in the Polissia area). Pine and spruce sphagnum forests where spruces and pines are mixed with black alders are typical for the most humid places.

Among the specific plant groups of the region, there are so called cretaceous forests (pine and oak-pine associations on the cretaceous deposits), whose fragments may be found in the forest-steppe part of the region, as well as plant associations of rock steppes (ground cherry, feather grass, cord-rooted sedge, alfalfa, etc.).

Old oak trees over 250 years old grow on an area of 54 hectares in the Ostrozhchyn settlement of the Ostroh district, on an area of 14 hectares in the Oleksandrivka settlement in the Dubne district. Oak plantations have been preserved in the Netreba settlement of the Rokytne district on an area of 52 hectares.

The second place after the forests is occupied by meadows, the total area of which exceeds 180 thousand hectares. The meadows are distributed throughout the territory of the region and are formed on the sites of cut mixed and deciduous forests.

A total of about 1.6 thousand species of plants are found in the Rivne Region. They form the green forests, colorful rugs of meadows and lawns, vast swamps. Among the plants there are many rare plants protected by law. Eighty species of vascular plants and fungi are listed in the Red Book of Ukraine. The species with an interesting biology – orchids and insectivores taken under protection in many countries around the world form a significant group of protected plants.

Tundra and taiga species in the flora of Ukraine remained from those times when the northern part of its territory was covered with the glacier. There are about two dozen of such species in the flora of the Rivne Region. For example, lycopodium whose creeping stems forming a green weave are abundantly covered with narrow hard leaves and which are similar to hairy animals. The scientific name "lycopodium" means "wolf's foot" in the Greek translation.

The territory of the 30-km zone of RNPP is located in the Volyn Polissia, which is the south-western edge of the mixed forest zone. The flora of the observed territory is characterized by typical features of Polissia nature: the predominance of swamps, meadows and boreal forests; the vegetation is a prominent boreal complex with the predominance of pine and mixed forests and mesotrophic swamps.

The flora of the studied territory is still largely preserved. The plowing is from 10 % in the northern and eastern part, 25-30 % in the western part and reaches 50-55 % in the central part. Forests dominate in the flora. The average forest cover is 40-50 %. The swampiness decreases from the north (20 %) to the south (0.5-4 %). Such pattern is not observed from the east to the west. The meadows are distributed relatively evenly and are concentrated both in river floodplains and on dry land. There are also watery vegetation and wastelands on sands. The share of synanthropic vegetation increased currently due to the presence of barren farm lands.

The main peculiarity of RNPP 30-km zone forests is their edaphic specificity due to predominant fluvioglacial and moraine sand deposits of light mechanical composition among the quaternary rocks. Pine forests dominate on such deposits. Deciduous species, primarily oak and hornbeam, are very limited. Their number is rather limited not because of climatic conditions favorable for their growth, but because of soil poverty. Therefore, the areas of deciduous forests are found only in some places in a complex with pine and oak-pine forests in the central and southern parts of the territory and they are confined to the moraine hills. Due to poor drainage of the most of the territory, alder forests became widespread. There are some traces of fir forests in the northern part of the territory. Birch forests, derivatives of pine forests, occupy relatively small areas. Forest felling is usually followed by the generation of pine breeding, which prevail among young and medieval plantings.

By the nature, pine forests (Pineta sylvestris) of the studied territories are related to sub-boreal pine forests [46] of broad-leaved coniferous forest belt, which includes the studied area. The flora of pine forests include boreal, nemoral species and species growing in the forest steppe. Boreal species dominate in the grassy-shrub layer or are found here in abundance.

Moss plays an important role in the pine forest coenosis. It often forms an overland tier. Moss is represented by genuine and sphagnum mosses.

Pine forests are represented by all species from lichen and sphagnum to complex broad-leaved pine enriched with nemoral species. Pine monodominant forests occupy a prominent place in the vegetation layer on the studied territory representing a lowland plain cut by moraine hills and sandy ridges. Different species grow on the elements of mesorelief, except relief lows mainly occupied by eutrophic or mesotrophic swamps. The largest areas area occupied by pleurocarpous moss and myrtillus pleurocarpous moss pine forests. The pure pine forests are less common or are distributed only in some places.

Oak-pine forests (Querceto roboris - Pineta sylvestris) are found throughout the studied territories, however, they are most widespread in the central and southern parts. Oak-pine forests are characterized by the presence of two-storied tree stand, undergrowth layer and relative species richness of grass-shrub layer combining boreal and nemoral species. They occupy the foot of slopes and leveled areas.

The tree layer of oak-pine forests is formed by pine (first sublayer) and oak (II sublayer). In addition to these species, there are silver birches, aspen in tree stand and alder in lowlands.

The undergrowth is presented only in old-growth frontier forests. It is usually formed by hazel, and buckthorn (Frangula) in lowlands.

The grassy-shrub layer of these forests is usually well-developed, more rich and varied than in monodominant pine forest coenosis. Boreal species usually dominate: blueberries, bracken, oxalis. Oak-pine myrtillus forests are the most widespread here, bracken-myrtillus and oxalis are less widespread.

In addition to the described main associations of forests of the pine formation, there are other that are less widespread: pine lichen forests, molinia, sphagnum, heather, cowberry, oak-pine pleurocarpous forests, convallaria forests, as well as pine and oak-pine juniper forests, fir-pine forests, pine forests rare for Polissia and Ukraine.

Oak forests (Querceta roboris) are distributed is small arrays on the territory of RNPP 30-km area among the pine and oak-pine forests. Oak forests grow at upper parts of the relief occupying the most sod and the richest types of sod-podzolic sandy soils.

The main arrays of oak forests are concentrated in the northern and central parts, where there carbonate rocks or basalts close to the surface. On such soils, the oaks are highly competitive and form pure high-yielding tree stands. The second dominant place is given to hornbeam. There are some occurrences of silver birch, aspen, linden.

The undergrowth is formed by hazel with insignificant amount of buckthorns. The grass stand is formed by nemoral and boreal species.

Among the oak forests, there are associations of acidophilic ecological and genetic link [46] formed on poor and very sour soils. These are hazel-myrtillus, hazel-quaking grass, hazel-beadruby oak forests, buckthorn-myrtillus, buckthorn-quaking grass oak forests.

Neutrophic oak forests grow on medium-rich acidic and slightly acidic soils and are represented by hazel-slender sedge, hazel-stellaria chickweed, hazel-goutweed oak forests.

There are some hornbeam positions in the most drained conditions for oak formation. In the grass stand, there are local nemoral species referred to the helophobe complex. Boreal species are plenty, but do not play an essential role.

Black alder forests (Alneta glutinosae) are found throughout the territory and are confined to the lows of watersheds and river valleys, especially to the terraces near flood plains. Soils under them are from sod-podzolic-gley soils to silt-gley soils. Plain alder forests are fed by running water and the hollow basin alder forests are fed by low flow and stagnant water. Such environmental conditions are optimal for alder growth. Tree stands are high-yielding formed by alder, aspen, downy birch, oak, ash. The undergrowth is often formed of buckthorn and sometimes of raspberries. Grass stand is formed of forest, hydrophilic, swamp, meadow-swamp species.

Depending on the species dominating in grass stand, alder forests have a typical spatial distribution in the 30-km zone.

In the northern part, sedge and fern stands are the most widespread. They refer to the alders of medium running water nutrition. Variable water regime and rich mineral nutrition contribute to the good growth of tree stand and development of relatively poor grass stand.

In the southern part, tall grass stands are the most widespread. They belong to strong running water nutrition. They territories are characterized by high soil fertility, rapid spring sewage, lowering the level of groundwater in the summer. The most common associations are nettle stands and Queen of the meadow stands. Tree stand is characterized as high-yielding, the undergrowth is spaced. There are meadow-swamp species in the poorly differentiated undergrowth. The moss cover is slightly represented.

In the northern part of the surveyed territory, there are small spruce forests (Piceeta abietis). Their characteristic features include the high closeness of crowns and, as a result, strong shading, loose soil structure, the absence of a clearly defined layer of undergrowth and poorly developed grass-shrub layer, in which evergreen species predominate, which reproduce mostly vegetatively, and there is a well-developed moss cover.

Spruce forests of this territory (as in all Polissia) occupy a kind of ecological niche on the border of the interface between three main forest forming species of Polissia – pine, oak and alder. These species serve as components of the tree layer of the most of spruce phytocoenoses. Spruce forests are characterized by the feature that they are formed in specific edaphic conditions, that means mainly on fairly moist soils in river valleys, lowland and transitional swamps. Spruce is a components of pine, oak and alder forests on rather large territories in different edaphic conditions.

In the phytocoenotic relation, spruce forests are represented by the predominant associations – oxalis and myrtillus spruce forest.

Silver birch forests (Betuleta pendulae) are found throughout the studied area, but do not occupy large territories. Young and medieval plantations form the most part of birch forests. Birch forests with monodominant tree stand are rare. In the tree stand formed by birch, there are pines, as well as downy birch and alder in more humid ecotopes.

With age, birches in birch forests are gradually replaced by pines, when they enter the category of mature and the change of rocks in them is already completed.

Grass-shrub cover of birch forests is diverse in species. They include forest species, but there are also meadow and marginal species in these light forests. When formed on the place of pine forests, birch forests usually inherit their grass-shrub layer. Assectator species of original pine forests sometimes are predominant in this layer. These are primarily cereals, which managed to dominate in changed conditions.

In the phytocoenotic relation, birch forests are represented by myrtillus, molinia, bracken, quacking grass associations.

Downy birch forests (Betuleta pubescentis) are found in separate plots mainly in lines along swamp edges and in small flat lows among pine forests. They represent a kind of ecotone between the swampy pine forests and forest sphagnum and lightly forested swamps. In these humid forests, there are pine, silver birch, alder and aspen are found individually in the tree stand. Downy birch forests are represented by two groups of associations: downy birch - long-stem moss and downy birch - sphagnum moss. The first is formed at the border with pine and silver birch forests. Polytrichum mosses create an aspect in these forests.

Communities of the second group are the transition from swampy forests to sphagnum swamps. Swamp species dominate in their grass-shrub layer and the number of forest species is extremely small. The moss cover is formed by sphagnum mosses.

Swamps are a characteristic element of this territory landscape. Together with surrounding forest massifs they form large hydrogeological complexes. They are represented by eutrophic and mesotrophic types.

In the area under study, eutrophic swamps occur in negative forms of relief – river valleys, river basins. The largest of their areas are concentrated in the Styr River floodplain, in its northern and southern parts. Grass swamp predominate among eutrophic swamps: sedge; bulrush, glyceria reed and acorus to lesser extent. Grass-moss (sedge-hypnum moss) swamps occupy small areas.

Sedge coenoses formed in conditions of significant moisture by rich alluvial and diluvial waters are the most widespread. The largest territories are occupied by coenoses with predominant acute sedge. Coenoses of glyceria maxima predominate among high-grass swamps.

Grass-moss, mainly sedge-hypnum moss, swamps occur everywhere, but do not occupy large areas. They are formed in conditions of stagnant moisture and a significant layer of peat. The irrigation degree of grass-moss associations is low and conditions of mineral nutrition are worse, that is why the moss layer is always well developed. The grass stand is represented by sedge, mainly predominated by Carex rostrata and Carex elata.

Forest eutrophic swamps are found rarely in the northern part of the studied area and are represented by alder swamps. Bulrush and hydrophilic mixed herbs predominate in the grass stand.

Poor sandy soils being a part of the soil cover, as well as geomorphological features of the territory and forming of swamps in closed drainless basins explain significant sphagnum mesotrophic associations in the vegetation cover. Mesotrophic swamps are represented by groups of lightly forested sphagnum and grass-sphagnum swamps. Lightly forested swamps are formed by periphery of large swamp massifs under less humid conditions. Usually, they are surrounded by swampy forests by periphery, and in the direction towards the center of massifs they are replaced by open sphagnum mesotrophic swamps. Lightly forested coenoses occur on strongly moist swamps with deep peat deposits and there is a spaced layer of low pine, bunch of grey willow. Grass-shrub layer is developed to different degrees. The floral core is created by swamp and forest-swamp species with the predominance of Carex lasiocapa. The amount of forest species is small. Sphagnum species dominate in rather dense and monotonous moss cover.

Treeless grass-sphagnum associations are common in large swamp massifs. They predominate on open watered swamp hollows, which are often difficult to pass. Such swamps are represented almost exclusively by Carex lasiocapa-sphagnum formations. Significantly smaller areas are occupied by grain crop-sphagnum associations, bluejoint and reed-sphagnum.

Meadow vegetation of the surveyed territory is represented by floodplain and dry meadows. Floodplain meadows are found mainly in the Styr River floodplains, especially in the middle of the most elevated part, where the river cuts outwash deposits. Swamp meadows predominate here, the lesser part is taken by peaty meadows.

Meadows are located on medium-high elements of the relief and are formed on fresh and humid sod and meadow soils. They are represented by tall-grass and low-grass meadows. The tall-grass meadows are occupied predominantly by meadow fescue, white apera. Thin apera, red fescue, meadow koeleria are predominant in low-grass meadows. These associations differ in rich floral composition.

Swamp meadows are formed on areas with excessive constant moistening on swamp muddy-gley soils placed in the peripheral or central parts. Grass stand is created mainly by reed canary grass and Agrostis stolonifera.

Peaty meadows are formed on sites with stagnant moisture with peat- and peat-gley soils. Tufted hair grass is dominating.

Dry meadows were formed on the places of mixed forests on different elements of relief and soil. They are represented by dry land and lowland meadows. Dry land meadows are predominant on the occupied area. They grow on watershed massifs, hills and slopes, as well as on dry lowlands and are represented by native and hollow meadows.

Native meadows are formed mainly on slopes of watershed ridges, flat areas. Their soils are mainly sod sandy of different podzolic degree [66]. Colonial bent grass is the predominant formation of these meadows. Smaller areas are occupied mainly by the associations of red fescue and soft grass.

Lowland meadows are better represented in the conditions of hill and bar relief among bedding rocks of dense and waterproof formations with high level of groundwater. Lowland meadows are characterized by constant moisture, predominance of sod-gley soils with signs of swamp formation. There are peaty meadows predominating among lowland meadows. There are small areas of rough meadows. Tufted hair grass meadows predominate among peaty meadows, but they do not occupy large areas. They are formed mainly on flat reliefs with water holding for a long time. The groundwater of these lows usually falls gradually due to which the soils are gleyed to a considerable depth.

Rough meadows of lowland areas characterized by acidic and poor soils are found mainly in combination with peaty meadows. The lowland option of rough meadows is presented only by the matgrass formations.

The presence of lakes, oxbow lakes, main reclamation channels contributed to the formation of aquatic vegetation. Cattail families, reed, lacustrine associations predominate among coastal and aquatic vegetation. On the water surface, there are white water lilies, snow white lilies, cow lilies, wild hyacinth, spirodela associations. Water submerged communities are represented by pondweed families.

Due to poor sod-podzolic soils in nutrients, grass and less often shrub wastelands are formed on the place of pine forests. The grassy wastelands are mainly occupied by associations from gray hair grass. There are rare occurrences of matgrass, bent grass associations. Wastelands are dominating among shrub associations.

Anthropogenic changes in the vegetation of the studied territory under modern conditions are vectorized in the direction of expanding the areas of pine monocultures on the place of mixed forest associations. Due to excessive grazing, meadows undergo significant transformations. The areas of floodplain forests reduced. As a result of neglection of farm lands, the share of segetal and ruderal vegetation increases.

There are 486 species of plants in natural plant groups. Flowering plants prevail with a share of over 95, which is fully consistent with the data for the flora of Ukrainian Polissia.

The flora of the studied territory is referred to the migratory type flora formed by the flora of humid, arid and arctaliptic groups. The leading flora positions are occupied by boreal species. Species with Holarctic and Eurasian types of habitats prevail among them. Boreal elements form the species of meadows, swamps and coniferous forests. The domination of the boreal flora is due to edaphic conditions. Depending on the environmental factors, mesophytes and mesotrophs predominate. The typical peculiarity of Polissia is the presence of nemoral elements, which are less than boreal, but play a significant role primarily in leafy oak and hornbeam forests. The presence of southern elements in pine forests is of a particular interest: winter daphne, viper’s grass, lupine clover, carex michelli, etc. The flora of open sandy deposits next to boreal elements are formed by psamophytes: false cornflower jurinea, sheep’s bit scabious, silene lithuanica, Ukrainian goat’s-beard, etc.

The brioflora of the territory is characterized as nemoral-boreal with a significant predominance of the boreal element, which corresponds to its location in the zone of mixed forests. The brioflora of forest formations is the richest and most diverse. This is due to the presence of a number of ecotopes favorable for the development of bryophytes, namely: forest soils, bark of living trees, rotting wood.

Therefore, the flora of RNPP 30-km zone is an interesting object, both from the floristic and phytocoenotic points of view. The vegetation has a pronounced boreal complex, which is dominated by pine forests and mesotrophic swamps in the presence of a large number of swampy forests on one side and dry pine forests on the other. There is a number of rare associations of national and regional levels. The flora of swamps, meadows, coniferous forests is predominated by the boreal species, the poverty of ecotopes of which created favorable opportunities for their growth. In the soxological sense, the flora is marked by the presence of a large group of Red Book species, glacial relics, frontier-areal species.

2.3 Fauna

The fauna of vertebrate species in the region is widely represented by mammals, birds, reptiles, amphibians, cyclostomes and fish.

The Polissia region is characterized by a large variety of fauna, among which there are representatives of vertebrate animals rare in the modern Ukraine (elk, lynx, wood grouse, black grouse, hazel grouse, etc.).

The forest-steppe zone of the region has a large number of hare, foxes, mouse-like rodents and shrews, but the species composition of the forest fauna here is much poorer than in the Polissia forests (however with larger population of squirrels, pine marten and somewhat less wolves, wild boars, etc.). At the same time, there are many types of vertebrates, which occur throughout the region territory without certain regional species distribution. Anseriformes, wader and meadow birds (ducks, sandpipers, quails, etc.) are the representatives of ornithofauna.

The most common families of vertebrates in the Rivne Region:

- mammals: squirrel, beaver, boar, wolf, vesper, hare, shrew, hedgehog, cats, mole, marten, mice, nutria, deer, horseshoe bat, vole, hollow-horned ruminant, hamster;
- birds: bunting, raven, finche, pigeon, nightjar, thrush, woodpecker, lark, accentor, cuckoos, oriole, duck, firecrest, wren, swallow, stork, gull, flycatcher, podicep, hoopoe, waxwing, rail, treecreeper, wagtail, swift, roller, tit bird, warbler, falcon, shrike, black grouses weaver, pheasant, heron, starling, hawk;
- reptiles: anguines lizard, serpentine, viper, tortoise, lizard;
- amphibians: frog, tree toad, painted frog, true toad, salamander;
- fish: carp, salmon, perch, catfish, cod, pike, sculpin, loach, stickleback.

Within the zoocoenoses of pine-birch forests dominating in the Polissia part of the region and which are characterized by reduced feeding and protective potential, the relative depauperation of the vertebrate fauna is observed. There is a clear dependence of fauna species composition and density of certain populations on the age and composition of tree stands and on the season.

Some species of reptiles and amphibians (frogs, tree toads, sand lizards, anguine lizards, grass snakes, vipers) and some nesting birds (black grouse, short-eared owl, nightjars, etc.) dominate in young pine-birch forests (up to 10 years), especially in spring and summer. Hazel grouses, chaffinch, tit birds, flycatchers that nest mostly in older forests, find food in young forests.

With the development of pine-birch forests, their crowns are closely joined, which increases the protective capabilities of the forest and contributes to the spread of foxes, boars, roe deers, raccoon dogs, etc. At the same time, the number of birds decreases in the 25-30-year-old forests, amphibians and reptiles are disappearing.

The undergrowth is intensively developed in old (50-60 years) pine forests, which positively impact the species diversity and density of the animal world, especially birds and mouse rodents. Recently, the number of elks has increased notably in pine-birch forests of the Rivne Polissia.

Zoocoenoses of oak-pine forests that are typical mostly for the southern part of the region differ with the high species diversity and density of birds and mouse rodents (forest vole, yellow-necked mouse), notable in the warn season. At the same time, there is increased number of predatory birds and animals of the associated food chain, especially martens, weasel, foxes, ferrets.

The rich forage base of oak-pine forests, the availability of convenient places for nesting and digging holes, the high protective ability of dense forests contribute to the broad development of other types of vertebrates – amphibians (toads, moor frogs, tree toads, tritons), reptiles, birds (especially thrush, woodpeckers, sparrows and black grouses), other diverse animals, including valuable fur and industrial species (roe deers, boars, etc.).

Zoocoenoses of water bodies and river floodplains are characterized by numerous water objects (rivers, natural and artificial reservoirs) and adjacent plots of floodplains. These zoocoenoses are characterized by the wide spreading of ichthyofaunal (common roach, bream, dace, ide, redeye, tench). In addition to these, there are representatives of pike, catfish, perch, loaches. In recent decades, the acclimatization of certain species of salmon, white amur, silver carps and other species of industrial fish has been carried out successfully. However, the cultivation of carps is the basis of pond management in the region.

Zoogeographic zoning [47] provides the following systematic position RNPP 30-km zone:

1. Boreal European-Siberian subregion;

1.2. East-European area, region of mixed, deciduous forest and forest-steppe;

1.2.a. East-European area, mixed forest and forest-steppe;

1.2.a.a. Subregion of Western or Volyn Polissia [67].

According to S.I. Medvedev [48], RNPP area shall be referred to the Right Bank Polissia of broadleaf and mixed forests.

The fauna of the studied region is represented by complexes typical for the Polissia [49]. According to the references, more than 60 species of mammals and about 200 species of birds live here.

Entomologically, Central European forest fauna is well represented here. There are species, whose geographical range in the east is confined by the Dnipro River (Cychrus attenuatus F., Carabus intricatus L., C. arvensis Hrbst., Corymbites purpureus Poda, Phausis splendidula L., Hoplia graminicola F., H. hungarica Burm., Anisoplia villosa Goeze, Amphimallon ruficornis F.).

Within RNPP 30-km zone, there are six main types of entomocomplexes. Out of them, there are five terrestrial (forest, shrub, meadow, swamp, anthropogenic) and one water entomocomplex. Forest entomocomplexes refer to the most common and valuable in RNPP 30-km zone.

Forest entomocomplexes comprise the species of insects that are conservatively linked to the main forest species – pine, birch, oak, alder, etc. Forests in the surveyed territory occupy a large area, but they are secondary (planted or sprout forests) and entomologically are often very poor. This is especially true for monocultural plantings of pine trees. They are well represented by pests – conifer tussock moth (Lymantriidae), pine moth (Dendrolimus pini L.), bordered white (Bupalus piniarius L.) and conifer sawflies (Diprion pini L. i Neodiprion sertifer Geoffr.), grey pine weevil (Brachyderes incanus L.), pine weevil (Brachonyx pineti F.). Pine trunk pests are represented by larger and smaller pine shoot beetle (Blastophagus piniperda L. and B. minor Hart.), bark beetles (Ipidae), timberman beetle (Acanthocinus aedilis L.) and other long-horn beetles (Cerambicidae). In the fresh pine tree stumps and logs, there are large pine weevils (Hylobius abietis L.). Forest edges, especially young pine plantings are rich in saddle-backed bush cricket (Ephippiger F.) and weevils (Rhinoncus castor F) often occur on the lawns.

At the same time, entomophagous insects in pine monoculture plantations have a relatively poor species composition. There are several species of bracon flies (Braconidae), ichneumon flies (Ichneumonidae) and chalcides (Chalcidoidea). Out of bracon flies, there are parasites named xylophages (Doryctinae). Forest entomocomplexes in mixed tree stands are more rich in the species of insects. The consortium of a common oak (Quercus robur L.) is the most rich in species. In ecological and environmental aspects, oak is the most valuable breed of the country. Within RNPP 30-km zone, there are some leaf-eating insects on oaks including some species of tortrix moths (rose leaf tortrix moth - Archips rosana L., golden tortrix moth - A. xylosteana L., great brown tortrix moth

- A. podana Sc. etc.). There is a number of geometer moths (brindled moth - Lycia hirtaria Cl., winter moth - Operophthera brumata L., great oak moth - Ennomos quarcinaria Hufn. etc.), different owlet moths (green owlet moth - Dichonia aprilina L., brown oak owlet moth - Dryabota protea Bkh. etc.).

Common lackeys (Malacosoma neustria L.) and some species of pine tussock moth (Lymantriidae) are also typical. Out of leafeating insects, there are Tischeria moths on the oak. There are also oak trunk pests, especially jewel beetles (Buprestidae) and long-horn beetles (Cerambicidae). Weevils Strophosoma capitatum Deg. are a major species on young oaks and other deciduous trees. The undergrowth is a place for common weevils – strawberry root weevils (Otiorhynchus ovatus L.) and black weevils (O. tristis Scop.).

There were some occurrences of green grasshoppers - Tettigonia viridissima L. The forest edges and lawns are the places for dark bush-cricket Pholidoptera cinerea L. and wood cockroach Ectobius sylvestris Poda.

Among insects-entomophages, there were bracon flies from the families of Dolichogenidea, Apanteles, Aleiodes, Meteorus etc. found on oaks. Also, there were ichneumons and chalcids (both primary parasites and hyperparasites). Tachina flies were also revealed in the forest edges.

Meadow biotops, as well as ruderal vegetation, are the richest in the insect species, such as orthopterous insects (Orthoptera) and beetles (Coleoptera: Carabidae, Curculionidae). Swamps and floodplain areas are usually the habitats for the northern (boreal) elements of entomofauna, while meadow and anthropoghenic entomocomplexes include northern (steppe and forest-steppe) types of insects (Aiolopus thalassinus F.).

There were 18 species of insects identified in the surveyed area, which are included into endangered lists: Red Book of Ukraine and European Red List. Of these, seven species for the Rivne Region are not listed in the Red Book of Ukraine.

Eleven species of amphibians were revealed in RNPP 30-km zone. The most common are lake frogs (Rana ridibunda), which inhabits most of the acquatic and near-water biotopes. Pond frogs (Rana lessonae) is much less common. The usual species are grey frog (Bufo bufo), grass frog (Rana temporaria), digging toad (Pelobates fuscus). Moor frog (Rana arvalis) is common at meadows, swamps and other watercourse biotopes. Less common are red-bellied toad (Bombina bombina), common tree frog (Hyla arborea), common newt (Triturus vulgaris) and crested newt (Triturus cristatus).

The reptile fauna in RNPP 30-km zone is represented by seven species. Common pond turtles inhabiting a number of surveyed pond and some next to them, sand lizard (Lacerta agilis) preferring dry and sunny areas inhabits sparse forests, groves, young forests, slopes of hills and ravines, shrub thickets. There is a number of snakes including grass snake (Natrix natrix), which lives along the banks of rivers, lakes, floodplain meadows, in reed beds and other areas. Less common are viviparous lizard (Lacerta vivipara) and anguine lizard (Anguis fragilis). Less often are common vipers (Vipera berus) and smooth snake (Coronella austriaca) included in the Red Book of Ukraine, which inhabit forest outskirts and shrubs.

Birds are the most numerous group of vertebrate animals of RNPP 30-km zone. The ornithofauna of the region comprises 11 species included in the Red Book of Ukraine. There is a total number of 190 species of birds, including 65 species nesting in RNPP 30-km zone. However, according to the references, 120 species of birds usually nest in this region [50].

A number of birds visit the surveyed region irregularly or are migrating birds [50, 51].

The most numerous and often occurring birds of the forest complexes are as follows: common chaffinch (Fringilla coelebs), tree pipits (Anthus trireialis), large tit bird (Parus major), blackcap (Sylreia atricapilla), yellowhammer (Emberiza citrinella), treecreepers (Certhia familiaris), hawfinch (Coccothraustes coccotraustes), white-collared flycatcher (Ficedula albicollis), greater spotted woodpecker (Dendrocopos major), wood warbler (Phylloscopus sibilatrix), common buzzard (Buteo buteo), raven (Corvus corax), jay (Garrulus grandarius), siskin (Spinus spinus), robin (Eritacus rubecula) etc. There are common goshawks (Accipiter gentiles), nighthawk (Caprimuldus europaeus), oriole (Oriolus oriolus), ring dove (Columba palumbus), cuckoo (Cuculus c anorus), crested tit bird (Parus cristatus), common rosenfinch (Carpodacus erythrinus), etc. are also common. Hazel grouse (Tetrastes bonasia) is less common and black grouse (Lyrurus tetrix) is even less common [51]. There were twice indications of red kites (Milvus milvus) and one indication of falcon (Falco peregrinus), which is one of the most rare birds in this region [50, 52].

The following birds were indicated among water-swamp and meadow complexes: grey heron (Ardea cinerea), common moorhen (Gallinula chloropus), common coot (Fulica atra), mute swan (Cygnus olor), mallard (Anas platyrhynchos), marsh harrier (Circus aeruginosus), yellow wagtail (Motacilla flava), black-headed gull (Larus ridibundus), black tern (Chlidonias niger), common kingfisher (Alcedo atthis). Along rivers and lakes (open meadow areas, shrub thickets, floodplain, etc.) there are: yellowhammer (Emberiza citrinella), whinchat (Saxicola rubetra), thrush nightingale (Luscinia luscinia), marsh warbler (Acrocephalus palustris), great reed warbler (Acrocephalus arundinaceus), bluethroat (Cyanosilvia svecica), river warbler (Locustella fluviatilis), etc. The rarer occurrences are: corn crake (Krex krex), night heron (Nycticorax nicticorax), great-crested grebe (Podiceps cristatus). Even less common: clack stork (Ciconia nigra) and common crane (Grus grus), sometimes those species nesting in the zone [50-52]. Rather common, but not numerous species of sandpiper: woodcock (Scolopax rusticola), common snipe (Gallinago gallinago), great snipe (Gallinago media), green sandpiper (Tringa ochropus).

Common species for open biotopes (fields, wastelands, areas along forest line, etc.): Eurasian skylark (Alauda arvensis), crested lark (Galerida cristata), Northern wheatear (Oenahthe oenanthe). Less often are common species: hoopoes (Upopa epops), kestrel (Cerchneis tinnunculus), greenfinch (Chloris chloris), common quail (Coturnix coturnix), etc. On the areas adjacent to humid meadows, natural water bodies, there are some species of corn crake (Krex krex), more often a gull (Vanellus vanellus). Species living in sparse tree and shrub vegetation alternating with open biotopes: grey yellowhammer (Emberiza citrinella), goldfinch (Carduelis carduelis), common linnet (Cannabina canabina), common yellowhammer (Emberiza citrinella), red-backed shrike (Lanius collurio), tawny pipit (Anthus campestris), etc., according to the data presented in [50, 53- 55].

The fauna of mammals in the studied region is likely to include about 50 species [53]. We have identified 46 species of mammals. Species composition is determined primarily by the significant forest area and relative sparse population. Six species included in the Red Book of Ukraine live in the territory: otter (Lutra lutra), steppe polecat (Mustela eversmanni), badger (Meles meles), water shrew (Neomis anomalis); extremely rare: garden dormouse (Eliomys guercinus) [56] and western barbastelle (Barbastella barbastella) (single occurrence).

The Rodentia family is represented by: Tundra vole (Microtus oeconomus), bank vole (Clethrionomys glareolus), European pine vole (Microtus subterraneus), common vole (Microtus arvalis), muskrat (Ondatra zibethica), beaver (Gastor fiber), brown rat (Rattus norvegicus), squirrel (Sciurus vulgaris).

The dormouse family is represented by four species: edible dormouse (Myoxus glis), hazel dormouse (Muscardinus avellanarius), forest dormouse (Dryomus nitedula) and garden dormouse (Eliomys quercinus).

The murids family is represented by: house mouse (Mus musculus), field mouse (Apodemus agrarius), forest mouse (Sylvaemus sylvaticus), harvest mouse (Micromys minutus), yellow-necked mouse (Sylvaemus tauricus), birch mouse (Sicista betulina).

Representatives of Insectivora indicated in the region: hedgehog (Erinaceus europaeus), common shrew (Sorex araneus), pygmy shrew (Sorex minutus), mole (Talpa europaea). Less common: lesser white-toothed shrew (Crocidura suarecolens) and bicolored shrew (Crocidura leucodon); much less common: water shrew (Neomys fodiens), lesser water shrew (Neomys anomalus).

Common representatives of Chiroptera family in this region: forest bat (Vespertilio nathusii), common noctule (Nyctalus noctula), common pipistrelle (Vespertilio pipistrellus). According to literature data, the bats are represented by at least ten species [53, 57].

The most widespread and the most numerous representative of Carnivora family is the fox (Vulpes vulpes). There were only few indications of raccoon dog (Nyctereutes procyonoides), which lives in dense thickets along rivers, etc. We also indicated the otter (Lutra lutra), beach marten (Martes foina), forest marten (Martes martes), least weasel (Mustela nivalis), stoat (Mustela erminea), European polecat (Mustela putorius), steppe polecat (Mustela eversmanni). Common wolf (Canis lupus) was indicated on the territory, however it is very rare. According to the survey, there were some indications of lynx (Felix lynx), which is extremely rare [52, 57].

The European hare (Lepus europaeus) is very widespread [58].

The ungulates in the region are represented by species common for Polissia: elk (Alces alces), roe deer (Capreolus capreolus) and wild boar (Sus scrofa).

2.4 Species of fauna and flora included in the Red Book of Ukraine and recommendations for the inclusion

2.4.1 Protection and reproduction of flora species included in the Red Book of Ukraine and those subject to international treaties

As of 01 January 2017, there were 49 species of flora and three species of mushrooms included in the Red Book of Ukraine revealed in the territory of the Rivne Nature Reserve. 214 species of plants (most of them have a safe or unidentified status and only six are close to the threat of disappearance) are included in the European Red List (IUCN Red List of Threatened Species. Version 2015.4). There are four species in the Annex 1 to the Berne Convention. 19 species are referred to regionally rare species (according to the “List of Regionally Rare and Endangered Species of Plants in the Rivne Region” approved by the decision of the regional council No. 1196 dated 27 March 2009). The condition of the populations of the most species included in this list is characterized as stable. There are proper conditions for their growth in the nature reserve. Such species as northern firmoss, narrow-leaved helleborine, greater butterfly-orchid, pasqueflower, leatherleaf, lousewort, common marsh pennywort have a small spread, but this is due to a small percentage of ecotopes in which they grow on the territory of the reserve.

According to survey results, the flora of the “Derman-Ostroh” National Nature Reserve counts 929 species, of which there are 650 of the vascular species, 120 of bryophytes, 91 of algae and 64 species of fungi. The park flora includes 95 species of plants that must be protected at different levels, including 90 vascular species, four species of moss and one of fungi. These are species listed in Annex 1 to the Berne Convention (7 species), in the CITES list (18 species) and the European Red List (1 species), in the Red Book of Ukraine (49 species under the state level of protection) and the list of plants protected in the Rivne Region (44 species under the regional level of protection). Eleven vegetative groups included in the Green Book of Ukraine were revealed on the territory of the park. The rare species are regularly monitored on permanent test areas, the condition of the populations of most species is stable.

Table 2.1. Species of plants and fungi under protection in 2016

Indicators	Rivne Nature Reserve	Derman-Ostroh National Nature Reserve
Total number of species of plants and fungi, units	1235	929
Species of plants and fungi included in the Red Book of Ukraine, units	52	49
Species of plants and fungi included in Annexes to the Convention on the Conservation of European Wildlife and Natural Habitats, units	4	7
Species of plants and fungi included in Annexes to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), units	12	18

Table 2.2. List of species of plants and fungi protected at the state and regional levels (as of 01 January 2017)

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Common gratiola, Gratiola officinalis L.				+	LC
Sand milkvetch, Astragalus arenarius L.				+	
Liquorice milkvetch, Astragalus glycyphyllos L.				+	
Common polypody, Polypodium vulgare L.				+	
Northern firmoss, Huperzia selago (L.) Bernh. ex Schrank et Mart.	+				
Dwarf birch, Betula humilis Schrank.	+				
Silver birch, Betula pendula Roth				+	
Downy birch, Betula pubescens Ehrh.				+	
Dark-bark birch, Betula obscura A.Kotula	+				
Fragrant orchid, Gymnadenia conopsea (L.) R. Br.	+		+		
Marsh grass of Parnassus, Parnassia palustris L.					LC
Menyanthes, Menyanthes trifoliata L.				+	
Rolling hen-and-chicken, Jovibarba sobolifera (Sims) Opiz	+				
White helleborine, Cephalanthera damasonium (Mill.) Druce.	+		+		
Narrow-leaved helleborine, Cephalanthera longifolia (L.) Fritsch	+		+	+	
Red helleborine, Cephalanthera rubra (L.) Rich.	+		+		
Downy willow, Salix lapponum L.	+				
Stark willow, Salix starkeana Willd.	+				
Swamp willow, Salix myrtilloides L.	+				
Yellow loosestrife, Lysimachia vulgaris L.				+	LC

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Meadow loosestrife, Lysimachia nummularia L.				+	
Common heather, Calluna vulgaris (L.) Hull				+	
Water speedwell, Veronica anagallis-aquatica L.				+	LC
Heath speedwell, Veronica officinalis L.				+	
European speedwell, Veronica beccabunga L.				+	LC
Marsh speedwell, Veronica scutellata L.				+	LC
Great water-parsnip, Sium latifolium L.				+	
Water chickweed, Callitriche cophocarpa Sendtner				+	
High bugleweed, Lycopus exaltatus L.				+	
European bugleweed, Lycopus europaeus L.				+	
Garland flower, Daphne cneorum L.	+				
Whorled-lead watermilfoil, Myriophyllum verticillatum L.				+	
Spiked watermilfoil, Myriophyllum spicatum L.				+	
Water soldiers, Stratiotes aloides L.					
Austrian yellowcress, Rorippa austriaca (Crantz) Bess.				+	
Great yellowcress, Rorippa amphibia (L.) Bess				+	
Yellowcress brachycarpous, Rorippa brachycarpa (C.A. Mey.) Hayek				+	
Fern-leaf dropwort, Filipendula vulgaris Moench				+	
Slender green feather moss, Hamatocaulis vernicosus (Mitt.) Hedenäs.		+			
Fringed pink, Dianthus superbus L.				+	
Dianthus carnation, Dianthus pseudoserotinus Błocki	+	.			
Blandow's helodium moss, Helodium blandowii (F.Weber et D.Mohr) Warnst.	+				
Prostrate knotweed, Polygonum aviculare L.				+	
Longroot smartweed, Polygonum amphibium L.				+	
Marshpepper knotweed, Polygonum hybropiper L.				+	
Ladysthumb, Polygonum persicaria L.				+	
Yellow water-lily, Nuphar lutea (L.) Smith				+	
Ukrainian hawthorn, Crataegus ucrainica Pojark				+	
Bird's-nest orchid, Neottia nidus-avis (L.) Rich.	+		+		
Bush vetch, Vicia sepium L.				+	
Common avens, Geum urbanum L.				+	
Sheperd's purse, Capsella bursa-pastoris (L.) Medik.				+	
Leathery grapefern, Botrychium multifidum (S.G.Gmel.) Rupr.	+				
Common pear, Pyrus communis L.				+	
Creeping lady's-tresses, Goodyera repens (L.) R. Br.	+		+	+	
Common yarrow, Achillea millefolium L.				+	

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Common mullein, Verbascum Thapsus L.				+	
Green wind-blown moss, Dicranum viride (Sull. et Lesq.) Lindb.		+			
Common oak, Quercus robur L.				+	
Common frogbit, Hydrocharis morsus-ranae L.				+	
Large bitter-cress, Cardamine amara L.				+	
Lady's smock, Cardamine pratensis L.				+	
Common knitback, Symphytum officinale L.				+	
Yellow widelip orchid, Liparis loeselii (L.) Rich.	+	+	+	+	
Lesser spearwort, Ranunculus flammula L.				+	LC
Groveling buttercup, Ranunculus reptans L.				+	
Creeping buttercup, Ranunculus repens L.				+	
Great spearwort, Ranunculus lingua L.				+	
Alternate-leaved golden-saxifrage, Chrysosplenium alternifolium L.				+	
Bog cranberry, Oxycoccus microcarpus Turcz. Ex Rupr.	+				
Common St. John's wort, Hypericum perforatum L.				+	
Siberian St. John's wort, Hypericum elegans Stephan ex Willd.				+	
Northern running-pine, Diphasiastrum complanatum (L.) Holub	+				
Deep-rooted running-pine, Diphasiastrum tristachyum (Pursh) Holub	+				
Diphasiastrum, Diphasiastrum zeilleri (Rouy) Holub	+				
Chickweed, Stellaria media (L.) Vill.				+	
Hoary willowherb, Epilobium parviflorum Schreb.					LC
Common teayblade, Listera ovata (L.) R. Br.	+		+		
Lady's-slipper orchid, Cypripedium calceolus L.	+	+	+		
Early marsh-orchid, Dactylorhiza incarnata (L.) Soo	+		+	+	
Common spotted orchid, Dactylorhiza fuchsii (Druce) Soo	+		+	+	
Common centaury, Centaurium erythrae Rafn.				+	
European goldenrod, Solidago virgaurea L.				+	
European bur-reed, Sparganium emersum Rehmann.				+	
Branched bur-reed, Sparganium erectum L.				+	
Guelder rose, Viburnum opulus L.				+	
Marsh marigold, Caltha palustris L.				+	LC
Marsh foxtail, Alopecurus geniculatus L.				+	
Field meadow foxtail, Alopecurus pratensis L.				+	
Shortawn foxtail, Alopecurus aequalis Sobol.				+	
Meridian fennel, Carum carvi L.				+	
Wood club-rush, Scirpus sylvaticus L.				+	

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Rooting club-rush, Scirpus radicans Schkuhr				+	
Lily of the valley, Convallaria majalis L.				+	
Owlheaded clover, Trifolium alpestre L.				+	
Alsike clover, Trifolium hybridum L.				+	
Red clover, Trifolium pratense L.				+	
White clover, Trifolium repens L.				+	
Hare’s-foot clover, Trifolium arvense L.				+	
Marsh helleborine, Epipactis palustris (L.) Crantz	+		+	+	LC
Dark-red helleborine, Epipactis atrorubens (Hoffm. Ex Bernh.) Schult.	+		+	+	
Broad-leaved helleborine, Epipactis helleborine (L.) Crantz	+		+	+	
Common gladiolus, Gladiolus imbricatus L.	+				
Sheep’s fescue, Festuca ovina L.				+	
Red fescue, Festuca rubra L.				+	
Common nettle, Urtica dioica L.				+	
Burning nettle, Urtica urens L.				+	
Lakeshore club-rush, Schoenoplectus lacustris (L.) Palla				+	
Scented Solomon’s seal, Polygonatum odoratum (Mill.) Druse				+	
Soft hornwort, Ceratophyllum submersum L.				+	
Rigid hornwort, Ceratophyllum demersum L.				+	
European white water lily, Nymphaea alba L.				+	
White water lily, Nymphaea candida J. Et C. Presl				+	
Rice cutgrass, Leersia oryzoides (L.) Sw.				+	
Greater sweet-grass, Gliceria maxima (C. Hartm) Holub.				+	
Floating sweet-grass, Glyceria fluitans (L.) R. Br.				+	
Large-leaved linden, Tilia platyphyllos Scop.				+	
Marsh clubmoss, Lycopodiella inundata (L.) Holub	+				LC
Martagon lily, Lilium martagon L.	+				
Yellow marsh saxifrage, Saxifraga hirculus L.	+	+			
Greater burdock, Arctium lappa L.				+	
Perennial honesty, Lunaria rediviva L.	+				
Lesser butterfly-orchid, Platanthera bifolia (L.) Rich.	+		+	+	
Greater butterfly-orchid, Platanthera chlorantha (Cust.) Reichenb.	+		+	+	
Hop clover, Medicago lupulina L.				+	
Common oregano, Origanum vulgare L.				+	
Blue eryngo, Eryngium planum L.				+	
Common soapwort, Saponaria officinalis L.				+	

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Bog orchid, Hammarbya paludosa (L.) O.Kuntze	+		+	+	
European pennyroyal, Mentha pulegium L.				+	LC
Water mint, Mentha aquatica L.				+	DD
Lesser devil's bit, Succisella inflexa (Kluk) G.Beck	+				
Three-ranked hump-moss, Meesia triquetra (L. Ex Jolycl.) Angstr.	+				
Creeping bentgrass, Agrostis stolonifera L.				+	LC
Velvety bentgrass, Agrostis canina L.				+	
Lake quillwort, Isoetes lacustris L.	+			+	
Wild carrot, Daucus carota L.				+	
Pink stinkhorn, Mutinus ravenelii	+				
Dog stinkhorn, Mutinus caninus (Huds.) Fr.	+				
Pinemat manzanita, Arctostaphylos uva-ursi (L.) Spreng.				+	
Yellow foxglove, Digitalis grandiflora Mill.					
Marsh calla, Calla palustris L.				+	
Water dropwort, Oenanthe aquatica (L.)Poir.				+	
European mistletoe, Viscum album L.				+	
Bog sedge, Carex limosa L.				+	
Tufted sedge, Carex elata All.(C. Omskiana Meinsh.)				+	LC
Greater tussock-sedge, Carex paniculata L.				+	LC
Slender tufted-sedge, Carex acuta L.				+	LC
Lesser pond-sedge, Carex acutiformis Ehrh.				+	LC
Dioecious sedge, Carex dioica L.	+				
Lesser tussock-sedge, Carex diandra Schrank					LC
Devalliana sedge, Carex davalliana Smith.	+				
Shade sedge, Carex umbrosa Host.	+				
Fibrous tussock-sedge, Carex appropinquata Schum.				+	
Bottle sedge, Carex rostrata Stokes				+	
Cyperus sedge, Carex pseudocyperus L.				+	LC
Greater pond-sedge, Carex riparia Curt.				+	LC
Bladder sedge, Carex vesicaria L.				+	
Slender sedge, Carex lasiocarpa Ehrh.				+	
Creeping sedge, Carex chordorriza Ehrh.	+			+	
Peat sedge, Carex heleonastes	+				
Host's sedge, Carex hostiana DC.	+				
Black sedge, Carex nigra (L.) Reichard.					LC
Common reed grass, Phragmites australis (Cav.) Trin. Ex Steud.				+	
Goldmoss stonecrop, Sedum acre L.				+	
Perennial ryegrass, Lolium perenne L.				+	

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Paludella moss, Paludella squarrosa (Hedw.) Brid.	+				
Early marsh-orchid, Dactylorhiza incarnata (L.) Soo	+		+	+	
Heath spotted-orchid, Dactylorhiza maculata (L.) Soo	+		+		
Broad-leaved marsh orchid, Dactylorhiza majalis (Reichenb.) P.F. Hunt et Summ.	+		+		
Common spotted orchid, Dactylorhiza fuchsii (Druce) Soo	+		+	+	
Common agrimony, Agrimonia eupatoria L.				+	
Bittersweet nightshade, Solanum dulcamara L.				+	
Common tormentil, Potentilla erecta (L.) Raeusch				+	
Common liverleaf, Hepatica nobilis Mill.				+	
Yellow iris, Iris pseudacorus L.				+	
Siberian iris, Iris sibirica L.	+				
Common coltsfood, Tussilago farfara L.				+	
Sweetscented bedstraw, Galium odoratum (L.) Scop.				+	
Lady’s bedstraw, Galium verum L.				+	
Cleavers, Galium aparine L.				+	
Common snowdrop, Galanthus nivalis L.	+				
Water violet, Hottonia palustris L.				+	
Purple loosestrife, Lythrum salicaria L.				+	LC
Common club moss, Lycopodium clavatum L.				+	
Interrupted club-moss, Lycopodium annotinum L.	+				
Broadleaf plantain, Plantago major L.				+	
Narrowleaf plantain, Plantago lanceolata L.				+	
Absinthe, Artemisia absinthium L.				+	
Common mugwort, Artemisia vulgaris L.				+	
Field wormwood, Artemisia campestris L.				+	
Marsh puffball, Bovista paludosa Lév.	+	.			
Three-ranked spear-moss, Pseudocalliergon trifarium (F. Weber et D. Mohr) Loeske	+				
Common bladderwort, Utricularia vulgaris L.				+	
Lesser bladderwort, Utricularia minor L.	+			+	
Flatleaf bladderwort, Utricularia intermedia Hayne	+			+	
Slender cottongrass, Eriophorum gracile Koch.				+	
Broad-leaved cottongrass, Eriophorum latifolium Hoppe					LC
Lesser celandine, Ficaria verna Huds.				+	
Green figwort, Scrophularia umbrosa Dumort.					LC
Alpine pondweed, Potamogeton alpinus Balb.				+	LC
Small pondweed, Potamogeton berchtoldii Fieb.				+	
Shining pondweed, Potamogeton lucens L.				+	
Longleaf pondweed, Potamogeton nodosus Poir.				+	

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Curled pondweed, Potamogeton crispus L.				+	
Whitestem pondweed, Potamogeton praelongus Wulf.				+	
Various-leaved pondweed, Potamogeton gramineus L.				+	
Broad-leaved pondweed, Potamogeton natans L.				+	
Claspingleaf pondweed, Potamogeton perfoliatus L.				+	
Grass-wrack pondweed, Potamogeton compressus L.				+	
Flat-stalked pondweed, Potamogeton friesii Rupr.				+	
Red pondweed, Potamogeton rutilus Wolfg.				+	
Narrowleaf cattail, Typha angustifolia L.				+	
Broadleaf cattail, Typha latifolia L.				+	
Yellow azalea, Rhododendron luteum Sweet		+		+	
Ground ivy, Glechoma hederaceae L.				+	
Hairy ground ivy, Glechoma hirsute Waldst.& Kit.				+	
English sundew, Drosera anglica Huds.	+				
Round-leaved sundew, Drosera rotundifolia L				+	
Spoonleaf sundew, Drosera intermedia Hayne	+				
Lesser duckweed, Lemna minor L.				+	
Common duckweed, Schoenus ferrugineus L.	+				
Felwort, Swertia perennis L.	+				
Bulbous rush, Juncus bulbosus L.	+			+	LC
Toad rush, Juncus bufonius L.				+	
Common rush, Juncus effusus L.				+	
Compact rush, Juncus conglomeratus L.					LC
Round-fruited rush, Juncus compressus Jacq.					LC
Jointleaf rush, Juncus articulatus L.				+	LC
Marsh spike rush, Eleocharis palustris (L.) Roem.et Schult.				+	
Common spike rush Eleocharis acicularis (L.) Roem. Et Schult.				+	
Mamillate spike rush, Eleocharis mamillata H.Lindb.	+			+	
Ovate spike rush, Eleocharis ovata (Roth) Roem. Et Schult.				+	
European scopolia, Scopolia carniolica Jacq.	+				
Scorpion scorpidium, Scorpidium scorpioides (Hedw.) Limpr.	+				
Lithuanian catchfly, Silene lithuanica Zapal.	+				
Eastern pasqueflower, Pulsatilla patens (L.) Mill.	+	+			
Spreading pasqueflower, Pulsatilla latifolia (L.) Mill., P. Patens	+	+			
Common duckweed, Spirodela polyrrhiza (L.) Schleid.				+	
Arrowhead, Sagittaria sagittifolia L.				+	

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Wild strawberry, Fragaria vesca L.				+	
Flowering rush, Butomus umbellatus L.				+	LC
Common self-heal, Prunella vulgaris L.				+	
Timothy-grass, Phleum pratense L.				+	
Marsh gentian, Gentiana pneumonanthe L.				+	
Common butterwort, Pinguicula vulgaris L.	+				
Smooth meadow grass, Poa pratensis L.				+	
Heath dog-violet, Viola canina L.				+	
Johnny Jump up, Viola tricolor L.				+	
Leatherleaf, Chamaedaphne calyculata (L.) Moench	+				
Fragile stonewort, Chara delicatula C. Agardh	+				
Marsh horsetail, Equisetum palustre L.				+	LC
Scouring horsetail, Equisetum hyemale					
Field horsetail, Equisetum arvence L.				+	
Water horsetail, Equisetum fluviatile L.				+	
Common hop, Humulus lupus L.				+	
Garden asparagus, Asparagus officinalis L.				+	
Yellowdrop milkcap, Lactarius chrysorrheus Fr.	+				
Broad-leaved garlic, Allium ursinum L.	+			+	
Crow garlic, Allium vineale L.				+	
Common chicory, Cichorium intibus L.				+	
Northern water hemlock, Cicuta virosa				+	
Lanceleaf water plantain, Alisma lanceolatum With				+	LC
European water-plantain, Alisma plantago-aquatica L.				+	
Nodding beggarticks, Bidens cernua L.				+	
Three-lobe beggarticks, Bidens tripartita L.				+	
Marsh pea, Lathyrus palustris L.					LC
Flat pea, Lathyrus sylvestris L.				+	
Marsh woundwort, Stachym palustris L.				+	
Greater celandine, Chelidonium majus L.				+	
European blueberry, Vaccinium myrtillus L.				+	
Dog rose, Rosa canina L.				+	
Marsh scheuchzeria, Scheuchzeria palustris L.	+				
Lousewort, Pedicularis sceptrum-carolinum L.	+				
Great water dock, Rumex hydrolapathum Huds.				+	
Red sorrel, Rumex acetocella L.				+	
Common pennywort, Hydrocotyle vulgaris L.	+			+	
False cornflower jurinea, Jurinea pseudocyanoides Klok.		+			
European crab apple, Malus sylvestris Mill.				+	
Bukovyna golden ray, Ligularia bucovinensis Nakai	+	+			

Species name (English, Latin)	Red Book of Ukraine *	Berne Convention	CITEC	European Red List *	Red List of IUCN **
Siberian golden ray, Ligularia sibirica Cass.	+	+			
Total	80	11	21	205	34

Note: * categories of species of the Red Book of Ukraine 2009

**Red List of the International Union for Conservation of Nature and European Red List
Near Threatened (NT)
Least Concern (LC)
Data Deficient (DD)

Table 2.3. List of endangered species of vascular plants, algae, fungi and lichens

Systematic group of plants	Endangered species					
	2000	2012	2013	2014	2015	2016
Vascular plants	13	66	66	69	70	117
Fungi	-	2	3	3	4	4
Algae	-	1	1	1	1	1
Moss	-	3	3	2	2	4
Lichens	-	-	-	-	-	-
Total:	13	72	73	75	77	126

Table 2.4. List of endangered vascular plants, algae, fungi and lichens as of 2016

Systematic group of plants	Number of species	Endangered species
Vascular plants	117	Sand milkvetch, Astragalus arenarius L. Wall rue, Asplenium ruta-muraria L Maidenhair spleenwort, Aspleniumtrichomanes L Snowdrop anemone, Anemones sylvestris L.
		Monkshood, *Aconitum lasiostomumReichenb*. Northern firmoss, *Huperzia selago (L.) Bernh. ex Schrank et Mart.* Hard shield fern, *Polystichum aculeatum(L.) Roth* Braun’s holly fern, *Polystichum braunii(Spenn) Fee* Dark-bark birch, *Betula obscura* A.Kotula Dwarf birch, *Betula humilis Schrank.* Fragrant orchid, *Gymnadenia conopsea (L.) R. Br.* Rolling hen-and-chicken, *Jovibarba sobolifera* (Sims) Opiz Narrow-leaved helleborine, *Cephalanthera longifolia* (L.) Fritsch White helleborine, *Cephalanthera damasonium (Mill.) Druce.* Red helleborine, *Cephalanthera rubra (L.) Rich.*

Systematic group of plants	Number of species	Endangered species
		European valerian, *Valeriana simplicifolia(Reichenb.) Kabath* Downy willow, *Salix lapponum* L. Stark willow, *Salix starkeana* Willd. Swamp willow, *Salix myrtilloides* L. European dwarf cherry, *Cerasus fruticosa Pall.* Garland flower, *Daphne cneorum L.* Dianthus carnation, *Dianthus pseudoserotinus Błocki* Dusky crane's bill, *Geranium phaeum L.* Ukrainian hawthorn, *Crataegus ucrainica Pojark* Bird's-nest orchid, *Neottia nidus-avis* (L.) Rich. Common oak fern, *Gymnocarpium dryopteris (L.) Newm*. Limestone fern, *Gymnocarpium robertianum (Hoffm.) Newm* Leathery grapefern, *Botrychium multifidum (S.G.Gmel.) Rupr.* Creeping lady's-tresses, *Goodyera repens* (L.) R. Br. Bristly bellflower, *Campanula cervicaria L.* Yellow widelip orchid, *Liparis loeselii* (L.) Rich. Fly honeysuckle, *Lonicera xylosteum L* Bog cranberry, *Oxycoccus microcarpus Turcz. ex Rupr.* Northern running-pine, *Diphasiastrum complanatum (L.) Holub* Deep-rooted running-pine, *Diphasiastrum tristachyum (Pursh) Holub* Diphasiastrum, *Diphasiastrum zeilleri (Rouy) Holub* Early marsh-orchid, *Dactylorhiza incarnata (L.) Soo* Common spotted orchid, *Dactylorhiza fuchsii (Druce) Soo* Common teayblade, *Listera ovata (L.) R. Br.* Lady's-slipper orchid, *Cypripedium calceolus L.* Rocky eremogone, *Eremogone saxatilis L.* Least bur-reed, *Sparganium minimum Wallr* Bastard balm, *Melittis sarmatica Klok.* Dwarf milkwort, *Polygala amarella Crantz* European bugdane, *Cimicifuga europaea Schipcz., C. foetida* Marsh helleborine, *Epipactis palustris (L.) Crantz* Dark-red helleborine, *Epipactis atrorubens (Hoffm. ex Bernh.) Schult.* Broad-leaved helleborine, *Epipactis helleborine (L.) Crantz* Common gladiolus, *Gladiolus imbricatus L.* European globe flower, *Trollius europaea L.* Marsh clubmoss, *Lycopodiella inundata (L.) Holub* Martagon lily, *Lilium martagon L.* Yellow marsh saxifrage, *Saxifraga hirculus L.* Perennial honesty, *Lunaria rediviva L.* Golden flax, *Linum flavum L.* Lesser butterfly-orchid, *Platanthera bifolia (L.) Rich.* Greater butterfly-orchid, *Platanthera chlorantha (Cust.) Reichenb.* Lesser devil's bit, *Succisella inflexa (Kluk) G.Beck* Lake quillwort, *Isoetes lacustris L.*

Systematic group of plants	Number of species	Endangered species
		Bog orchid, *Hammarbya paludosa (L.) O.Kuntze* Lithuanian forget-me-not, *Myosotis lithuanica (Schmalh.) BessexDobrocz*. One-flower wintergreen, *Moneses uniflora (L.) A. Gray* European columbine, *Aquilegia vulgarisL.* Greater tussock-sedge, *Carex paniculata L.* Dioecious sedge, *Carex dioica* L. Devalliana sedge, *Carex davalliana Smith.* Shade sedge, *Carex umbrosa Host.* Bog sedge, *Carex limosa L.* Dwarf sedge, *Carex humilis L* Blue sedge, *Carex flacca Schreb* Creeping sedge, *Carex chordorriza Ehrh.* Peat sedge, *Carex heleonastes* Host's sedge, *Carex hostiana DC.* Paludella moss, *Paludella squarrosa (Hedw.) Brid.* Common spotted orchid, *Dactylorhiza fuchsii (Druce) Soo.* Early marsh-orchid, *Dactylorhiza incarnata (L.) Soo.*
		Heath spotted-orchid, *Dactylorhiza maculata (L.) Soo* Broad-leaved marsh orchid, *Dactylorhiza majalis (Reichenb.) P.F. Hunt* True oxlip, *Primula elatior(L.) Hill* Siberian iris, *Iris sibirica L.* Common snowdrop, *Galanthus nivalis L.* Interrupted club-moss, *Lycopodium annotinum L.* Common ivy, *Hedera helix L.* Lesser bladderwort, *Utricularia minor* L. Flatleaf bladderwort, *Utricularia intermedia Hayne* English sundew, *Drosera anglica Huds.* Spoonleaf sundew, *Drosera intermedia Hayne* Round-leaved sundew, *Drosera rotundifolia L* Common duckweed, *Schoenus ferrugineus L.* Felwort, *Swertia perennis L.* Jacob's-ladder, *Polemonium caeruleum L.* Bulbous rush, *Juncus bulbosus* L. Mamillate spike rush, *Eleocharis mamillata H.Lindb*. European scopolia, *Scopolia carniolica Jacq*. Scorpion scorpidium, *Scorpidium scorpioides (Hedw.) Limpr.* Lithuanian catchfly, *Silene lithuanica Zapal.* Mountain currant, *Ribes lucidum Kit* Eastern pasqueflower, *Pulsatilla patens (L.) Mill.* Spreading pasqueflower, *Pulsatilla latifolia (L.) Mill., P. patens* Common rock-rose, *Helianthemum nummularium (L.) Mill.* Broad-leaved sermountain, *Laserpitium latifolium L.* Ostrich fern, *Matteuccia struthiopteris (L.) Tod* Common butterwort, *Pinguicula vulgaris L.*

Systematic group of plants	Number of species	Endangered species
		Marsh gentian, *Gentiana pneumonanthe L* Long beach fern, *Phegopteris connectilis (Michx.) Watt* Sand violet, *Viola rupestris F.W.Schmidt* Leatherleaf, *Chamaedaphne calyculata* (L.) Moench Variegated horsetail, *Equisetum variegatum Shleich. exWeb. etMohr* Great horsetail, *Equisetum telmateia Ehrh* Broad-leaved garlic, *Allium ursinum L.* Marsh scheuchzeria, *Scheuchzeria palustris L.* Lousewort, *Pedicularis sceptrum-carolinum L.* Broad buckler-fern, *Dryopteris austriaca(Jacq.) Woynarex Schinzet Thell* Crested wood fern, *Dryopteris cristata (L.) A. Gray* Common pennywort, *Hydrocotyle vulgaris* L. Bukovyna golden ray, *Ligularia bucovinensis Nakai* Siberian golden ray, *Ligularia sibirica Cass.*
Fungi	4	Pink stinkhorn, *Mutinus ravenelii (Berk. et M.A. Curtis) E. Fish* Dog stinkhorn, *Mutinus caninus (Huds.) Fr.* Yellowdrop milkcap**,** *Lactarius chrysorrheus Fr.* Marsh puffball, *Bovista paludosa Lév***.**
Algae	1	Fragile stonewort, *Chara delicatula* C. Agardh
Lichens	-	
Moss	4	Green wind-blown moss, *Dicranum viride (Sull. et Lesq.) Lindb.* Slender green feather moss, *Hamatocaulis vernicosus (Mitt.) Hedenäs.* Paludella moss, *Paludella squarrosa (Hedw.) Brid.* Scorpion scorpidium, *Scorpidium scorpioides (Hedw.) Limpr*
Total:	126	

2.4.2 Protection and reproduction of fauna species included in the Red Book of Ukraine and those subject to international treaties

The main nature reserves of the region involved into the reproduction and protection of rare and endangered species of animals include the Rivne Nature Reserve, “Derman-Ostroh” National Nature Reserve. The natural complex is protected in general in these nature reserves, including its fauna.

As of 01 January 2017, there were 250 species of animals revealed in the Rivne Nature Reserve, which are protected according to the state legislation and international agreements. Among them: 80 species of the Red Book of Ukraine, 44 species of the European Red List, 23 species of the IUCN Red List, 173 species of Annex 2 of Berne Convention, 35 species of the CITES list, 60 species of the AEWA list, 12 species of EUROBATS list, 113 species of CMS list.

The status of the most species from the above lists on the reserve territory is characterized as stable. However, the final evaluation will need longer and more specialized observations.

As of 01 January 2017, the territory of the “Derman-Ostroh” National Nature Reserve has the registered number of 485 species of animals with 245 invertebrates (spiders – 1 species, insects – 233 species, mollusks – 11 species) and 240 vertebrates (mammals – 61 species, birds – 146 species, reptiles – 6 species, amphibians – 12 species, fish – 15 species). In 2016, the studies revealed five new species of bats (grey long-eared bat, parti-coloured bat, Natterer's bat, common barbastelle, soprano pipistrelle) in of the "Derman-Ostroh" National Nature Reserve. Besides, two new species of birds were indicated. The number of background species of animals were studied, in particular records of mammals were checked. The species diversity and number of birds were studied. The birds were recorded on the ecological profile No. 1. The nests of carnivorous birds and black storks were checked and listed in the Novomalyn and Mostivsky forestries.

Speaking about the fauna, 52 species are included into the Red Book of Ukraine, 37 species to the European Red List, 203 species to Annexes 2 and 3 of the Berne Convention. 20 species are protected by the Washington Convention. 70 species are protected by the Bonn Convention. 28 species of animals are included in IUCN Red List.

During 2016, the employees of the park recorded 12 indications of rare species of animals. The status of rare species of flora and fauna is assessed as satisfactory. It is necessary to conduct scientific studies for the inventory of rare species, accounting of their number and development of nature protection measures. In 2016, there were recommendations developed on the conservation of black stork in the territory of the National Nature Reserve. Together with volunteers of the World Wild Fauna (WWF): production and arrangement of four artificial platforms for nesting of black stork, ten artificial nests for tit birds, eight artificial nests for bats, four artificial nests for owls. Four artificial nests for grey owls were arranged on the territory of the Verkhivsk forestry (service zone of the park).

The number of protected species and the list of protected fauna are presented in Table 2.5

Table 2.5. Species of animals under protection in 2016

Indicators	Rivne Nature Reserve	Derman-Ostroh National Nature Reserve
Total number of species of fauna, units	1349	485
Species of fauna included in the Red Book of Ukraine, units	80	52
Species of fauna in Annexes to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), units	35	20
Species of fauna included in Annexes of the Convention on the Conservation of European Wildlife and Natural Habitats (Berne Convention), units	173	203
Species of fauna included in Annexes of the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention, CMS), units	113	70
Species protected in accordance with the African-Eurasian Migratory Waterbird Agreement (AEWA), units	60	31
Species protected in accordance with the Agreement on the Conservation of Populations of European Bats (EUROBATS), units	12	15
Species of fauna included in the European Red List	44	37
Species of fauna included in the IUCN Red List	23	28

Table 2.6. List of species of fauna under protection (as of 01 January 2017)

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
INSECTS								
Violet carpenter bee, Xylocopa violacea	Rd							
Large white-faced darter, Leucorrhinia pectoralis (Charp.)		2						
Death's head hawkmoth, Acherontia atropos	Rd							
Green chafer beetle, Protaetia aeruginosa Drury							NT	
Variable chafer, Gnorimus variabilis L.							NT	
Greater tiger moth, Pericallia matronula L.	Vr							
Scarlet tiger moth, Callimorpha dominula (L)	Vr							
Musk beetle, Aromia moschata (L.)	Vr							
Chequered skipper, Carterocephalus palaemon							V	
Emperor dragonfly, Anax imperator Laech	Vr							
Large copper, Lycaena dispar rutilus [Haw.]		2					E	LR
Kentish glory, Endromis versicolora (L.)	Vr							
Moorland clouded yellow, Colias palaeno (L.)	Zn							
Stag beetle, Lucanus cervus L.	Rd	3					NT	
Hermit beetle, Osmoderma barnabita	Vr	2					E	VU
Black-winged damselfly, Calopteryx virgo L.	Vr							
Forest caterpillar hunter, Calosoma sycophanta	Vr							
Carpenter bee, Xylocopa valga Gerst.	Rd							
Westwood snow flea, Boreus westwoodi Hagen	Nd							
Common yellow swallowtail, Papilio machaon L.	Vr							
Purple emperor, Apatura iris (L.)	Vr							
Clouded Apollo, Parnassius mnemosyne	Vr	2					*	
Red wood ant, Formica rufa L.							V	LR/nt
European red wood ant, Formica polyctena								LR/nt
Common ant lion, Myrmeleon formicarius L.							K	
Woodland brown, Lopinga achine (Scop.)		2						
Flat bark beetle, Cucujus cinnabarinus (Scop.)	Vr						NT	
Square-necked beetle, Cucujus haematodes Er.							EN	
Diving beetle, Dytiscus latissimus L.	Nv	2					E	VU
Poplar admiral, Limenitis populi (L.)	Vr							
Scarce swallowtail, Iphiclides podalirius	Vr							
False ringlet, Coenonympha oedippus (Fabr.)		2					EN	LR/nt
Common ringlet, Coenonympha tullia (Muller)							VU	
Purple emperor, Apatura iris	Vr							
Marsh fritillary, Euphydryas aurinia		2						
Scarce fritillary, Euphydryas maturna		2					E	
Assmann's fritillary, Melitaea britomartis Assm.							NT	

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Grey emperor moth, Hipparchus statilinus (Hufn)	Rd							
Great peacock moth, Saturnia pyri	Vr						E	
Small emperor moth, Eudia pavonia (L.)	Rd							
Tau emperor moth, Aglia tau	Vr							
Large blue, Maculinea arion		2					V	LR
Silver-studded blue, Maculinea nausithous		2					E	LR
Scarce large blue, Maculinea teleius		2					E	LR
Blue underwing, Catocala fraxini (L.)	Vr							
Clifden nonpareil, Catocala fraxini	Vr							
Dark crimson underwing, Catocala sponsa	Rd							
Poplar admiral, Limenitis populi	Vr							
Banded darter, Sympetrum pedemontanum (Alioni)	Vr							
Menetriesi ground beetle, Carabus menetriesi (Humm.)	Rd							
LEECHES								
European medicinal leech, Hirudo medicinalis L.	Vr							
MOLLUSCS								
Narrow-mouthed whorl snail, Vertigo angustior							V	LR
FISH								
Monkey goby, Neogobius fluviatilis		3						
European eel, Anguila anguila (L.)								CR
Amur bitterling, Rhodeus amarus		3						
Lake minnow, Eupallasella percnurus (Pall)	Zn							
Crucian carp, Carassius carassius (L.)	Vr							
Common carp, Cyprinus carpio								VU
AMPHIBIA								
European fire-bellied toad, Bombina bombina		2					LC	
Moor frog, Rana arvalis Nilsson		2					LC	LC
Edible frog, Pelophylax esculentus		3					LC	LC
Lake frog, Pelophylax ridibundus		3					LC	LC
Pool frog, Pelophylax lessonae		3					LC	LC
European grass frog, Rana temporaria		3					LC	LC
Common spadefoot, Pelobates fuscus		2					LC	
European fire-bellied toad, Bombina bombina L.		2						
European tree frog, Hyla arborea L.		2						
European green toad, Bufo viridis		2						
Natterjack toad, Bufo calamita Laurenti	Vr	2						
Common toad, Bufo bufo		3					LC	LC
Eastern tree frog, Hyla orientalis		2					LC	LC
Smooth newt, Lissotriton vulgaris		3					LC	
Great crested newt, Triturus cristatus Laurenti		2						
Common spadefoot, Pelobates fuscus Laurenti		2						

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
REPTILES								
Slowworm, Anguis fragilis		3					LC	
Grass snake, Natrix natrix		3					LC	LR
Common European adder, Vipera berus		3					LC	LC
Smooth snake, Coronella austriaca Laurenti	Vr	2						
European pond turtle, Emys orbicularis L.		2					NT	LR/nt
Viviparous lizard, Zootoca vivipara		3					LC	LC
Sand lizard, Lacerta agillis		2					LC	LC
BIRDS								
Saker falcon, Falco cherrug	Vr	2	2	2			E	EN
Great snipe, Gallinago media (Lath.)	Zn	2		1,2	+			NT
Common snipe, Gallinago gallinago (L.)		3		1,2	+			
Jack snipe, Lymnocryptes minimus (Brün.)		3		1,2	+			
Icterine warbler, Hippolais icterina (Vieill.)		2						
Golden eagle, Aquila chrysaetos (Linnaeus)	Vr	2	2	1,2				
Common kestrel, Falco tinnunculus L.		2	2	2				
Ruff, Philomachus pugnax (L.)		3		1,2	+			
Eurasian bittern, Botaurus stellaris (L.)		2		2	+			
Common little bittern, Ixobrychus minutus		2		2	+			
Golden oriole, Oriolus oriolus (L.)		2						
Common yellowhammer, Emberiza citrinella L.		2						
Common reed bunting, Emberiza schoeniclus (L.)		2						
Willow warbler, Phylloscopus trochilus (L.)		2						
Wood warbler, Phylloscopus sibilatrix (Bechst.)		2						
Greenish warbler, Phylloscopus trochiloides (Sund.)		2						
Common chiffchaff, Phylloscopus collybita (Vieill.)		2						
European robin, Erithacus rubecula (L.)		2		2				
Eurasian wren, Troglodytes troglodytes (L.)		2						
Red-throated loon, Gavia stellata Pontop.		2		2	+			
Black-throated loon, Gavia arctica L.		2		2	+		V	
Marsh tit, Parus palustris L.		2						
Willow tit, Parus montanus Bodd.		2						
Wood grouse, Tetrao urogallus (L.)	Zn	2						
Common goldeneye, Bucephala clangula (L.)	Rd	3		1,2	+			
Rock dove, Columba livia		3						
Stock dove, Columba oenas L.	Vr	3						
Common redstart, Phoenicurus phoenicurus (L.)		2		2				
Black redstart, Phoenicurus ohruros (Gmel.)		2		2				
Spotted nutcracker, Nucifraga caryocatactes (L.)		2						
European turtle dove, Streptopelia turtur		3						

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Eurasian collared dove, Streptopelia decaocto		3						
Eurasian tree sparrow, Passer montanus		3						
Black-tailed godwit, Limosa limosa (L.)		3		1,2	+			
Bean goose, Anser fabalis (Latham)		3		1,2	+			
Snow goose, Chen caerulescens (L.)				1,2				
Greater white-fronted goose, Anser albifrons (Scop.				1,2	+			
Greylag goose, Anser anser (L.)		3		1,2	+			
Lesser white-fronted goose, Anser erythropus	Vr	2		1,2	+		E	VU
Corn crake, Crex crex (L.)		2					R	NT
Redwing, Turdus iliacus L.		3		2				
Song thrush, Turdus philomelos C.L.Brehm		3		2				
Common blackbird, Turdus merula L.		3		2				
Mistle thrush, Turdus viscivorus L.		3		2				
European nightjar, Caprimulgus europaeus L.		2						
White-backed woodpecker, Dendrocopos leucotos (Bechst.)	Rd	2						
Great spotted woodpecker, Dendrocopos major (L.)		2						
Lesser spotted woodpecker, Dendrocopos minor (L.)		2						
Middle spotted woodpecker, Dendrocopos medius (L.)		2						
Syrian woodpecker, Dendrocopos syriacus		2						
Eurasian three-toed woodpecker, Picoides tridactylus (L.)	Vr	2						
Woodlark, Lullula arborea		3						
Eurasian skylark, Alauda arvensis		3						
European green woodpecker, Picus viridis L.	Vr	2						
Grey-headed woodpecker, Picus canus Gmel.		2						
Black woodpecker, Dryocopus martius (L.)		2						
Common crane, Grus grus (L.)	Rd	2	2	1,2	+			
European greenfinch, Chloris chloris (L.)		2						
Rough-legged buzzard, Buteo lagopus (Pontop.)		2	2	1,2				
Short-toed snake eagle, Circaetus gallicus (Gmel.)	Rd	2	2	1,2				
Common cuckoo Cuculus canorus		3						
Goldcrest, Regulus regulus (L.)		2						
Common chaffinch, Fringilla coelebs		3						
Northern wheatear, Oenanthe oenanthe (L.)		2		2				
Common buzzard, Buteo buteo (L.)		2	2	1,2				
Black-crowned night heron, Nycticorax nycticorax (L.)		2						
Red-footed falcon, Falco vaspertinus L.		2	2	2			V	NT
River warbler, Locustella fluviatilis (Wolf)		2						

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Savi's warbler, Locustella luscinioides (Savi)		2						
Wood sandpiper, Tringa glareola L.		2		1,2	+			
Common greenshank, Tringa nebularia (Gunnerus)		3		1,2	+			
Common redshank, Tringa totanus (L.)		3		1,2	+			
Green sandpiper, Tringa ochropus L.		2		1,2	+			
Spotted redshank, Tringa erythropus (Pall.)		3		1,2	+			
Common linnet, Acanthis cannabina (L.)		2						
Hawfinch, Coccothraustes coccothraustes (L.)		2						
Ruddy turnstone, Arenaria interpres (L.)		2		2	+			
Common merganser, Mergus merganser L.		3		1,2	+			
Lesser smew, Mergus albellus L.		2		1,2	+			
Red-breasted merganser, Mergus serrator L.	Vr	3		1,2	+			
Mallard, Anas platyrhynchos L.		3		1,2	+			
Lesser whitethroat, Sylvia curruca (L.)		2						
Barred warbler, Sylvia nisoria (Bechst.)		2						
Garden warbler, Sylvia borin (Bodd.)		2						
Common whitethroat, Sylvia communis Lath.		2						
Eurasian blackcap, Sylvia atricapilla (L.)		2						
Common raven, Corvus corax		3						
Eurasian wryneck, Jynx torquilla L.		2						
White-winged tern, Chlidonias leucopterus (Temm.)		2		2	+			
Whiskered tern, Chlidonias hybrida (Pall.)		2						
Caspian tern, Hydroprogne caspia (Pall.)	Vr	2		2	+			
Little tern, Sterna albifrons Pall.	Rd	2		2	+			
Common tern, Sterna hirundo L.		2		2	+			
Black tern, Chlidonias niger (L.)		2		2	+			
Common curlew, Numenius arquata (L.)	Zn	3		1,2	+			NT
Grey partridge, Perdix perdix		3					V	
Common moorhen, Gallinula chloropus		3						
Sand martin, Riparia riparia (L.)		2						
Common house martin, Delichon urbica (L.)		2						
Barn swallow, Hirundo rustica L.		2						
Whooper swan, Cygnus cygnus (L.)		2		1,2	+			
Mute swan, Cygnus olor (Gmel.)		3		1,2	+			
White stork, Ciconia ciconia (L.)		2		2	+			
Black stork, Ciconia nigra (L.)	Rd	2	2	2	+			
Eurasian coot, Fulica atra L.		3		2	+			
Montagu's harrier, Circus pygargus (L.)	Vr	2	2	1,2				
Western marsh harrier, Circus aeruginosus (L.)		2	2	1,2				
Hen harrier, Circus cyaneus (L.)	Rd	2	2	1,2				
Pallid harrier, Circus macrourus (S.G.Gmelin)	Zn	2	2	1,2			NT	NT

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Black-headed gull, Larus ridibundus		3						
Little gull, Larus minutus Pall.		2						
Common gull, Larus canus		3						
European herring gull, Larus argentatus Pontopp.							NT	
Eastern imperial eagle, Aquila heliaca Savigny	Rd	2	1	1,2				VU
Long-tailed duck, Clangula hyemalis (L.)				1,2	+			
Collared flycatcher, Ficedula albicollis (Temm.)		2		2				
Red-breasted flycatcher, Ficedula parva (Bechst.)		2		2				
Spotted flycatcher, Muscicapa striata (Pall.)		2		2				
European pied flycatcher, Ficedula hypoleuca (Pall.)		2		2				
Common sandpiper, Actitis hypoleucos (L.)		2		1,2	+			
Gadwall, Anas strepera L.	Rd			1,2	+			
Hoopoes, Upupa epops L.		2						
Bohemian waxwing, Bombycilla garrulous (L.)		2						
White-tailed eagle, Haliaeetus albicilla (L.)	Rd	2	1	1,2			R	
Hazel grouse, Tetrastes bonasia (L.)	Vr							
European honey buzzard, apivorus (L.)		2	2	1,2				
Great reed warbler, Acrocephalus arundinaceus (L.)		2						
Sedge warbler, Acrocephalus schoenobaenus (L.)		2						
Acquatic warbler, Acrocephalus paludicola (Vieill.)	Zn	2					V	VU
Eurasian reed warbler, Acrocephalus scirpaceus (Hermann)		2						
Marsh warbler, Acrocephalus palustris (Bechst.)		2						
Water rail, Rallus aquaticus		3						
Common quail, Coturnix coturnix (L.)		3		2				
Eurasian treecreeper, Certhia familiaris L.		2						
Greater spotted eagle, Aquila clanga Pall.	Zn	2	2	1,2				VU
Lesser spotted eagle, Aquila pomarina C.L.Brehm	Zn	2	2	1,2				
Eurasian hobby, Falco subbuteo L.		2	2	2				
Merlin, Falco columbarius L.		2	2	2				
Great crested grebe, Podiceps cristatus		3						
Little grebe, Podiceps ruficollis (Pall.)		2						
Red-necked grebe, Podiceps grisegena (Bodd.)		2		2	+			
Horned grebe, Podiceps auritus (L.)		2		2	+		NT	VU
Black-necked grebe, Podiceps nigricollis C.L.Brehm		2						
Little ringed plover, Charadrius dubius L.		2		2	+			
White wagtail, Motacilla alba L.		2						
Western yellow wagtail, Motacilla flava L.		2						
Citrine wagtail, Motacilla citreola Pall.		2						
Temminck's stint, Calidris temminckii (Leisl.)		2		1,2	+			

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Dunlin, Calidris alpina (L.)		2		1,2	+			
European nuthatch, Sitta europaea L.		2						
Spotted crake, Porzana porzana (L.)		2		2	+			
Little crake, Porzana parva (Scop.)		2		2	+			
Common pochard, Aythya ferina (L.)		3		1,2	+			
Eurasian eagle-owl, Bubo bubo (L.)	Rd	2	2					
Eurasian penduline tit, Remiz pendulinus (L.)		2						
Common kingfisher, Alcedo atthis (L.)		2						
Peregrine falcon, Falco peregrinus Tunst.	Rd	2	1	2				
Eurasian wigeon, Anas penelope L.		3		1,2	+			
Common swift, Apus apus		3						
European golden plover, Pluvialis apricaria (L.)		3		2	+			
Grey plover, Pluvialis squatarola (L.)		3		2	+			
European roller, Coracias garrulus L.	Zn	2		2			V	NT
European blue tit, Parus caeruleus L.		2						
Great tit, Parus major L.		2						
Bearded reedling, Panurus biarmicus (L.)		2						
Long-tailed tit, Aegithalos caudatus		3						
Coal tit, Parus ater L.		2						
European crested tit, Parus cristatus L.		2						
Common scoter, Melanitta nigra (L.)		3		1,2	+			
Bluethroat, Luscinia svecica (L.)		2		2				
Boreal owl, Aegolius funereus (L.)	Rd	2	2					
Little owl, Athene noctua		2	2					
Eurasian pygmy owl, Glaucidium passerinum (L.)	Vr	2	2					
Osprey, Pandion haliaetus (L.)	Zn	2	2	2				
Eurasian woodcock, Scolopax rusticola L.		3		1,2	+			
Short-eared owl, Asio flammeus (Pontop.)	Rd	2	2					
Great grey owl, Stris nebulosa Forster	Rd	2	2					
Long-eared owl, Asio otus (L.)		2	2					
Brown owl, Strix aluco L.		2	2					
Thrush nightingale, Luscinia luscinia (L.)		2		2				
Great grey shrike, Lanius excubitor L.	Rd	2						
Red-backed shrike, Lanius collurio L.		2						
Black grouse, Lyrurus tetrix (L.)	Zn							
Dunnock, Prunella modularis (Scop.)		2						
Whinchat, Saxicola rubetra (L.)		2		2				
African stonechat, Saxicola torquata		2		2				
Velvet scoter, Melanitta fusca (L.)		3		1,2	+			
Northern lapwing, Vanellus vanellus (L.)		3		2	+		V	
Grey heron, Ardea cinerea		3						
Great egret, Egretta alba (L.)		2		2	+			

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Little egret, Egretta garzetta (L.)								
Ferruginous duck, Aythya nyroca Güld.	Vr			1,2	+			NT
Tufted fuligula, Aythya fuligula (L.)		3		1,2	+			
Common redpoll, Acanthis flammea (L.)		2						
Common rosefinch, Carpodacus erythrinus (Pall.)		2						
Eurasian siskin, Spinus spinus (L.)		2						
Fieldfare, Turdus pilaris L.		3		2				
Garganey, Anas querquedula L.		3		1,2	+			
Common teal, Anas crecca L.		3		1,2	+			
Northern shoveler, Anas clypeata L.				1,2	+			
Black kite, Milvus migrans (Bodd.)	Vr	2	2	1,2				
Tree pipit, Anthus trivialis (L.)		2						
Meadow pipit, Anthus pratensis (L.)		2						
European serin, Serinus serinus (Pall.)		2						
European goldfinch, Carduelis carduelis (L.)		2						
Northern goshawk, Accipiter gentiles (L.)		2	2	1,2				
Eurasian sparrowhawk, Accipiter nisus (L.)		2	2	1,2				
MAMMALS								
Bicolored shrew, Crocidura leucodon	No	3						
Lesser white-toothed shrew, Crocidura suaveolens		3						
European beaver, Castor fiber		3						
European badger, Meles meles		3					NT	
Common shrew, Sorex araneus		3						
Eurasian pygmy shrew, Sorex minutus		3						
Common noctule, Nyctalus noctula Schreber	Vr	2		2		+		
Lesser noctule, Nyctalus leisleri (Kuhl.)	Rd	2		2		+		
Red noctule, Nyctalus noctula	Vr	2		2		+		
Red squirrel, Sciurus vulgaris		3						
Eurasian otter, Lutra lutra L.	No	2	1				NT	NT
Wolf, Canis lupus L.		2	2					
Forest dormouse, Dryomys nitedula		3						
Hazel dormouse, Muscardinus avellanarius		3						
Brown long-eared bat, Plecotus auritus (L.)	Vr	2		2		+	I	
Grey long-eared bat, Plecotus austriacus	Rk	2		2		+		
Stoat, Mustela erminea L.	Nd	3						
European hare, Lepus europaeus		3						
Mountain hare, Lepus timidus L.	Rd							
Serotine bat, Eptesicus serotinus Schreber	Vr	2		2		+		
European roe deer, Capreolus capreolus		3						
Beech marten, Martes foina		3						
European pine marten, Martes martes		3						
Water shrew, Neomys anomalus	Rd	3						

Species name (Ukrainian, Latin)	Red Book of Ukraine	Berne Convention	CITES	CMS	AEWA	EUROBATS	European Red List	Red List of IUCN
Least weasel, Mustela nivalis		3						
Parti-coloured bat, Vespertilio murinus L.	Vr	2		2		+		
European elk, Alces alces		3						
Northern birch mouse, Sicista betulina	Rk	2						
Southern birch mouse, Sicista subtilis	Zn	2					NT	
Nathusius's pipistrelle, Pipistrellus nathusii Keys.et.Blas.	Nd	2		2		+		
Common pipistrelle, Pipistrellus pipistrellus Schreber	Vd	3		2		+		
Soprano pipistrelle, Pipistrellus pygmaeus Leach	Nd	2		2		+		
Greater mouse-eared bat, Myotismyotis	Vr	2		2		+		
Daubenton's bat, Myotis daubentonii Kuhl	Vr	2		2		+		
Whiskered bat, Myotismystacinus	Vr	2		2		+		
Natterer's bat, Myotis nattereri	Vr	2		2		+		
Brandt's bat, Myotis brandtii (Eversmann)	Rd	2		2		+		
Bechstein's bat, Myotis bechsteini	Zn	2		2		+		
European mink, Mustela lutreola L.	Zn	2					E	EN
Red deer, Cervus elaphus		3						
Eurasian lynx, Lynx lynx L.	Rd	3	2					
Great water shrew, Neomys fodiens		3						
European polecat, Mustela putorius L.	No	3						
Common barbastelle, Barbastella barbastellus Schr.	Zn	2		2		+	V	NT
Total:	104	277	36	120	60	17	56	40

Note:
* categories of species of the Red Book of Ukraine 2009
zk (zn) – endangered
vr – vulnerable
rd (rk, ridk) – rare
no (neots) – unvalued

**Berne Convention
2 – Annex 2
3 – Annex 3
there are species from Annex II of the Convention for vertebrates; Annex III of the Convention includes 83.6 % of vertebrate fauna, some of which are common species for Ukraine and which do not need specific protection

***Washington Convention (CITES)
1 – Annex 1
2 – Annex 2
3 – Annex 3

****Bonn Convention
1 – Annex 1
2 – Annex 2

***** European Red List
Endangered E
Vulnerable V
Rare R

******IUCN European Red List
Endangered (EN)
Vulnerable (VU)
Near Threatened (NT)

Not well known K
Unidentified I
Threatened species being studied *

Low Risk (LR)
Least Concern (LC) – category not considered in the Table

30 new species of animals were revealed by detailed scientific research on the territory of nature reserves during the last nine years.

Table 2.7. List of animal species under protection and species that appeared on the territory of the Rivne Nature Reserve in 2008-2016

Name of species	Appeared	Disappeared	Cause
2008			
Black-winged damselfly	+		Revealed in detailed research
Emperor dragonfly	+		--//--
Red-footed falcon	+		--//--
Spotted nutcracker	+		--//--
Soprano pipistrelle	+		--//--
Serotine bat	+		--//--
2009			
Banded darter	+		--//--
Musk beetle	+		--//--
Westwood snow flea	+		--//--
2010			
Menetriesi ground beetle	+		--//--
Kentish glory	+		--//--
Common little bittern	+		--//--
River warbler	+		--//--
2011			
Brown long-eared bat	+		--//--
2012			
Diving beetle	+		--//--
Carpenter bee	+		--//--
Saker falcon	+		--//--
Caspian tern	+		--//--
Boreal owl	+		--//--
Common barbastelle	+		--//--
Lesser noctule	+		--//--
2013			
European medicinal leech	+		--//--
2014			
Flat bark beetle	+		--//--
Acquatic warbler	+		Re-registration during territory survey
2015			
Flat bark beetle	+		Revealed in detailed research
Acquatic warbler	+		Re-registration during territory survey
Lesser white-fronted goose	+		Identified in flying
2016			

Name of species	Appeared	Disappeared	Cause
Pallid harrier	+		Identified in flying
Golden eagle	+		Identified in flying
Eastern imperial eagle	+		Recording of a flight according to telemetry data
Natterer's bat	+		Revealed in detailed research
Brandt's bat	+		Revealed in detailed research
Mountain hare	+		Revealed in detailed research

All listed rare species of animals are regularly (constantly or sporadically) registered on the territory of the Rivne Nature Reserve and are typical for the region, so the indication of a new species in the inventory listing is the result of some more detailed research, rather than the emergence of a new species. The absence of a species can be proved only under conditions when the species is not indicated for several years of observation (under normal conditions the number and presence of species in a particular area depends on the dynamics in the population waves of the species, environmental and meteorological conditions of the current year).

Table 2.8. Protection and reproduction of fauna

District	Total number of fauna species included in the Red Book of Ukraine, units	Number of fauna species included in the Red Book of Ukraine, reproduced in the reserve, units	Number of populations of fauna species in the Red Book of Ukraine that are extinct, units
Volodymyrets	30	-	-
Dubrovytsia	39	-	-
Rokytne	43	-	-
Sarny	48	-	-
Zdolbuniv, Ostroh	52	-	-

Table 2.9. Endangered fauna species

Systematic group of animals	Endangered species					
	2000	2012	2013	2014	2015	2016
Insects	3	27	29	29	30	32
Other invertebrates	-	-	1	1	1	1
Bone fish	1	3	3	2	2	2
Amphibia	1	1	1	1	1	1
Reptiles	2	2	2	1	1	1
Birds	9	35	35	35	36	35
Mammals	5	17	22	24	23	28

2.5 Register of nature reserves

According to the data of the environmental protection departments of the Volyn and Rivne Regions, RNPP 30-km zone includes 48 (including “Bile Ozero”) nature reserves with different conservation status (Figure 2.1), the area of which is more than 12 thousand hectares. Basically, these are nature reserves of national significance located within the Manevychi district of the Volyn region and the Volodymyrets district of the Rivne Region.

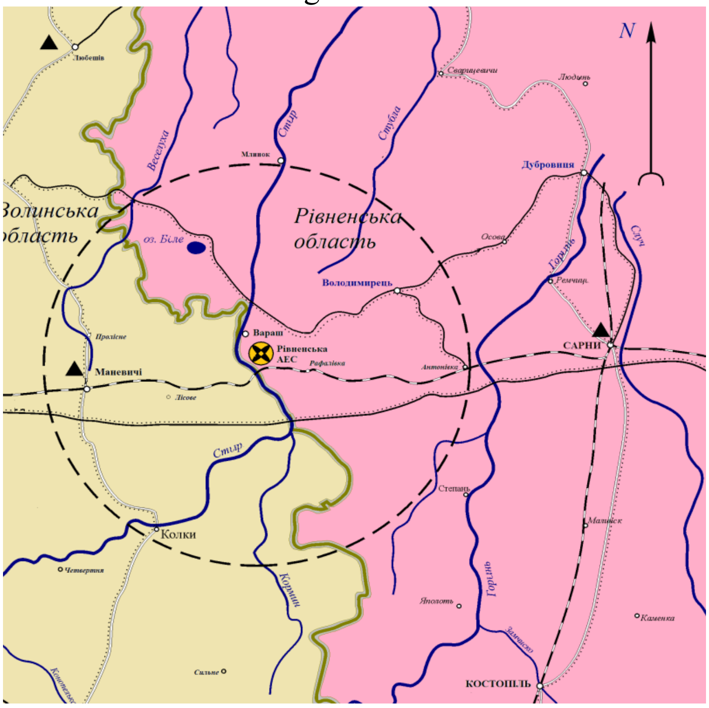

Figure 2.1. Location of RNPP and indication of RNPP 30-km zone, which covers the territory of the Volyn and Rivne Regions

Botanical and forest reserves (23 and 7 reserves correspondently), which are places for rare and minor species, are among the objects of the nature reserve fund. Besides, there are four hydrological sanctuaries, five common zoological reserves, four ornithological, two complex and one swamp reserves. The Bile Ozero Reserve was created in 2000.

There are Kolodiisky and Kostiukhnivsky Botanical Sanctuaries with a total area of 17.0 hectares to the west of RNPP in the immediated vicinity of the nuclear power plant in the floodplain of the Holubytsia River (tributary of the Styr River). Besides, there are Vovchytsky Botanical Reserve (10.0 hectares), Chorna Dolyna Ornithological Sanctuary, Manevytsky Forest Reserves (16.0 hectares), Dubyna (70.1 hectares), Berezovyi Hai (10.5 hectares), Manevytsky Common Zoological Reserve (138.0 hectares), hydrological sanctuary at the Hlybotske Lake (9.5 hectares).

There are Okonski Dzherela Hydrological Sanctuary (0.55 hectares), Okonski Fir Wood Reserve (2.6 hectares) and Hradiivska Dubyn Forestry (7.5 hectares) to the north-west of RNPP.

Chartoryisky Common Zoological Sanctuary (188.0 hectares) and Chartoryisky Fir Wood Botanical Sanctuary (5.9 hectares) are located to the south of RNPP in the floodplain of the Okonka River. Besides, there are Zarichchia Forest Sanctuary (20.0 hectares), Telchisky Common Zoological Sanctuary (66.7 hectares) and Zhuravychivska Forest Sanctuary (2.4 hectares).

There are seven botanical reserves to the south-east of RNPP: Velykoosnytsky (57.2 hectares), Maloosnytsky (9.0 hectares), Telchivsky (33.0 hectares), Osoka (56.5 hectares), Common Oak (0.3 hectares).

There are several reserves to the north-east of RNPP for different purposes. Vizhar (36.0 hectares), Khinotsky (2267.0 hectares), Chervonoselsky (1004.0 hectares) are the botanical reserves. There is one of the largest botanical reserves named Voronkovsky Reserve with an area of 2277.0 hectares and Voronky Lake with the swamp sanctuary (23.0 hectares). There is an Antonivka Park (9.7 hectares) in the Antonivka village for conservation of artificially created plantations and Volodymyretsky Park (3.0 hectares) in the Volodymyrets village.

There is the ornithological reserve Urochyshche Styrske (273.0 hectares) to the north of RNPP at a considerable distance from the nuclear power plant. There are Mulchytsky (3410.0 hectares) and Ozersky (1840.0 hectares) Botanical Sanctuaries, Likot Common Zoological Reserve (144.0 hectares), Chornyi Busel Ornithological Reserve (1840.0 hectares) and Karasynsky Forest Reserve (9.4 hectares) to the north-west.

Therefore, nature reserve fund objects in RNPP 30-km zone are distributed unevenly. The largest number of nature reserves is concentrated in the northern (N - 1, NE - 10, NW - 5) and southern (S - 5, SE - 7, NW - 4) directions from RNPP (16 nature reserves). Nine reserves are located to the west of RNPP. The largest nature reserves are located in the north-east and north-west of RNPP 30-km zone with the total area of 11452.7 hectares. The total area of the reserves located in the southern directions is 449.7 hectares and 271.1 hectares for the reserves located to the west of RNPP.

Table 2.10. Register of nature reserves

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
1 Voronky Lake	Swamp	23.0 (27.4)	Voronky village, Volodymyretsky district	Zoria Collective Farm	Solution of oblast executive committee No. 343 dated 22 November 1983
2 Velykoosnytsky	Botanical	57.2 (22.1)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 39, area 3, 15-18	Kolky State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
3 Volchytsky	Botanical	10.0 (16.8)	Manevychi district, Kostiukhnivka village, Volchytske Forestry, square 3, area 1	Manevychi State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
4 Kolodiisky	Botanical	9.5 (12.9)	Manevychi district, Kostiukhnivka village, Volchytske Forestry, square 8, area 3	Manevychi State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
5 Kostiukhnivsky	Botanical	7.5 (13.1)	Manevychi district, Kostiukhnivka village, Volchytske Forestry, square 15, area 3-5	Manevychi State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
6 Maloosnytsky	Botanical	9.0 (20.7)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 32, area 22	Kolky State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
7 Manevytsky	Botanical	6.3 (18.3)	Manevychi district, Manevychi village, Volchytske Forestry, square 40, area 23	Manevychi State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
8 Osoka	Botanical	56.5 (22.3)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 40, area 1, 12, 14, 16, 21	Kolky State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
9 Telchivsky	Botanical	33.0 (21.2)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 39, area 3, 15-18	Kolky State Forestry	Solution of oblast executive committee No. 493 dated 30 December 1980
10 Chartoryisky Fir Wood	Botanical	5.9 (11.9)	Manevychi district, Stary Chartoryisk village, square 55, area 3, 6	Manevychi State Forestry	Solution of oblast executive committee No. 4/3 dated 09 December 1998
11 Okonsky Fir Wood	Botanical	2.6 (20.0)	Manevychi district, Severynivka village, square 3, area 20	Manevychi State Forestry	Resolution of oblast executive committee No. 361-r dated 20 November 1986
12 Common Oak-1	Botanical	0.01 (20.7)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 32	Kolky State Forestry	Solution of oblast executive committee No. 255 dated 11 July 1972
13 Common Oak-2	Botanical	0.01 (18.8)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 25, area 23	Kolky State Forestry	Solution of oblast executive committee No. 255 dated 11 July 1972
14 Common Oak-3	Botanical	0.01 (18.0)	Manevychi district, Velyka Osnytsia, Osnytske Forestry, square 15, area 17	Kolky State Forestry	Solution of oblast executive committee No. 255 dated 11 July 1972

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
15 Khinotsky	Botanical	2267.0 (27.4)	Khinotske Forestry, square 1, 2, 4, 5, 9, Stepanohradske Forestry, square 30, 33, 34, 37, 38, 41, 42, Khinotske Forestry, square 3, 6, 7, 8, Stepanohradske Forestry, square 27-29, 31, 32, 36, 40, 46		
16 Ozersky	Botanical	1840.0 (28.4)	Ozeretske Forestry, square 1, 2, 5-7, 10-15, 17-20 Ozeretske Forestry, square 4, 8, 20, Partyzanske Forestry, square 55-57	Rafalivka State Forestry	Solution of oblast executive committee No. 343 dated 22 November 1983
17 Mulchytsky	Botanical	3410.0 (24.6)	Ozeretske Forestry, square 33-37, 39, 40, 46, 47, 52, Mulchytske Forestry, square 3, 5, 7, 8, 15-18, 23, 24, 27-32	Rafalivka State Forestry	Solution of oblast executive committee No. 343 dated 22 November 1983
18 Krasnoselsky	Botanical	1004.0 (21.2)	Krasnoselske Forestry, square 15, 24-27, 40-43	Volodymyrets State Forestry	Solution of oblast executive committee No. 343 dated 22 November 1983
19 Voronkovsky	Botanical	2277.0 (29.4)	Voronkovske Forestry, square 17, 22-26, 28-34, 36-42, 46, 51, 52, Zoria Collective Farm, Voronkovske Forestry, square 18-21, 27, 35, 44-48	Volodymyrets State Forestry, Zoria Collective Farm	Solution of oblast executive committee No. 343 dated 22 November 1983
20 Vizhar Land	Botanical	36.0 (18.9)	Druzhba Collective Farm, Dovhovolia village	Druzhba Collective Farm	Solution of oblast executive committee No. 343 dated 22 November 1983
21 Lypne Land	Botanical	40.0 (21.4)	Urozhai Collective Farm, Lypno village	Urozhai Collective Farm	Solution of oblast executive committee No. 343 dated 22 November 1983

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
22 Antonivka Park	Botanical	9.7 (27.3)	Antonivka village, Volodymyrets district	Antonivka Village Council	Solution of oblast executive committee No. 33 dated 28 February 1995
23 Potky Land	Botanical	9.0 (28.3)	Zoria collective farm, Voronky village	Zoria collective farm	Solution of oblast executive committee No. 343 dated 22 November 1983
24 Volchytsky	Ornithological	290.0 (17.1)	Manevychi district, Volchytske Forestry, square 5, area 4, square 20, 21	Manevychi State Forestry	Resolution of oblast executive committee No. 18-r dated 03 March 1993
25 Zhuravychivska	Botanical	2.4 (29)	Manevychi district, Rudnyky village, Rudnykivske Forestry, square 33, area 2	Kolky State Forestry	Solution of oblast executive committee No. 17/19 dated 11 July 1972
26 Okonski Dzherela	Hydrological	0.55 (25.7)	Manevychi district, Okonsk village	Manevytsky Fabrication Shop	Solution of oblast executive committee No. 255 dated 11 July 1972
27 Rudnykivsky	Forest	6.5 (28.2)	Manevychi district, Rudnyky village, Rudnykivske Forestry, square 29, area 4	Kolky State Forestry	Solution of oblast executive committee No. 17/19 dated 17 March 1994
28 Hlybotske Lake	Hydrological	9.5 (28.9)	Manevychi district, Horodok village, Horodokske Forestry, square 13, area 46, 47, 51	Horodok State Forestry	Solution of oblast executive committee No. 401 dated 23 November 1979
29 Poroda Land	Hydrological	36 (21.0)	Volodymyrets district	Volodymyrets State Forestry	Solution of oblast executive committee dated 1983
30 Tseptsevytske Dzherelo	Hydrological	1.0 (28.4)	Volodymyrets district	Volodymyrets State Forestry	Solution of oblast executive committee dated 1972

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
31 Volodymyretsky Park	Complex	3.0 (19.6)	Volodymyrets village, Residential School	Volodymyrets Residential School	Solution of oblast executive committee No. 317 dated 20 June 1972
32 Hradiivska Dubyn	Forest	7.5 (27.7)	Manevychi district, Hradie village, Hradievske Forestry, square 49, area 30	Kolky State Forestry	Solution of oblast executive committee No. 17/19 dated 17 March 1994
33 Dubyna	Forest	70.1 (22.7)	Manevychi district, Manevychi village, Manevychi Forestry, square 25, area 23, square 26, area 10, square 29, area 5, 14, 19, square 30, area 8, 13	Manevychi State Forestry	Solution of oblast executive committee No. 226 dated 31 October 1991
34 Zarichchia	Forest	20.0 (16.6)	Manevychi district, Zarichchia, Telkivske Forestry, square 7, area 21	Kolky State Forestry	Solution of oblast executive committee No. 17/19 dated 17 March 1994
35 Karasynsky	Forest	(26.5)	Manevychi district	Manevychi State Forestry	
36 Manevytsky	Forest	16.0 (24.6)	Manevychi district, Manevychi village, Manevychi Forestry, square 14, area 3	Manevychi State Forestry	Resolution of oblast executive committee No. 361-r dated 20 November 1986
37 Karasynsky	Common zoological	225.0 (29.8)	Manevychi district, Zamostie village, Karasynske Forestry, square 40, 41	Manevychi State Forestry	Solution of oblast executive committee No. 226 dated 31 October 1991
38 Berezovyi Hai	Forest	10.5 (22.9)	Manevychi district, Prylisne village, Horodok Forestry, square 53, area 2	Horodok State Forestry	Solution of oblast executive committee No. 226 dated 31 October 1991

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
39 Teletsky	Common zoological	66.7 (18.0)	Manevychi district, Kulykovychi village, Teletske Forestry, square 14, area 6, 12, 23, 40	Kolky State Forestry	Resolution of oblast executive committee No. 18-r dated 03 March 1993
40 Chartoryisky	Common zoological	188.0 (9.9)	Manevychi district, Chartoryisk village, Chartoryiske Forestry, square 29, 40	Manevychi State Forestry	Solution of oblast executive committee No. 226 dated 31 October 1991
41 Lokot	Common zoological	144.0 (25.9)	Manevychi district, Serkhiv village, Serkhivske Forestry, square 2	Manevychi State Forestry	Resolution of oblast executive committee No. 18-r dated 03 March 1993
42 Manevytsky	Common zoological	138.0 (28.1)	Manevychi district, Manevychi Forestry, square 2	Manevychi State Forestry	Solution of oblast executive committee No. 226 dated 31 October 1991
43 Chornyi busel	Ornithological	32.1 (27.7)	Manevychi district, Karasyn village, Karasynske Forestry, square 44, area 18, square 57, area 29, square 64, area 19	Manevychi State Forestry	Resolution of oblast executive committee No. 18-r dated 03 March 1993
44 Styrske Land	Ornithological	273.0 (29.0)	Bilsky Collective Farm in Telkovychi village, Dibrivsky Collective Farm	Bilsky Collective Farm, Dibrivsky Collective Farm	Solution of oblast executive committee No. 343 dated 22 November 1983
45 Romanshchyna Land	Ornithological	90.0 (26.3)	Volodymyrets district	Volodymyrets State Forestry	
46 Chorna Dolyna	Ornithological	419.0 (18.8)	Manevychi district, Haluzia village, Haluzia Forestry, square 48-50	Manevychi State Forestry	Resolution of oblast executive committee No. 18-r dated 03 March 1993

Reserve name	Category	Area, hectares (distance from RNPP, (km)	Reserve location	Enterprise, organizations, land using establishments supervising the reserve	Resolution, solution according to which the reserve was created
47 Cherensky	Botanical	903.0 (28.7)	Manevychi district, to the north of Karasyn village, Zamostie village, Karasyn Forestry, square 26, area 6, square 27, area 2, square 29, area 16, square 30, area 2, 4, square 31-33, square 37-38	Manevychi State Forestry	Resolution of the Council of Ministers of Ukraine No. 383 dated 03 August 1978

2.5.1 Protected areas and objects subject to special protection

There is a network of the nature reserve fund, which as of 01 January 2017 consists of 311 territories and objects with a total area of 181.5 thousand hectares making 9.05 % of a total area of the region, including 27 objects of the national significance with a total area of 64.9 thousand hectares and 283 objects of local significance with a total area of 116.6 thousand hectares [44] in order to ensure balanced environmental development, conservation of the populations of flora and fauna species.

The most significant objects of the nature reserve fund in the region are as follows:

Rivne Nature Reserve with a total area of 42.3 thousand hectares is the largest reserve in Ukraine and it consists of four massifs located on the territory of Volodymyrets, Dubrovytsia, Rokytne, Sarny districts. The most beautiful lakes of Ukrainian Polissia, Somyne and Bile, and several wetlands of international significance “Perebrody”, “Syra Pohonia”, “Somyne” are located in this reserve.

The entire complex of nature with all its biodiversity, including the floral component, is under protection on the territory of the Rivne Nature Reserve.

Derman-Ostroh National Nature Park with an area of 5.448 thousand hectares is located on the territory of Ostroh and Zdolbuniv districts. It occupies a narrow part of the Small Polissia, which is closed between the Misotsky ridge and Kremenets hill. The park was created in order to preserve valuable natural territories, historical and cultural complexes and objects; create conditions for organized tourism, rehabilitation and other recreational activities in natural conditions keeping to the regime of protecting nature reserves and objects.

Three regional landscape parks:

Prypiat-Stokhid with an area of 21.6 thousand hectares is located on the territory of Zariche district. It represents one of the unique natural complexes in Ukraine and Eastern Europe, because the Prypiat River and Stokhid River merging here resemble the Danube Delta.

Nadsluchansky with an area of 17.2 thousand hectares is located on the territory of Berezne district and has unique landscapes of the so-called Nadsluchanska Switzerland.

Derman-Mostivsky with an area of 19.8 thousand hectares is located on the territory of Zdolbuniv district. The intention of park creation was to preserve the traditional management activities on the territory and to develop new types of activities – recreation and tourism, as well as to promote the conservation of unique typical nature complexes, historical and cultural monuments of ancient Derman and other settlements.

The State Dendrological Park of the Berezne Forest College with an area of 29.5 hectares in the Berezne city with about 750 species of flora, out of which 18 species are included in the Red Book of Ukraine. In addition to the plants typical for this area, there are exotic representatives of the Far East, Siberia, Crimea, Caucasus, Central Asia, America, Japan and China.

Rivne Zoological Park with an area of 11.6 hectares in Rivne is a unique natural complex in the city system, which combines the natural environment and artificial structures and serves for the keeping of different types of animals in captivity. The main tasks of the zoo is to keep and demonstrate living representatives of wild fauna, educational activities, conservation and breeding of rare, endangered species of animals, research and development activities on studying biology of wildlife. The zoo contains 175 species of animals, of which ten species are included in the Red Book of Ukraine.

Table 2.11 Structure and dynamics of nature reserves (national significance and local significance)

Category of object	Number				Area, thousand hectares				Area of strict reserves, thousand hectares			
	2000	2014	2015	2016	2000	2014	2015	2016	2000	2014	2015	2016
Nature reserves	1	1	1	1	47.047	42.289	42.289	42.289	42.289	42.289	42.289	42.289
National nature parks	-	1	1	1	-	5.448	5.448	5.448	-	-	-	-
Regional landscape parks	2	3	3	3	38.871	58.708	58.708	58.708	-	-	-	-
National significance sanctuaries	13	13	13	13	16.457	16.720	16.720	16.720	-	-	-	-
including:												
- common zoological	1	1	1	1	0.100	0.100	0.100	0.100	-	-	-	-
- botanical	8	8	8	8	12.321	12.301	12.301	12.301	-	-	-	-
- landscape	1	1	1	1	0.927	0.905	0.905	0.905	-	-	-	-
- forest	1	1	1	1	0.110	0.110	0.110	0.110	-	-	-	-
- hydrological	2	2	2	2	2.999	3.304	3.304	3.304	-	-	-	-
LOCAL SIGNIFICANCE SANCTUARIES	98	112	112	112	49.679	53.887	53.887	53.887	-	-	-	-
including:												
- common zoological	6	6	6	6	7.797	7.037	7.037	7.037	-	-	-	-
- botanical	31	38	38	38	28.718	32.372	32.372	32.372	-	-	-	-
- landscape	3	10	10	10	1.407	2.201	2.201	2.201	-	-	-	-
- forest	15	16	16	16	2.084	2.143	2.143	2.143	-	-	-	-
- hydrological	10	11	11	11	1.760	2.442	2.442	2.442	-	-	-	-
- ornithological	9	9	9	9	1.556	1.556	1.556	1.556	-	-	-	-
- entomological	18	16	16	16	0.371	0.344	0.344	0.344	-	-	-	-
- geological	4	4	4	4	2.731	2.460	2.460	2.460	-	-	-	-
- ichtyological	2	2	2	2	3.255	3.255	3.255	3.255	-	-	-	-
National nature monuments	8	8	8	8	0.391	0.420	0.420	0.420	-	-	-	-
including:												
- complex	1	1	1	1	0.048	0.091	0.091	0.091	-	-	-	-
- botanical	4	4	4	4	0.256	0.243	0.243	0.243	-	-	-	-
- zoological	1	1	1	1	0.014	0.013	0.013	0.013	-	-	-	-
- hydrological	2	2	2	2	0.073	0.073	0.073	0.073	-	-	-	-

Local nature monuments	41	59	59	59	0.306	0.394	0.394	0.394	-	-	-	-
including:												
- complex	11	13	13	13	0.112	0.114	0.114	0.114	-	-	-	-
- botanical	23	31	31	31	0.186	0.220	0.220	0.220	-	-	-	-
- hydrological	5	13	13	13	0.005	0.056	0.056	0.056	-	-	-	-
- geological	2	2	2	2	0.003	0.003	0.003	0.003	-	-	-	-
Dendrological parks	1	1	1	1	0.029	0.029	0.029	0.029	-	-	-	-
Zoological parks	1	1	1	1	0.012	0.012	0.012	0.012	-	-	-	-
Parks and monuments of garden and park art of national significance	2	2	2	2	0.039	0.039	0.039	0.039	-	-	-	-
Parks and monuments of garden and park art of local significance	11	12	12	13	0.121	0.128	0.128	0.140	-	-	-	-
State protected lands	90	97	97	97	3.011	3.455	3.455	3.455	-	-	-	-
including:												
- forest	80	86	86	86	2.183	2.626	2.626	2.626	-	-	-	-
- swamp	10	11	11	11	0.828	0.829	0.829	0.829	-	-	-	-
Total in the region	268	310	310	311	155.963	181.530	181.530	181.542	42.289	42.289	42.289	42.289

2.6 Assessment of RNPP impact on the flora and fauna

The experience in the mitigation of accidents at Chornobyl NPP and monitoring the processes in all sectors of human life, including the assessment of impacts on the environment, in particular, on the flora, shows that it is necessary to consider not only the impact of radioactive contamination, but the whole complex of environmental factors.

This is due to the fact that even such a powerful accident, which led to huge economic, social and other losses, human casualties, affected the plants only as changes in the internal structure of organisms, and teratomas of certain organisms practically did not affect the population, species and higher levels. On the other hand, the accumulation of radionuclides by plant organisms, which serve as food for animals and ultimately are delivered to a human, closely correlates with other environmental factors (for example, humidity, acidity of soils, etc.).

It is not possible to separate the impact of RNPP operation on the flora, therefore, it is necessary to evaluate the whole urban complex, which includes both the nuclear power plant with its infrastructure and Varash with a system of communications, etc., in general.

Such an impact shall be considered in two aspects: direct related to the operation of the nuclear power plant that is the source of environmental contamination by radionuclides (in particular, in the event of accident) and indirect caused by different forms of anthropogenic impact (urbanization, recreation, felling, amelioration, etc.).

The second aspect is the most important, not only because in the event of accident after the resettlement of people and changes in the economic activities there will be significant changes in the structure of ecosystems, but also because the structure of ecosystems largely determines their stability, the method and intensity of radionuclide distribution cycles. Given this, it is necessary to consider first the indirect change in the ecosystems, which occur due to the agricultural activities of people in RNPP 30-km zone. There may be changes in the composition of forests, populations of flora and fauna. More detailed study was conducted in the assessment of possible impact of RNPP on the environment. The information on the assessment of RNPP impact is presented in Annex A to this study.

2.6.1 Methodology for assessment of environmental factors

Due to the fact that the analysis of environmental factors is rather complicated, expensive and requires a lot of experiments with many repetitions, involvement of a large number of specialists, the appropriate equipment, obtaining simultaneous results for the entire RNPP 30-km zone, it is really impossible to do it.

Therefore, we applied a qualitatively another approach – the method of phytoindication, tested on many objects, including the study of KhNPP and ChNPP 30-km zone. We decided to choose the phytoindication method because plants react very sensitively to changes in various environmental factors, external effects. Due to their biological characteristics, they have different thresholds of sensitivity and show a different reaction, which is often seen visually. Biological objects of different levels of organizations are used as indicators and indexes (assessment objects).

Superorganism systems of existence and functioning were used as indicators: organisms, populations and species, ecosystems (biogeocoenoses).

Separate species of plants (species indication) and their combinations (synphytoindication) were used as indicators. The choice of species indicators was caused, on the one hand, by the roles of a certain species in biocoenosis, and on the other hand by the degree of its study, behavior of the indicative value in relation to the impact of a particular environmental factor. Particular attention was paid to rare species recorded in the Red Book of Ukraine [59].

The method of synphytoindication was developed at the M.G. Kholodny Institute of Botany of the NAS of Ukraine [60]. Its essence lies in the fact that the plant community, which forms its internal microsphere, largely determines a set of species that delicately reacts to the environmental changes and reflects the ecology of the ecotope. Therefore, the flora composition of the coenosis is a good and sensitive indicator of the state, functioning and dynamics of ecosystems. The methodology includes the development of the scales of species, which reflect the impact of certain environmental factors, the database and the corresponding data processing program. In this case, the standard methods of statistical processing of data (x (arithmetic mean), σ (mean deviation), etc.) and methods of regression, ordination, correlation, gradient analysis [61] were used.

The existing database makes it possible to assess the changes in factors such as soil moisture, total salt and acid regime, nitrogen content, carbonates in soil, a number of microclimatic factors, and other. The following scales were used for this purpose.

In relation to soil moisture (Hd), the species are divided into 23 groups (together with intermediate groups).

1. Hyperxerophytes – plants of extremely dry desert ecotopes with very limited rainfall penetration of root-bearing soil layer (productive stock of soil moisture Wpr = 15-25 mm).

3. Perxerophytes – plants of very dry semi-deserted ecotopes with limited rainfall penetration of root-bearing soil layer (Wpr = 25-40 mm).

5. Xerophytes – plants of dry steppe ecotopes with limited rainfall and melt water penetration of root-bearing soil layer (Wpr = 40-60 mm).

7. Subxerophytes – plants of dry meadow-steppe ecotopes with insignificant rainfall and melt water penetration of root-bearing soil layer (Wpr = 60-80 mm).

9. Submesophytes – plants of dry forest-meadow ecotopes with moderate rainfall and melt water penetration of root-bearing soil layer (Wpr = 80-100 mm).

11. Mesophytes – plants of fresh forest-meadow ecotopes with full rainfall and melt water penetration of root-bearing soil layer (Wpr = 100-150 mm).

13. Hygromesophites – plants of moisture forest-meadow ecotopes with temporary excessive moisture of root-bearing soil layer with groundwater (Wpr = 150-185 mm).

15. Hygrophytes – plants of damp forest-meadow ecotopes with practically constant capillary moistening of root-bearing soil layer (Wpr = 185-235 mm).

17. Perhygrophytes – plants of wet swamp-forest-meadow ecotopes with maximum capillary moistening of root-bearing soil layer (Wpr = 235-310 mm).

19. Subhydrophytes – plants of wet ecotopes of swamps and highland subalpine belt (Wpr = 310-360 mm).

21. Hydrophytes – plants of coastal-water habitats with permanent watering of root-bearing soil layer (Wpr > 360 mm).

22. Hyperhydrophytes – plants of acquatic habitats with constant flooding.

Acid soil regime (Rc) depends on the chemical composition of the soil and soil-forming rocks, as well as the vegetation type. In relation to the acid regime, all species are divided into 13 ECOGROUPS [62].

1. Hyperacidophils – species that grow on very acid (pH 3.5-3.7) soils. oligotrophic swamps. alpine meadows. etc.

2. Peracidophils – species that grow on rather acid (pH 3.7-4.5) soils.

3. Acidophils – species that grow on acid (pH 4.5-5.5) sod podzolic soils.

7. Subacidophils – species that grow on slightly acid (pH 5.5-6.5) soils.

9. Neutrophils – species that grow on neutral acid (pH 6.5-7.1) soils.

11. Basiphils – species that grow on alkaline (pH 7.2-8.0) soils.

13. Hyperbasiphils – species (alkaliphilic organisms) that grow on very alkaline (pH 8.0-10.0) soils.

The total salt regime (Tr) is a very important characteristic of soils, since it affects soil-forming processes and define the possibilities of adaptation of plant organisms. The 19-point scale, which includes ecotopes from oligotrophic to supergalophyte, on which the corresponding species grow, is constructed based on this indicator.

1. Oligotrophs – species that grow on soils very poor in salts (30-80 mg/dm^3 of dry residue of soil-water extract), HCO_3^-, SO_4^{2-}, Cl^- are absent.

3. Semioligotrophs – species that grow on leached soils poor in salts (75-100 mg/dm^3 of dry residue of soil-water extract), HCO_3^-, SO_4^{2-}, Cl^- are absent.

5. Mesotrophes – species that grow on soils poor in salts (95-150 mg/dm^3 of dry residue of soil-water extract), HCO_3^- is present, SO_4^{2-}, Cl^- are absent.

7. Semieurytrops – species that grow on soils rich in salt (150-200 mg/dm^3 of dry residue of soil-water extract), with content of HCO_3^- - 4-16 mg/100 g of soil, and traces of SO_4^{2-}, Cl^-.

9. Eutrophs – species that grow on rich, but balanced in salt soils, black earth without soil salination (content of HCO_3^- - 30-50 mg/100 g of soil), and SO_4^{2-}, Cl^- in small quantities.

11. Suboligotrophs – species that grow on carbonate-based soils (excess of HCO_3^- salts).

13. Subgalotrophs – species that grow on soils with sulfate type of salinity.

15. Mesogalotrophs – species that grow on soils with excessive sulfate type of salinity.

17. Halotrophs (halophytes) – species that grow on soils with chloride type of salinity.

19. Superhalotrophs (superhalophytes) – species that grow on soils with excessive chloride salinity.

Carbonates ($CaCO_3$, $MgCO_3$) not only participate in soil-forming processes, but also act as a parent rock (chalk, limestone, dolomite) with specific flora. In dry conditions, carbonates face intensive processes of species formation, as evidenced by the presence of endemic species. In relation to the content of carbonates in the soil, the species are divided in 13 groups:

1. Hypercarbonatephobes – species that grow on soils, which do not contain $CO_3{}^{2-}$ even in small amounts.

3. Carbonatophobes – species that grow on carbonate soils.

5. Hemicarbonatophobes – species that avoid carbonate soils.

Acarbonatophiles – species of neutral ecotopes that withstand a small amount of carbonates in the soil.

9. Hemicarbonatophiles – species that grow on soils rich in carbonates (on a forest basis).

11. Carbonatophiles – speies (optional carbonatophiles) that grow on soils rich in carbonates (rendzina soils).

13. Hypercarbonatophiles – species (obligate carbonatophiles) that grow on deposits of carbonates in the absence of soil.

Nitrogen (Nt) is an important constituent element of the soil and it determines its fertility, restricting the spread of many species. In the soil, it is found in different forms often inaccessible for plants. Therefore, for phytoindication, it is necessary to take into account mineral forms of nitrogen that are assimilated by plants - (NO_3) and ammonium (NH_4 +). If necessary, as related to nitrogen, the plants are divided into 11 groups.

1. Anitrophiles - species that grow on nitrogen-free soils, outcrops, deposits of bed rocks (carbonates, granites, sands).

3. Subanitrophiles – species that grow on soils very poor in mineral nitrogen.

5. Hemianitrophiles – species that grow on soils relatively poor in mineral nitrogen.

7. Heminitrophiles – species that grow on soils relatively rich in mineral nitrogen.

9. Eunitrophiles – species that grow on soils rich in mineral nitrogen.

11. Hypernitrophiles – species that grow on soils excessively rich in mineral nitrogen.

For each species, there are amplitude values that reflect the min and max of its growth in the range of the abovementioned scales. The second indicator is the values of the species in the coenosis expressed in points: 1 – the projective cover of species up to 1 %, 2 - 2-5 %, 3 - 6-20 %, 4 - 21-50 % and 5 -> 50 %.

On the basis of two indicators (the ecological amplitude of the species (x) and the degree of its projective cover (p), the average indicators of a certain factor for the ecotope (v) were calculated:

$$V = \Sigma x_i p_i / \Sigma p_i \quad (1)$$

The data obtained were subject to generally accepted statistical processing. The indicators lying beyond 3σ, a triple quadratic deviation, are dumped as erroneous, random.

Average indicators (V) were used to assess the syntaxon amplitudes, compare them with each other, assess dependences between the changes of one or another factors. To do this, one used the method of ordination analysis, the essence of which was that it is necessary to indicate ball scale for one factor on the x-axis, and indicate ball scale for another factor on y-axis. It is necessary to indicate values of these factors at the intersection of x-y-axes for each described area. The results of ordination made it possible to reveal the ecological specificity of syntaxones and threshold values of tolerance of different types of communities to the change in certain indicators.

2.6.2 Possible effects on the fauna of RNPP 30-km zone

In normal operation of the nuclear power plant, there will be no noticeable effects of RNPP 30-km zone on the fauna. Certain effects can be caused only by a further increase of the recreation impact on the Styr River floodplain. Due to the peculiarities of the vegetation, the pine forests adjacent to RNPP and Varash are characterized by impoverishment of the fauna and almost practical absence of rare and protected species. Maximum credible accident cannot significantly affect the rare and protected species of animals, since they are almost absent in pine forests.

In case of beyond design-basis accident, the changes in the fauna will be caused by the changes in agricultural activities, which will lead to a radical alteration of phytocoenoses (reduction of recreational and pasture loads, the appearance of large wastelands, etc.).

In the maximum credible accident and beyond design-basis accident, there will be accumulation of radionuclides in the food chains, which can cause negative changes in the structure of higher trophic levels, as well as the violation of the genetic structure of populations, the growth of the mutation background and remote genetic effects, and the strengthening of microevolutionary processes.

CONCLUSIONS

During the studies carried out within this project, the researchers collected and analyzed results of surveying different factors that impact the environment during the last five-seven years. However, earlier references starting from 80-ies of the previous century and sometimes even earlier were also used.

According to paras. 1.4.1-1.4.5 of this study of additional contamination of soils by radionuclides during normal operation of the power units, RNPP does not lead to any changes in soil properties. The results on checking dynamics of radioactive and chemical contamination of soils in future under normal operation of RNPP indicate that there will be no impact on soils in future.

Therefore, there is no need to take measures aimed at reducing individual doses for the public. The measures aimed at reducing the level of contamination depending on the degree of contamination based on justification and expediency criteria can be as follows: removing of the top soil layer, dust suppression, counter measures in agriculture, etc.

In agriculture, the need for taking special measures may be fulfilled only due to the exceeding of the established levels for the contamination of agricultural products, which may lead to exceeding of dose limit set for the public. Given the results of laboratory research (section 1.4.5.1 – 1.4.5.3) on the conducted check of milk, vegetables and grain cultures, there is no exceeding of specific activity of radionuclides, which will lead to exceeding dose limits for the public. Besides, it was shown that the existing level of background contamination of these territories by ^{137}Cs (about 35 – 38 Bq/m^2) can lead to exceeding of established permissible levels of this radionuclide in some agricultural products. Proper land use contributes to reducing the intensity of the migration of radionudclides in chains of agrobiocoenoses, increasing soil fertility and reducing erosion processes, that is why this issue is the most important in this surveyed region and is the one that needs maximum attention. Consideration of the ecological state of soils during the conduct of agricultural activities on the surveyed territory will contribute to their resistance to man-made contaminants and will in general contribute to the reproduction of the ecological state of biosphere.

However, since the accident at Chornobyl NPP, critical territories have been well studied and technologies have been developed to get products from these territories, which meet DR-2006 (permissible levels for radionuclides of 137Cs and 90Sr in food products and drinking water (State Health and Safety Standards DR-2006).

In case of emergencies, taking of long-term counter measures is based on results of radiation monitoring and other criteria established in NRBU-97.

The soil cover of RNPP 30-km zone is quite diverse. Its structure comprises sod podzolic, sod, alluvial, meadow, meadow-swamp, peat and peat-swamp soils, as well as peatlands of different compositions (a total of about 280 soil types). Due to the diversity of soil-forming rocks, different degrees of gleying, waterlogging, washing and soil peat content, the soil cover of RNPP 30-km zone is diverse in terms of both species and in their distribution.

The largest areas in the structure of RNPP 30-km soil cover are occupied by sod podzolic soils that are confined to the interriver and ancient alluvial plains and were formed under mixed and pine forests in conditions of stagnant and flowing water regime on ancient alluvial and water-glacial deposits. They are distributed almost throughout the territory and mostly in the central, western, eastern and south-eastern parts of the zone.

The analysis of the landscape structure of the territory allowed the identification of 18 individual landscapes united into four types of landscapes. Since the entire studied territory is located in the zone of mixed forests, zonal differences were the main criterion for the allocation of landscape types.

The background in the landscape structure of the territory include the inter-river plains, floodplain terraces, river floodplains. Subdominant lands are first the numerous wet and swampy cavities, sand dunes and oases, separate morainic hills, as well as slopes, mostly gentle; proluvial-diluvial hillsides; relatively poorly developed erosion network (mainly hollows), lowlands, potholes. The main role in their formation is played by moraine-water-glacial deposits (mainly sandy with the inclusion of debris of crystalline rocks, gravel and pebbles, less often – clay), ancient alluvial and alluvial sand and loam deposits.

The landscape-geochemical structure depends directly on the complexity of the landscape structure, which determined the originality of the landscape-geochemical and biochemical processes. Geosystems of RNPP 30-km zone belong to the six geochemical classes allocated on typomorphic elements: acid – 22.6 %, acid gley – 21.9 %, gley – 50 %, acid calcium – 0.4 %, calcium acid-gley – 0.3 %, calcium gley – 2.5 %.

Half of the territory of the geosystems within RNPP 30-km zone refer to the gley class.

RNPP caused insignificant impact on the change of water and physical properties of adjacent soils due to changes in the level of groundwater during its construction. It is possible to talk about the general effect of RNPP and land use only if the event when RNPP effluents enter the agricultural lands. Therefore, as a result of agrochemical treatment, the contaminating agents penetrate the soil profile to the depth of plowing sole and they evenly mix. In fact, there is an accelerated process of migration of those small amounts of contaminating agents, which can settle on the soil due to emissions from NPP.

Most of the soil cover in RNPP 30-km zone is represented by acidic sod-podzolic soils of light mechanical composition. They are characterized by high acidity, high permeability. In these conditions, there is an increased mobility of so-called cationogenic elements - Ca, Sr, Ba, Ra, Cu, K – and their entry into groundwater. The absorbing complex of these soils is unsaturated, so the part of elements got into the upper layer of soil and is absorbed by colloidal complexes in the exchange state.

Swamp soils, which occupy a significant part of the soil cover of RNPP 30-km zone, are also not resistant to man-made loads.

The degradation processes of soils related to the construction of RNPP are distributed only within the industrial site. Their presence in RNPP 30-km zone is not related to NPP operation. The main types of soil degradation in 30-km zone are related to the intensive use of soils for agricultural purposes, the implementation of a set of drainage ameliorations and further development of ameliorated lands.

The content of copper, zinc and cadmium in the soil of the territory adjacent to RNPP is located on the percentage abundance level. The probability of contamination of agricultural products by these microelements above the MPC is very low.

Soils of light mechanical composition (sand, gley-sand and sandy loam) prevail in RNPP 30-km zone. Light loamy soils have a small distribution, mainly in floodplains of rivers, middle loamy soils are rather rare.

Sod podzolic soils with a low content of humus of 0.1-3 % are predominant within RNPP 30-km zone. They occupy an area of 1864.3 km^2. The soils with a content of humus of 3.1-5.0 % are distributed on the territory of 205.7 km^2. The soils with a content of humus of 5.1-7.0 % are distributed on the territory of 152.5 km^2. Also, large areas are occupied by soils with a content of humus of 7.1-8.0 % and more than 8.0 % (524.6 km2) related to the presence of meadow, meadow-swamp soils and peatlands of varying capacity. Soils with a weak acid reaction (an area of 1269.9 km2) are the most widespread here. Smaller territories are occupied by soils with an acid and neutral reaction (an area of 604.9 km2 and 702.1 km2). Alkaline and low-alkaline soils are insignificantly distributed. Indicators of hydrologic acidity (mg eq/100 g of soil) range from 1.33 to 45.6 mg eq/100 g.

The whole range of gleyed soils (an area of 1382.8 km2) is presented in the studied region.

Indicators of calcium and magnesium in soils of RNPP 30-km area are homogeneous. The content of calcium for sod podzolic soils does not exceed 4 mg eq/100 g, for meadow-swamp, sod and peat soils – 10-17 mg eq/100 g. The highest indicators are in meadow gley sandy soils – 26 mg eq/100 g. The percentage nitrogen content is quite low – 0.08-0.4%.

The content of phosphorus in the soils of the surveyed territory is low – 0.02-0.09 %. In sod-concealed podzolic soils, sod weakly developed soils and meadow soils, it reaches 0.13-0.17 %. The percentage of potassium varies from 0.3 to 1.1 %. The smallest amount of potassium is found in peaty-swamp soils and peatlands – 0.3 %. Sod podzolic soils have 0.6 % of potassium, meadow-swamp – 0.7 %, sod – 0.9 %.

The density of the studied soils is characterized by an almost stable value close to 2.5 g/cm^3. The exceptions are swamp, peat-swamp soils and peatlands with the density of 1.5-1.7 g/cm^3. The values of volumetric mass vary a little, but variation boundaries are insignificant – 1.2-1.6 g/cm^3. The volumetric mass of peat soils is 0.2-0.25 g/cm^3.

The greatest mobility of man-made substances, including ^{137}Cs, is observed in swamp and meadow-swamp soils, that is in hydromorphic soils. As for automorphic soils, the indicators of considered water-physical properties (porosity, moisture content, maximum hygroscopy) are the largest in sod-podzolic sandy-light loamy soils and sod soils, and the lowest in sod-podzolic sandy soils.

In the analysis of land use structure, the following categories were identified:

1) agricultural lands, which include agricultural fields, cultural plantings within settlements (agrophytocoenoses of settlements), perennial plantings (gardens, hop yards, nursery gardens, etc.), pastures and grasslands:

2) forests;

3) swamps, lands occupied by water bodies, peatlands.

Forests (49.6 % of the whole territory) and agricultural lands (45.3 %) dominate in the land use structure of RNPP 30-km zone. The largest part of agricultural lands are made by fields 60.7 % and hayfields – 26.3 %.

The content of the moving forms of copper in the soils of the region is at level that is insufficient for normal plant growth. To increase the yield capacity, it is recommended to use microfertilizers containing this element.

The following elements are presented in the largest concentrations within RNPP 30-km zone: bromine (percentage abundance up to 15), chrome (up to 6), lead (up to 5), arsenic (up to 1). The rest of microelements, whose content has been determined - nickel, gallium, rubidium, strontium, stable isotopes – are contained in small amounts, percentage abundance of these elements does not exceed 1. It is typical that the high content of chrome, arsenic, bromine, lead is related to the Upper Prypiat and Sarny accumulative lowlands with prevailing sod-podzolic, sod and peat soils. High concentrations of arsenic, bromium and lead are related to soils, in which the content of organic substances is increased: sod, meadow, alluvial, peat.

Obtained experimental results did not make it possible to define the contribution of the above sources (motorway, peat briquette factory) in the general picture of the contamination of the regional environment by heavy metals. Data on the content of heavy metals in the soils and agricultural products did not show a statistically significant tendency to increasing in case of approaching the potential source of contamination.

The high content of bromine is associated with the natural conditions of the territory, and the high content of chrome, arsenic and lead in RNPP 30-km zone is likely to be of a man-made nature. It is necessary to state that high concentrations of these elements cannot be related to RNPP operation, which is explained by the fact that RNPP emissions do not include such elements as chrome, arsenic and lead.

The radiological situation in the region is determined by ^{137}Cs, mainly of Chornobyl origin. Contamination of RNPP 30-km zone consists of a superposition of global falls, falls resulting from the ChNPP accident and falls caused by aerosol emissions from operating units of RNPP. The last source of contamination is so insignificant that it is practically impossible to differentiate it from the total contamination. This is confirmed by the spatial distribution of radiocesium in the territories adjacent to the NPP, which does not correlate with the average wind rose for this region.

In the normal operation of NPP, there are two main sources of radionuclide income to the environment: gas-aerosol emissions and liquid discharges of NPP.

Under normal operation of RNPP, the formation of the primary field of contamination will depend on climatic conditions, especially the long-term wind regime (recurrence of winds of certain directions with certain velocities), taking into account the roughness of the earth's surface (orographic conditions and the height of the vegetation cover). According to this, radioactive releases will predominantly be spread in the eastern direction throughout the year. In the cold and warm periods, additional spread in north-western and south-eastern directions is possible.

Forecast assessment of geosystems under conditions of redistribution of strontium and cesium in landscapes as a result of water, air and biogenic migration is one of the important tasks. Such a comprehensive assessment of the territory envisages the consideration of all major types of migration taking into account their relationship and the set of factors that determine them.

On the territory of RNPP 30-km zone, the areas of potential occurrence of ^{137}Cs, ^{90}Sr are mainly concentrated in floodplains of a high and intermediate level, in low waterlogged floodplains, peatlands common in the north-western, north-eastern sectors, as well as small areas in the south-eastern, southern and south-western sectors of the zone. The main part of radionuclides in case of territory contamination will be carried out from the floodplains of RNPP 30-km zone during floods.

The transit of ^{137}Cs, ^{90}Sr can be performed according to the forms of the erosion networks, which are unevenly distributed throughout the zone and occur in the largest number in the north-eastern, western sectors of the zone, and in the immediate 10-km zone.

Primary accumulation with subsequent redistribution can take place in the central, north-eastern and western parts of the zone on the Volyn moraine ridge (on moraine-glacial, moraine-outwash, outwash plains and hills).

Since in NPP normal operation (according to research efforts of this EIA), there is practically no radioactive contamination of the territory, the performed assessment of ^{90}Sr and ^{137}Cs redistribution conditions is predictive and serves to analyze the possible contamination of the territory in the event of emergencies and to optimize the network of radioecological monitoring.

According to the geobotanical zoning, the surveyed territory of RNPP 30-km zone is located in the European broad-leaved region and refers to four geobotanical districts of the Polissia province.

According to the research and processing of the obtained materials, it has been established that natural vegetation occupies 66.5 % of the territory. Of these, 49.6 % are for forests, 10.9 % are for meadows, 4.6 % are for swamps, 1 % is for wastelands, 0.4 % is for aquatic vegetation.

Farmlands occupy 27.1 %, peat fields – 0.6 %, agrophytocoenoses with ruderal groups of settlements – 5.8 %.

Forests are predominant in the vegetation cover of the observation area, among which the dominant position belong to pine and oak-pine forests, which is due to edaphic factors. Relatively small areas are occupied by alder and birch forests and very small areas are occupied by oak, hornbeam-oak and fir forests. Meadow vegetation is represented by floodplain and continental meadows, where true meadows prevail. Eutrophic high-grass and mesotrophic sparsely-leaved and grass-shrub swamps dominate among swamps.

The forest fund has a great potential in harvesting technical, food and medical resources. Forest vegetation has a high aesthetic and recreational assessment. The use of forests for recreational purposes is insignificant, changes in plant cover are now far from the critical threshold.

The flora of the studied zone has 768 species representing 46.5 % of the entire flora of Polissia and 15 % of Ukrainian flora. The natural flora includes 613 species, 71 introduced species and 84 species of weeds. The species refer to 107 families and 311 genera. The spectrum of the ten leading families of boreal type is 9.3 % of the total number of families and 32.8 % of the total number of species. According to the number of species, boreal species such as Carex, Salix, Veronica, Juncus and Viola are predominant.

The vegetation is of great value and interest in the sozological respect. On a small area, there are 23 species from the Red Book of Ukraine, groups of relic species and species located on the habitat boundary. The rare species are represented by ten associations from the Green Book and 15 associations of regionally rare communities. The most valuable are the communities that act as relic species (lilies, yellow water-lily, swamp pod grass) and not widespread in Ukraine pine forests, fir and spruce forests located on the boundary of the habitat.

According to zoogeographical zoning, RNPP 30-km zone belongs to boreal European-Siberian subregion, Eastern European district, region of mixed, deciduous forest and forest-steppe area; subarea of Western or Volyn Polissia.

There are about four thousand species of insects inhabiting RNPP 30-km zone, which is about 14 % of the fauna of Ukraine.

In the greater part of RNPP 30-km zone, the natural entomocomplex is in a state of different degrees of degradation.

The analysis of possible changes in the conditions of hydrobionts shows that most of the main characteristics of the environment – temperature, salt content, gas regime will not change significantly due to the subsequence operation of RNPP units. In this regard, significant changes in the composition, number of populations and communities of hydrobionts are unlikely. However, the study of peculiarities related to the composition, the quantitative representation of hydrobiontes by major groups in the planktonic and contour subsystems show a certain specificity of the reaction of hydrobionts.

Microphytobenthos and microphytoperiphyton in river conditions are poorly developed due to significant flow velocities, low water transparency. Phytoperiphyton is well developed in open channels of NPP. It is likely that it will develop to a level when the periphyton algae, primarily filamentous blue-green, can become an obstacle to the equipment operation. The intensive photosynthesis of algae can affect the pH regime.

Investigation of zoobenthos in water reservoirs of RNPP showed that the development of zoobenthos organisms is slightly inhibited lower the industrial stormwater sewer system (ISSS) runoff in summer. In contrast, an increase in its abundance is observed in the autumn. In the operation of four power units, the changes in the development of water reservoirs are unlikely.

Studying the condition of forests showed that there are no damage to forest species by pollutants either on a regional scale or in the form of local fires in RNPP 30-km zone.

The assessment of RNPP effect on the vegetation was carried out both towards the direct radiation impact and impact of the economic activities caused by the operation of RNPP in the complex of social and economic development of the region. The effect of radiation is tangible only on the organism internal level and does not cause changes in the population, species or coenotic levels. The accumulation of radionuclides has a complex nature, depends on the species biology and is characterized by direct correlation with the soil moisture and the reverse correlation with acidity, the content of salts, in particular carbonates, on the basis of which common pine, heather (bilberries, blueberries, cranberries), mosses and lichens were proposed as sensitive bioindicators.

Under normal operation of NPP, when release of radionuclides will not exceed acceptable standards, the accumulation of radionuclides by plants will also not exceed the standards. The increased accumulation of radionuclides in the zone and beyond is caused not by RNPP operation, but by the accident at ChNPP in 1986.

Based on the increased accumulation of radionuclides by fungi, heather, especially in swamp ecosystems, it is necessary to perform radioecological monitoring and, if needed, to protect the population from using these resources.

In case of maximum design-basis and beyond design-basis accident, one can conclude that the distribution of radionuclides will be significantly different from the background depending on the properties of biological components and the specific environmental conditions.

It was necessary to consider the distribution of plant communities depending on humidity, acidity, salt regime of soils, content of carbonates and nitrogen in them, as well as the relationship between the change of these factors.

Increased effect of anthropogenic factors leads to such a change in the structure of ecosystems, which is aimed at increasing of the migration, transfer of radionuclides outside this ecosystem and prevents their accumulation.

Given the high yield (43.8 %) and the large number of settlements near RNPP, it is proposed to increase the percentage of afforestation by reducing the area of agricultural land in order to ensure protection against the consequences of possible extraordinary situations related to the environmental contamination.

In normal operation of RNPP units, there is no significant impact on the fauna of RNPP 30-km zone. Certain effect may be associated with the increase of recreational load on floodplain ecosystems of the Styr River.

Normal operation of RNPP will not have direct impact on RNPP 30-km zone fauna. Noticeable violations of the forage base, shelters, nesting sites and animal migration paths are not envisaged.

Possible violations of the forage base are mainly related to the changes in the vegetation, so even minor changes in the ratio of individual vegetation will inevitably affect the species composition and the ratio of certain groups of insects, acarians and other groups of animals. However, significant violations are possible mainly in the meadow complex due to cattle grazing. For other plant associations, changes are less significant and do not entail significant alterations in faunal complexes.

Some losses of meadow faunal complex are possible due to the degradation of meadow ecosystems as a result of increased recreational load, which, in the first place, can lead to a significant reduction in the species diversity of meadow entomocomplex.

Endemic species of animals in RNPP 30-km zone are absent. RNPP operation will not cause direct damage to rare, protected animals and species of the Red Book of Ukraine. Moreover, it should be noted that the maximum anthropogenic load is possible on the ecosystems that are the closest to Varash and RNPP, and due to the peculiarities of the vegetation (pine forests), ecosystems there are characterized by impoverishment of the fauna and almost complete absence of rare and protected species.

In case of design-basis accident at RNPP with the release of radioactive substances, there will be no changes in the species composition of invertebrates in the zone. Negative changes in populations of predatory and parasitic insects are possible, since they accumulate radionuclides through nutrition chains.

In case of beyond design-basis accident, potential changes in the fauna can be caused by changes in the economic activities, which can lead to significant reorganization of phytocoenoses (reduction of recreational and pasture loads, the appearance of large wastelands, etc.) and, correspondently, ecosystems in general. In conditions of maximum design-basis and especially beyond design-basis accident, there will be accumulation of radionuclides in the nutrition chains, which can cause changes in the structure of higher trophic levels, as well as a violation of the genetic structure of populations, the growth of the mutation background and remote genetic consequences, as well as microevolutionary processes.

Consequently, natural vegetation is largely preserved, plowing in the most of the territory is negligible and varies from 10 % in the northern and eastern part to 20-25 % in the western part. Only in the central part it rises to 43.5 %. Forests prevail in the vegetation with the average forest cover up to 49.6 %. Swamps in the surveyed territories are numerous and differ both in types of origin and in area.

There was a laboratory analysis performed in the environmental and chemical laboratory in the areas of sludge storage sites and landfill for construction and industrial waste of RNPP. The analysis of controlled characteristics shows that RNPP operation will not significantly affect the soil quality.

Soil sampling for the determination of radionuclides content is carried out in observation points with simultaneous sampling of grassy vegetation. Samples are taken in April-May in 22 control points from a layer of 0-5 cm and are measured with γ–spectrometers. The content of radionuclides in soil and vegetation is determined mainly by natural and man-made radionuclides (^{137}Cs of Chornobyl origin).

The fauna of RNPP OA is presented by animal complexes typical for the Polissia. More than 60 species of mammals and about 200 species of birds inhabit these territories. Rodents dominate among the first, but there are also predators: common fox, wolf, raccoon dog, weasel, stoat, etc. The birds are predominantly represented by tree-shrub species. The northern species of birds, black grouse, hazel grouse, wood grouse also occur in the Volyn Polissia. The reptiles are represented by common viper, common adder, smooth snake, anguine lizard, viviparous lizard, swamp turtle.

Many years of research has shown that radionuclide emissions do not increase the activity of man-made isotopes (^{137}Cs, ^{90}Sr, etc.). Accumulation of radionuclides in normal operation of NPP in vegetation will not exceed the permissible standards, and the current contamination by Chornobyl-origin ^{137}Cs in the observation area has been studied in details.

Given the accumulation of radionuclides by plants, the most contaminated are the swamps, and the highest concentration of radionuclides is indicated in moss, fungi and less in cranberries, blueberries.

The population should carefully use forest and swamp products, in particular mushrooms. Given that blueberries have a wider ecological amplitude, the magnitude of its contamination by radionuclides can significantly vary depending on local conditions. It is necessary to ensure thorough control of radionuclides in blueberries, the collection and purchase of which is carried out quite intensively.

In general, based on the analysis of changes in the background concentration of radionuclides with increasing of the distance from RNPP, it can be concluded that the radiation regime of NPP during its normal operation does not affect the vegetation and does not cause any changes at the level of individual plant species.

The use of cooling towers and spray pools instead of cooling pond made it possible to minimize negative impact of the NPP on ecosystems and preserve the valuable floodplain of the Styr River with meadow, shrub and forest complexes of animals.

REFERENCES

1. Енергетична стратегія України на період до 2030 року, схвалена розпорядженням Кабінету Міністрів України від 24.07.2013 р. № 1071-р.

2. Стратегічний план розвитку Державного підприємства «Національна атомна енергогенеруюча компанія «Енергоатом» на 2017-2021 роки.

3. Конвенція щодо оцінки впливу на навколишнє середовище в транскордонному контексті, ратифікована Законом України № 534 – XIV від 19.03.1999 р.

4. Протокол засідання міжвідомчої координаційної ради (МКР) з питань реалізації в Україні Конвенції про оцінку впливу на навколишнє середовище у транскордонному контексті (Конвенція ЕСПО) від 15 грудня 2016 року.

5. Закон України «Про оцінку впливу на довкілля» (Відомості Верховної Ради (ВВР), 2017, № 29, ст.315).

6. Директива 2001/42/ЄС Європейського Парламенту та Ради від 27 червня 2001 року «Про оцінку впливу окремих планів та програм на навколишнє середовище» (Офіційний вісник ЄС, L 197, 21 липня 2001 р.).

7. Договір від «27» березня 2018 р. № 347 «Проведення оцінки впливу на довкілля майданчику ВП «Рівненська АЕС» що було укладено між «ДП «НАЕК «Енергоатом» його відокремленим підрозділом – «Рівненською АЕС» та НТ - Інжиніринг.

8. Технічні вимоги на виконання послуги: «Проведення оцінки впливу на довкілля майданчику ВП «Рівненська АЕС». 083-01-ТВ-СОНС, затверджені головним інженером-першим заступником генерального директора ВП «Рівненська АЕС» від 06.02.2018 р. (Додаток А).

9. Закон України «Про оцінку впливу на довкілля» (Відомості Верховної Ради (ВВР), 2017, № 29, ст.315).

10. Закон України «Про охорону навколишнього природного середовища» від 25.07.1991 р № 1264-XII.

11. Закон України «Про екологічну експертизу» № 45/95-ВР від 09.09.1995 р.

12. Закон України «Про дозвільну діяльність у сфері використання ядерної енергії» від 11.01.2000 р. № 1370-XIV.

13. Закон України «Про використання ядерної енергії та радіаційну безпеку» від 08.02.1995 р. № 39/95-ВР.

14. Закон України «Про основні засади (стратегію) державної екологічної політики України на період до 2020 року» від 21.12.2010 № 2818-VI.

15. Закон України «Про об'єкти підвищеної небезпеки» від 18.01.2001 р.

16. ДСТУ ISO 14001:2006 Системи екологічного керування. Вимоги і керівні принципи.

17. Рекомендації щодо змісту матеріалів впливів діючих об'єктів на навколишнє середовище.

18. ДБН А.2.2-1-2003 «Склад і зміст матеріалів оцінки впливів на навколишнє середовище (ОВНС)».

19. ДБН А.2.2-1-2003 «Посібник до розроблення матеріалів оцінки впливів на навколишнє середовище».

20. Закон України «Про охорону атмосферного повітря» від 16.10.1992 р. № 2707;

21. Закон України «Про охорону навколишнього середовища» від 25.06.1991р. № 1264;

22. Закон України «Про інформацію» від 02.10.1992 р. № 2657;
23. Конвенція про доступ до інформації, участь громадськості в процесі прийняття рішень та доступ до правосуддя з питань, що стосуються довкілля від 06.07.1999 р. № 832-14;
24. Закон України «Про охорону земель» від 19.06.2003 р. № 0962;
25. Закон України «Про природно-заповідний фонд України» від 16.06.1992 р. № 2456;
26. Закон України «Про рослинний світ» від 09.04.1999 р. № 0591;
27. Закон України «Про тваринний світ» від 03.03.1993 р. № 3041 і від 13.12.2001 р. № 2894;
28. Земельний кодекс України від 25.10.2001 р. № 2768-14;
29. Постанова Кабінету Міністрів України от 27.07.95 р. № 554. Перелік видів діяльності та об'єктів, що становлять підвищену екологічну небезпеку;
30. Наказ Міністерства охорони навколишнього природного середовища України від 18.12.2003 N168 про затвердження Положення про участь громадськості у прийнятті рішень у сфері охорони довкілля.
31. Постанова Кабінету Міністрів України від 29.06.2011р. №771 «Про затвердження Порядку залучення громадськості до обговорення питань щодо прийняття рішень, які можуть впливати на стан довкілля.
32. Звіт про оцінку впливу нерадіаційних факторів ВП «Рівненська АЕС» ДП «НАЕК «Енергоатом» на оточуюче природне середовище за 2017 рік.
33. Доповідь про стан навколишнього природного середовища в Рівненській області у 2014 р. –Рівне, 2015 – 280 с.
34. Нетехнічне резюме. Матеріали з обґрунтування безпеки продовження терміну експлуатації енергоблоку № 3 ВП «Рівненська АЕС» у понад проектний термін/Міністерство енергетики та вугільної промисловості Державне підприємство «Національна атомна енергогенеруюча компанія «Енергоатом» ВП «Рівненська АЕС», 2018 р. -58 с.
35. Физико-географическое районирование Украинской ССР. Под редакцией В.П.Попова, А.М.Маринина, А.И.Ланько. Из-во Киевского университета, 1968.
36. Постанови Кабінету Міністрів України від 30.03.1998 № 391 «Про затвердження Положення про державну систему моніторингу довкілля».
37. «ГОСТ 17.4.2.01-81 Охорона природи. Ґрунти. Номенклатура санітарного стану».
38. Регламент радіаційного контролю Рівненської АЕС, 132-1-Р-ЦРБ.
39. Жаков Ю.А., Резников Ю.В., Сватков В.Ю., и др. "Изучить нулевой фон в районе строительства Ровенской АЭС" (заключительный отчет). Киевский НИИ общей и коммунальной гигиены им. А.Н. Марзеева. Москва-Киев, 1979.
40. Радиационная обстановка в районе строительства РАЭС. Ленинградский научно-исследовательский институт радиационной гигиены (ЛНИИРГ). Ленинград. 1997 г.
41. Ривненская АЭС. Энергоблоки № 3,4. Фактор безопасности № 14. Глава 5. Влияние на окружающую среду. 22.3,4.133.ОППБ.05 АТ03-14.564.ОД.1, - 2018 г., 84 с.
42. Річний звіт з оцінки радіаційного впливу ВП «Рівненська АЕС» на навколишнє середовище та населення у 2017 році. 132-12-ЗВ-18-ЦРБ, Вараш, 2018 р. -63 с.
43. Допустимі рівні вмісту радіонуклідів 137Cs та 90Sr у продуктах харчування та питній воді (Державні гігієнічні нормативи ДР-2006).
44. Доповідь про стан навколишнього природного середовища у Рівненській області у 2016 році / Департамент екології та природних ресурсів Рівненської облдержадміністрації, 2017 р., -224 с.].

45. Андриенко Т.Л., Шеляг-Сосонко Ю.Р. Растительный мир Украинского Полесья в аспекте его охраны. - Киев: Наук. думка, 1983. - 216 с.

46. Шеляг-Сосонко Ю.Р. Ліси формації дуба звичайного на території України та їх еволюція. - К.: Наук. думка, 1974. - 240 с.

47. Щербак Н.Н. Зоогеографическое деление Украинской ССР //Вестн. зоологии. - 1988, N3. - С. 22-31., Природа Украинской ССР: Ландшафты и физико-географическое районирование. - К.: Наукова думка, 1985. - 224 с.

48. Медведев С.И. Опыт эколого-зоогеографического районирования Украины на основе изучения энтомофауны //Тр. НИИ Биологии биол. ф-та Харьковского гос. университета. - 1957, Т.27. - С. 5-26.

49. Заповідники і національні природні парки України /Мінекобезпеки України. - К.: Вища шк., 1999. - 232 с.

50. Жежерин В.П. Орнитофауна Украинского Полесья и ее зависимость от ландшафтных условий и антропических факторов. Киев, 1969.-143с.

51. Кістяківський О.Б. Фауна промислових птахів Полісся УРСР. Зб. праць зоологічного музею, 1952.-112с.

52. Крыжановский В.И., Жежерин В.П. Редкие звери и птицы Украины и их охрана. – Киев: Реклама, 1979.-149с.

53. Татаринов К.А. Распространие и сезоные изменения численности куликов на западе Украины //Фауна и экология куликов. – Москва, 1973.-С.62-81.

54. Кістяківський О.Б. Птахи. Київ: Вид-во АН УРСР, 1957.-236 с.

55. Лопатин И.К. Зоогеография. - Минск: Вышэйшая школа, 1989, - 318 с.

56. Макарчук П.Е. О нахождении садовой сони (Eliomys quercinus L.) на территории Ровенсткой области //Вестн. зоологии.- 1973.- № 1.-С. 36-43.

57. Сокур І.Т. Звірі нашої країни. – Київ: Рад. шк. – 1971.-103с.

58. Татаринов К.А. Фауна хребетних заходу України: Екологія, значення, охорона. Львів, 1973.-192с.

59. Червона книга України. Рослинний світ. – К.: УЕ, 1996. – 603 с.

60. Дідух Я.П., Плюта П.Г. Фітоіндикація екологічних факторів. – К.: Наук. думка, 1994. – 280 с.

61. Регіональна доповідь про стан навколишнього природного середовища у Волинській області за 2016 рік. Волинська обласна державна адміністрація, управління екології та природних ресурсів України, 2016 р.

62. Регіональна доповідь про стан навколишнього природного середовища у Волинській області за 2017 рік. Волинська обласна державна адміністрація, управління екології та природних ресурсів України, 2017 р.

63. Вайнерт Э., Вальтер Р., Ветцель Т. и др. Биоиндикация загрязнений наземных экосистем. – М.: Мир, 1988. – 350 с.

64. Behaviour of radionuclides in natural and semi-natural environments / ECP-5 Final report / Eds. M.Belli and F.Tikhomirov. – EUR 16531. – Luxembourg, 1996. – 147 p.

65. Ведення сільського господарства в умовах радіоактивного забруднення території України внаслідок аварії на Чорнобильській АЕС на період 1999-2002 рр.: Методичні рекомендації. – Київ: Ярмарок, 1998. – 103 с.

66. Краснов В.П., Орлов О.О., Ірклієнко С.П. та ін. Особливості накопичення цезію-137 лікарськими рослинами Vacciniaceae S.F. Gray та Ericaceae Juss. на Українському Поліссі // Укр. ботан. журн. – 1995. – 52, №4. – С. 472-478.

67. Краснов В.П., Орлов А.А. Урожайность основных ягодных растений из сем. Ericaceae на Украинском Полесье и возможность эксплуатации их ресурсов после Чернобыльской катастрофы // Растительные ресурсы. – 1996. – Вып. 1-2. – С.41-48.

68. Ильин М.И. Закономерности поведения 90Sr и 137Cs чернобыльских выпадений в почвенно-растительном покрове кормовых угодий Полесья Украины // Проблемы сельскохозяйственной радиологии. – Сб. науч. трудов. – Вып. 4. / Под ред. Б.С.Пристера. – Киев, 1996. – С. 159 – 169.

69. Гулякин И.В., Юдинцева Е.В. Радиоактивные продукты деления в почве и растениях. – М.: Госатомиздат, 1962. – 184 с.

70. Павлоцкая Ф.И., Тюрюканова Э.Б. Миграция искусственных радионуклидов в природных биогеоценозах // Проблемы радиоэкологии и биологического действия малых доз ионизирующей радиации. – Сыктывкар: Коми-филиал АН СССР, 1976. – С. 30-45.

71. Орлов О.О., Ірклієнко С.П., Турко В.М., Дмитренко О.Г. Порівняльна оцінка інтенсивності акумуляції 137Cs та 90Sr різними деревними породами в Поліссі України // Вісник Житомирської агроекологічної академії. – 2001. – № 2.

72. Орлов А.А., Краснов В.П. Радиоэкологическая оценка ресурсов дикорастущего лекарственного сырья Украинского Полесья после аварии на Чернобыльской АЭС // Тр. первой Всеросс. конф. по ботан. ресурсоведению. – СПб, 1996. – С. 52-53.

73. Краснов В.П., Орлов А.А., Ирклиенко С.П. и др. Загрязнение цезием-137 лекарственных растений лесов Украинского Полесья // Растительные ресурсы. – 1996. – 32, вып. 3. – С. 36-43.

74. Тихомиров Ф.А., Санжарова Н.И. Поступление стронция-90 в травянистые растения как показатель распределения интенсивности корневой деятельности по почвенному профилю // Вестн. Москов. ун-та. – Сер. Почвоведение. – 1978. – № 1. – С. 73-78.

75. Юдинцева Е.В., Гулякин И.В. Агрохимия радиоактивных изотопов стронция и цезия. – М.: Атоиздат, 1968. – 472 с.

76. Rantavaara A.H. Transfer of radiocaesium through natural ecosystems to foodstuffs of terrestrial origin in Finland // Transfer of radionuclides in natural and semi-natural enviroments. / Ed. G.Desmet et al. – London-New York: Elsevier Applied Science, 1990. – P. 202-209.

77. Орлов О.О., Дідух Я.П. Фітоіндикація радіоактивного забруднення лісових екосистем // Укр. ботан. журн. – 1998. – 55, №5. – С. 536-541.

78. Орлов О.О. Використання флористичної класифікації рослинності для оцінки інтенсивності накопичення радіонуклідів у системі "грунт-надземна фітомаса" в лісах Полісся України // Укр. фітоцен. зб. – 1997. – Сер. А. Фітосоціологія. – № 2 (7). – К., 1997. – С. 12-18.

79. Орлов О.О., Каліш О.Б. Накопичення радіонуклідів рослинами нижніх ярусів лісової рослинності // Основи лісової радіоекології / Під ред. М.М. Калетника. – К., 1999. - С. 101-125.

80. Щеглов А.И., Тихомиров Ф.А., Сидоров В.П. и др. Поступление радионуклидов в продукцию лесного хозяйства в условиях радиационного загрязнения: Тез. докл. I Всесоюз. радиобиол. съезда (Москва, 21-27 авг. 1989 г.). – Пущино, 1989. – Т. 2. – С. 555-557.

81. Grueter H. Radioactive Fission Product Cs-137 in mushrooms in W. Germane during 1963-1970 // Health Phys. – 1971. – 20. – P. 697-706.

82. Eckl P., Hofmann W., Turk R. Uptake of natural and man-made radionuclides be lichens and mushrooms // Radiat. Environ. Biophys. – 1986. – 25. – P. 43-54.

83. Bakken L.R., Olsen R.A. Accumulation of radiocaesium in fungi // Can. J. Microbiol. – 1990. – 36, № 10. – P. 709-710.

84. Федорова В.Н., Миронов В.П., Макаревич В.И. Изучение накопления радинуклидов в плодовых телах съедобных грибов в БССР: Тез. докл. I Всесоюз. радиобиол. съезда (Москва, 21-27 авг. 1989 г.). – Пущино, 1989.– Т. 2. – С. 540-542.

85. Ernst W.H.O., Van Rooij L.F. 134/137Cs, fallout from Chernobyl in Dutch forests // Heavy metals in the enviroment 1. CEP consultants / Eds. S.E. Lindberg and T.C. Hutchinson. – Edinburgh, 1987. – P. – 284-286.

86. Dietl G. Zur Verteilung radioaktiver Casiumnuklide im Pilzfruchtkorper // Z. Mykol. – 1989. – 55, № 1. – S. 131-134.

87. Roemmelt R., Hiersch L., Wirth E. Uptake of Cs-134+137 by higher fungi (Basidiomycetes) in terrestrial ecosystems. Biological aspects of the cesium transfer // 4-e Symp. int. radioecol.Cadarache. – 1988. – P. 151-161.

88. Elstner E.F., Fink K., Holl W. et all. Radioactivity in mushrooms, mosses and soil samples of difined biotops in SW Bavaria two years after Chernobyl // Oecology. – 1989. – 80, № 2. – P. 173-177.

89. Reisinger A. Correlations between radiocesium activity of macrofungi and their systematic and ecological positions // IV Inter. Mycol. Congress. – Regensburg, 1990. – P. 339.

90. Smith M.L., Taylor H.W., Sharma H.D. Comparison of the Post-Chernobyl 137 Cs contamination from Eastern Europe, Sweden, and North America // Appl. Envirom. Microbiol. – 1993. – P. 134-139.

91. Накопичення радіонуклідів споровими рослинами і вищими грибами України / Під заг. ред. чл.-кор. НАН України С.П. Вассера. – К., 1995. – 131 с.

92. Основи лісової радіоекології. – К.: Держкомлісгосп України, 1999. – 252 с.

93. Котенко А.Г. Браконидымикрогастерины украинской части дельты Дуная и возможности их использования в биоиндикации // Фальцфейнівські читання: Зб. наук. праць (Херсон, 21-23 квітня 1999 р.). - Херсон: Айлант, 1999. - С. 204-207.

94. Червона книга України. Тваринний світ. - Київ:Українська енциклопедія, 1994. - 462 с.

95. Виноградская Т.А., Гринь В.Г., Кафтанникова О.Г. и др. Изучение и опыт прогнозирования гидрохимического и гидробиологического режимов водоемов-охладителей теплоэлектростанций юга Украины // Всесоюзное научно-техническое совещание по проблемам технического водоснабжения тепловых и атомных электростанций, Нарва 27-29 сент. 1976 г. – Нарва, 1976. – С. 20–22.

96. Стангенберг М. Естественные следствия сброса теплых вод в реки // Санитарная и техническая гидробиология. – М., 1967. – С. 49–59.

97. Мордухай-Болтовской Ф.Д. Формы воздействия тепловых и атомных электростанций на жизнь водоемов // Влияние тепловых электростанций на гидрологический и биологический режим водоемов: Материалы 2 симпоз. - Борок, 1974. – С.107–110.

98. Золотарева Н.С., Мусатов А.П., Санин М.В. О характере влияния термальных сточных вод на биоценозы водоемов // Водн. ресурсы, 1979, № 1. – С.65-75.

99. Кошелева С.И. Некоторые экологические аспекты использования водоемов-охладителей тепловых и атомных электростанций для рыбохозяйственных целей (обзор) // Гидробиол. журн. - 1990. – Т.26, № 1. – С. 32-39.

100. Протасов А.А., Сергеева О.А., Кошелева С.И. и др. Гидробиология водоемов-охладителей тепловых и атомных электростанций Украины. – Киев: Наук. думка, 1991. – 192 с.

101. Поліщук В.В., Травянко В.С., Коненко Г.Д. и др. Гідробіологія і гідрохімія річок Правобережного Придніпров'я. – К.: Наук. думка, 1978. – 271 с.

102. Малі річки України. – К.: Урожай. – 1991. – 294 с.

103. Кошелева С.И. Гидрохимический режим водоемов в условиях подогрева // Гидробиол. журн. – 1977. – 17, № 3. – С. 100–111.

104. Кошелева С.И. Гидрохимический режим водоемов-охладителей тепловых и атомных электростанций Украины. – Киев, 1990. – 179 с. Деп. в ВИНИТИ, 12.03.90, № 1778-В90.

105. Протасов А.А., Сергеева О.А., Кошелева С.И. и др. Гидробиологические исследования как научная основа для разработки принципов управления экосистемами водоемов-охладителей ТЭС и АЭС // Развитие гидробиологических исследований в Украине – Киев: Наук. думка, 1993. – С.53-66.

106. 15 лет спустя. Сборник материалов к юбилею (Ривненская АЭС (1981–1995)). – Одесса: Укр. ядерное об-во, 1995. – С. 3–51 с.

107. Звенигородский Э.Л. Методика экологической оценки качества поверхностных вод на основе нечеткой логики // Гидробиол. журн. – 1999. – 35, № 1. – С. 102–109.

108. Мордухай-Болтовской Ф.Д. Формы воздействивя тепловых и атомных электростанций на жизнь водоемов // Мат-лы II симп. «Влияние тепловых электростанций на гидрологический и биологический режим водоемов. – Борок, 1974. – С. 107–110.

109. Lyashenko A.V., Silayeva A/A/ A streem velocity influence on a macroozoobenthos development in the Kilian delta of the Danube. – Limnologische Berichte Donau, 1997, 32 Konf. der IAD, Wien, Osterreich, 1997. – wissenschaftliche Referate. – Band I. – P. 309–311.

Attachment A

AN IN-DEPTH ANALYSIS OF RNPP IMPACT ON THE FLORA AND FAUNA

The experience of mitigation of Chornobyl NPP accident consequences and monitoring of processes in all human life sectors, including the environmental impact assessment, in particular with regard to flora, should cover not only the radioactive contamination impact, but also the whole complex of environmental factors.

Due to the fact that the analysis of environmental factors is rather complicated, expensive and requires conduction of many experiments of repeatable accuracy, involvement of considerable number of experts and appropriate equipment to obtain simultaneous slice of the entire 30-km zone, it is really impossible to do it.

That is why, this Attachment contains the results of the in-depth studies, including studies carried out at KhNPP and ChNPP 30-km zones, and detailed in Volume 4 at RNPP- 4 environmental impact assessment (Rivne NPP, Unit 4, Environmental Impact Assessment, Volume 4. Characteristics of Natural Environment and Impact Assessment. Book 11. Flora and Fauna).

This Attachment is in Russian, since this is the language of the original document.

Specification of biological indicators for environmental assessment

Different European countries studied the sensitivity of plant species to air pollutants and, on this basis, corresponding phytoindication scales (Table 1) were developed mainly for trees and shrubs, that act as main coenoses forming setters and those forming society structure [63] (- insensitive or almost insensitive, 1 - low-insensitive, 2 - sensitive, 3 - high sensitive, .- reaction is understudied).

Table 1 - Plants – air pollution indicators

Plant species	**SO_2**	**HF**	**NH_3**	**HCl, Cl_2**
Scots Pine	3	2	2	3
Common Spruce	3	3	2	3
Weymouth pine	2	2	.	2
Common larch	2	2	2	2
English oak	-	-	-	2
Red oak	-	1	-	2
Common acacia	-	1	1	1
Norway maple	-	-	1	2
Cut-leaved maple	-	1	1	.
English field maple	-	-	-	.
Common privet	-	-	.	.
European hornbeam	2	2	3	3
Small-leaved lime	2	2	3	.
Large-leaved linden	2	.	3	.
Quickbeam	2	.	.	.
Common birch	2	1	2	.
Pubescent birch	2	2	.	.
Rattlertree	2	.	.	.
European beech	1	1	2	2

Plant species	SO_2	HF	NH_3	HCl, Cl_2
Sycamore	1	1	2	.
Elm tree	1	.	.	.
Aspen	1	.	.	1
Single-seed hawthorn	1	1	.	.
Blueash	1	1	.	.
Rosa canina	1	1	.	.
European elder	-	-	-	.
Red elder	-	-	-	.
European euonymus	-	.	-	.
Hedge-row rose	-	-	.	.
Common hazel	.	2	.	.
Cherry tree	.	2	.	.
European alder	.	1	.	3

Considering that the 30-km zone vegetation is formed mainly by pine woods of Scots pine interspersed with fir and leaf woods of common oak and hornbeam occupy small areas, this zone is very sensitive to such pollutants as SO_2, Cl_2, HCl, and less to HF, NH_3. At the same time, it is necessary to consider that pine woods partially occupy dry, unstable extreme ecotopes that rest on shifting sands with lithosolic soil cover, and fir woods fragmentary occurred on the southern border of their areal. This increases their sensitivity to external hazards and if for the first, due to the absence of competitors, it leads to denudation of tree layer and to the increase of deflationary processes, for the second - to substitution with more resistant species.

Therefore, very important condition for preservation and improvement of ecosystem resistance is prevention of air pollution by pollutants to which RNPP 30-km zone woods are very sensitive. NPP operation and commissioning of new units do not effect this situation.

The study of the state of the forests showed that RNPP 30-km zone is not characterized by regional or local damage of wood species by pollutants.

Selection of biological indicators for radioactive contamination assessment

The radioactive contamination assessment issue is topical, since radionuclides occurring in the environment are involved in cycling of matter. The autotrophic block here occupies one of the key positions, since, on the one hand, it accumulates these substances from the soil and air and, on the other hand, it is a food source for animals and humans.

Although the plant accumulates the radionuclides from various sources (soil, air, water) what strongly depends on the specific environmental conditions (trophicity, moisture) of the soil, but to a large extent it is determined by biological specificity of species, by such characteristics as age, lamina nature, place in biocoenosis, etc., and also depends on the radioactive element.

Specific activity, measured in Bq/kg, is the indicator of presence of certain radionuclide in the phytomass of species. The accumulation factor (AF) and transition factor (TF) are the integrated indicators of the intensity of accumulation of certain radionuclide by species phytomass from the soil. The accumulation factor shows the quantity of radionuclide that can be transited from 1 kg of the soil to 1 kg of phytomass, that is why AF value is dimensionless. Usually, when calculating AF, there is used plant and soil air-dry mass ratio, although in some cases, when the fresh plant phytomass is used for practical needs (for example, strawberries (Fragaria vesca L.) and bilberry – berries, timothy aboveground phytomass (Phleum phleoides (L.) Karst.) - soilage, etc.), this ratio is modified, at all this, radionuclide specific activity in phytomass is determined in fresh state, and in the soil - in the air-dry state. The transition factor for transition of certain radionuclide to particular plant phytomass is defined as a ratio of specific activity of radionuclide (Bq/kg) in the phytomass of particular plant to density of soil contamination by this radionuclide (Bq/m^2 or kBq/m^2), currently this factor has standard dimensions $m^2 \cdot kg^{-1} \cdot 10^{-3}$ [64]. In spite of rather unusual dimensions for botanists, this factor has deep physics and is quite visual - this is the site area which root layer contains, at average, the same number of radionuclides as in 1 kg of phytomass.

As AF, TF is mainly calculated for air-dry phytomass and soil, but there is possible to calculate it for fresh phytomass. After Chornobyl disaster, it was TI that became most used indicator of the intensity of accumulation of man-induced radionuclides in the phytomass, since, after this accident, most of radioactive contamination maps were composed considering the density of soil contamination by certain man-made radionuclides (usually ^{137}Cs, ^{90}Sr, ^{239} + ^{240}Pu).

Thus, taking the density of soil contamination with radionuclide and its TI value (transition from the soil to certain type phytomass) it is possible to calculate the expected content of the radionuclide in this type of plant, that is extremely important from a practical point of view [65, 66].

It is necessary to point out the absence of generalizing publication regarding accumulation of radionuclides in vascular plants, there is only fragmentary data mainly on individual groups - berry [67], medicinal [66], fodder [68], etc.

The intensity of accumulation of a certain radionuclide by plants, first of all, depends on physicochemical properties of certain radionuclide [69].

In particular, ^{137}Cs, the potassium analog, and ^{90}Sr, calcium analog, are accumulated in plants more intensively in comparison to ^{239}Pu and ^{240}Pu [70]. Data on the intensity of accumulation of other man-induced radionuclides by plants are very limited. This document provides information on the intake of radionuclides by plants exclusively from the soil (with the help of the roots), data on foliar intake of radionuclides are not considered.

In addition to radionuclide properties, the intensity of radionuclide accumulation by plants is affected by the interaction of particular plant biological characteristics and plant habitat conditions.

It was found out that plants differ by radionuclide accumulation rate. For example, ^{137}Cs specific activity in common oak and aspen timber (Table 2) is 4–5 times lower than in Scots pine and silver birch timber.

Among the main forest-forming species, the common oak is characterized by minimal accumulation of ^{90}Sr and Scots pine accumulates more than silver birch and sticky alder.

Table 2 – Specific activity of ^{137}Cs in components of phytomass of main forest forming species

Wood species	Average density of soil radioactive contamination, kBq/m^2	Average specific activity, kBq/m^2		
		internal bark	external bark	forest without bark
Scots pine	510±45	5.5	5.1	1.4

Wood species	Average density of soil radioactive contamination, kBq/m²	Average specific activity, kBq/m²		
		internal bark	external bark	forest without bark
Common birch	510±70	3.2	4.3	1.0
Common oak	560±65	0.8	8.4	0.3
Aspen	540±60	1.7	6.2	0.2

Internal bark contamination decreases in the following direction: Scots pine → silver birch →aspen → common oak, and external bark contamination - in the opposite direction - common oak → aspen →Scots pine →silver birch. ^{137}Cs specific activity in young Scots pines is higher than in old Scots pines (Table 3); it is higher in trees of higher growth class what correlates with the growth intensity process.

In Scots pine, the highest ^{137}Cs accumulation intensity is typical for such metabolically active tissues and organs as one-year old needles, radial and altitudinal growth of current year shoots, phloem (the value of ^{137}Cs AF varies between 0.3-0.4; ^{90}Sr - 1, 16-1.40), and the lowest - for inner bark of the timber (^{137}Cs AF equals to 0.04-0.06, and ^{90}Sr - 0.33-0,40) [71].

Table 3 - ^{137}Cs specific activity in timber of different age Scots pines, Bq/kg

Contamination density, Ci/km²	Age, year	Timber specific activity Bq/kg	Ratio
510	18 50	41588 17375	2.39
16,2	25 80	1627 496	3.28

The specified table, that highlights the results of the studies conducted at the territory of Chornobyl NPP 30-km zone, where contamination density is much more higher than in Rivne Region, demonstrates general trends in changing of ^{137}Cs specific activity in woods of Polissia. The increase of these indicators with age decreasing can be due not only to the change of ^{137}Cs activity, but also due to that ^{137}Cs radioactive contamination dose, obtained in 1986, that is 15 years ago, for 18-25-year-old and 50-80-year-old plants, differs fundamentally due to physiological processes, since for the first plants it was contamination growth condition, for the last – it was short contamination growth period in relation to their absolute age.

At the same time, more than 50% of ^{137}Cs total activity is accumulated in timber and a lot of in branches and leaves. Recalculation of total activity per unit mass demonstrates inverse relation: the highest ^{137}Cs specific activity is typical for leaves, in branches it is 2 times less, in barked timbers it is 7 times less, and in not barked timbers - 8 times less.

Studies, carried out in Polissia of Chornobyl NPP zone, demonstrate that decreasing accumulation of ^{90}Sr in timbers (Table 4) of the main forest-forming species forms the following row: aspen → Scots pine → silver birch → common oak what is demonstrated in the following table.

Table 4 - ^{90}Sr concentration in timber of the forest-forming species, Bq/kg

Contamination density, kBq/m^2	Forest species				
	Pine	Birch	Aspen	Black alder	Oak
104	962	666	1556	703	144
385	14800	7030	17390	8510	1628
3019	21460	23310	21830	19420	2257

At the same time, ^{90}Sr concentration in wood species does not correlate with soil contamination density and, within contamination limits of 100 up to 400 kBq/m^2, it increases substantially and of 400 up to 1000 kBq/m^2 it substantially decreases (for ≈1,4 times), what is stipulated, most probably, by physiological processes.

The accumulation of radionuclides by grass-shrub layer species also depends on radionuclide isotopic composition, its concentration in the environment, soil conditions, and the biological properties of species.

The average values of certain radionuclide transition into different species, that form an integral part of certain coenosis, vary widely. Thus, in Ukrainian Polissia, for young mixed herb and pine-oak woods the average values of ^{137}Cs transition to the top phytomass ranges from 47 in the shield fern (Dryopteris carthusiana (Vill.) HP Fuchs) to 0.9 in the blood-red geranium (Geranium sanguineum L.) [72]; for green-moss pine woods - from 357 in cowwheat (Melampyrum pratense L.) to 4.2 in narrow-leaved bluegrass (Poa angustifolia); for young herb-green-moss pine woods — from 590 in the adder-spit to 3.5 in the mountain parsley [66].

Based on TF average values [73], vascular plants are grouped in compliance with the intensity of accumulation of radionuclides: very high accumulation group - accumulators (TF> 100); high accumulation group (100> TF> 50); limited accumulation group (50> TF> 10); low accumulation group (10> TF> 1); very low accumulation group – discriminators (TF< 1). Such significant difference in intensity of accumulation of this radionuclide by different species under conditions of any kind of the ecotope is due to complex factors — the depth of certain species root systems, vertical distribution of radionuclide activity in the soil [74], species need for certain amount of potassium and accumulation of its analog ^{137}Cs at the absence of this macroelement [75]. In particular, it is necessary to point out the importance of statistical processing of considerable data files at TF specification even for one specie in one and the same ecotope and the impossibility of operating with TF single values [76]. Thus, most studies concluded that distribution of TF values in the data files of each ecotope is either normal or lognormal, at the same time, the TF average value variation factor (V%) usually makes 40-50% [73]. That is why, in all cases we give AF or TF average value.

Studies conducted in the Chornobyl zone showed that high accumulation is typical for Ericaceae, as well as for species inhabiting acidic soils such as sparrow sorrel, golden rod, sedges, ferns, club-mosses, as well as veronicas, shamrock, etc.

It was found that concentration of radionuclide accumulation depends not only on the biological properties of the species, but also on the physical and chemical soil conditions.

It is necessary to point out that one and the same species in different environmental conditions are characterized by significant difference of the average values of radionuclide transition into the phytomass. For example, for blueberry top phytomass the average values of ^{137}Cs transition are the following in the following associations: Serratulo-Pinetum J.Mat. 1981 - 9; Molinio-Pinetum J.Mat. (1983) 1984 - 68; Vaccinio uliginosi-Pinetum Kleist 1929-100 [77]; in first two associations ^{137}Cs transition into the blueberry top phytomass makes 5.4 and 56 respectively; and to the adder-spit - 8.8 and 189 [78]. Common denominators are the decrease of ^{137}Cs transition value at increasing soil trophicity and decreasing humidity [79].

There was established positive correlation between radionuclide accumulation and soil humidity (r = 0.76–0.83) and acidity, and negative correlation with respect to the increase of pH and salt content, in particular, content of carbonates and nitrogen in the soil (r = –0.92 –0.99) [77]. For example, for blueberries, the factor of ^{137}Cs transition from the soil to the phytomass ranges from 2.4 in oak woods (C_2) up to 250 in wet subor (B_5). For plants that cover large ecological area there was established the following logic: more acidic and poor sod-podzolic soils accumulate the radionuclides more intensively in comparison to gray or black soil. Thus, ^{137}Cs transition factor for heartsease (Viola tricolor L.) of sod-podzolic soils is 6.5 times more than for heartsease of gray soils and 13.2 times more than for heartsease of black soil.

The radionuclide accumulation intensity changes significantly in the process of plant ontogenesis. Common denominator for vascular plants is over-accumulation of ^{137}Cs and ^{90}Sr by the juvenile and immature specimens which metabolic processes are more intensive than the metabolic processes of adult and senile specimens. The abovementioned differences can be very significant. For example, in oak woods with forbs, the average value of ^{137}Cs transition into the juvenile and immature specimens made 27-30, to the adult specimens – 10, to senile specimens -6 (it is for the top phytomass of the adder-spit wet sudubrava in edaphotop). And for the top phytomass of the shield fern – for this radionuclide at the specified plant evolution stages in the same ecotope – 120, 50 and 30 respectively. We can observe the same tendency for the arboreal plants. That is why, on condition of data availability, we specify AF and TF values for adult specimens. If the data relates to other evolution stages - we specify AF and TF values on the case-by-case basis.

Mosses, lichens and mushrooms have very high sorption capacity and radionuclide accumulation rate. The moss-lichen storey accumulates the radionuclides 10-100 times intensively than grass-shrub storey, since mosses and lichens, unlike other plants, absorb radionuclides from the air. In particular, the sphagnum mosses, that retain 30-60 % of radionuclides of the moor, are some kind of radionuclide absorption pumps. In this case, ^{137}Cs radionuclides are accumulated more intensively than ^{90}Sr radionuclides. Also, the lichens accumulate the radionuclides very intensively. On this basis, mosses, lichens, as well as such well-studied specimens like Scots pine, bilberry, lingonberry and moorberry, can be used as radiation contamination indicators.

Approaches to the assessment of possible harm to forestry, mushroom and berry areas, recreation activity

Due to the fact that there are significant differences in the accumulation of radionuclides (in one and the same and in different ecotopes), it is necessary to assess possible accumulation of radionuclides by agriculturally important specimens available within their ecological areas, especially in those areas with maximum natural biobase (Table 5). Most accidental release radionuclides are not essential for metabolism, but ^{137}Cs and ^{90}Sr radionuclides are easily incorporated into biochemical cycles and accumulated in food chains.

Table 5 - ^{137}Cs accumulation by medicinal plants and berries in edaphotopes of Ukrainian Polissia which maximum regional biological reserve [80]

Intensiveness of ^{137}Cs accumulation from the soil	Type of biological product, state	Type of habitat conditions	TF, $m^2kg^{-1}10^{-3}$
Medicinal plants (air-dry state)			
Very high	Bilberry, (dry berries)	B_3	130
High	Red bilberry (leaves) Ledum palustre (shoot)	B_2-B_3 B_4	65 82
Moderate	May lily of the valley (herbage)	C_2-C_3	16
Berry plants (fresh berries)			
Moderate	Bilberry Red bilberry	B_3 A_2	11 12
Low	Bilberry Red bilberry Wild strawberry	B_2 B_2 B_2-B_3	8,2 8,3 5,8

The obtained data [80] demonstrates that ^{137}Cs concentration depends both on growing conditions, specimen biology and biological product state, in other words, with water evaporation the concentration increases so much that it belongs to other class.

The TF value for ^{137}Cs transition from the soil to medicinal plants and berries and wood contamination density make possible to calculate the hypothetical content of the specified radionuclide in certain types of biological product in certain edaphotope by formulae:

$$Am = TF \cdot As \quad (2),$$

where Am – ^{137}Cs specific activity, Bq/kg

TF – transition factor, $m^{2kg-1} \cdot 10^{-3}$

As – density of soil contamination by the radionuclide.

Comparing the calculated value with maximum permissible value, determined by the Regulation NRBU-97 (for medicinal plants - 600 Bq/kg, for fresh berries - 500 Bq/kg), the decision on possibility of procurement is taken on the case-by-case basis. In addition, using the appropriate regression equations, it is possible to calculate the expected radionuclide content in product, as well as to determine the maximum density of soil contamination for product procurement.

We can observe maximum accumulation of radionuclides in mushrooms that are heterotrophic organisms and absorb radionuclides as a sponge.

Grueter H. studies with regard to ^{137}Cs content in mushrooms of West Germany (1963-1970) showed not only the selective absorption of ^{137}Cs from the soil but also the presence of considerable number of other fission products, in particular ^{144}Ce, ^{106}Ru, ^{106}Rh, ^{90}Sr [81].

Eckl P. with coauthors [82] specified that the mushrooms uptake more ^{137}Cs and ^{40}K radionuclides than lichens, at that, the mushrooms are characterized by relatively stable level of potassium, whereas ^{137}Cs level changes considerably.

In general, Boletus cavipes activity level is 10 times higher than of other representatives of Boletaceae family. Concentration of radiocesium in Boletus edulis, B. elegans, B. appendiculatus is at the level of 82-15 Bq/kg for fresh weight, what is much more lower than specified by European Economic Society regulations accepted for foodstuff (600 Bq/kg for fresh weight).

Bakken L.R., Olsen R.A. [83], studding the accumulation of radiocaesium in mushrooms of Norway, confirmed positive correlation between radiocaesium and non-radioactive caesium concentrations and negative correlation – with soil pH values.

The question of the species-specific accumulation of radionuclides is important both in theoretical and in practical aspects, given that certain mushroom species are valuable and edible. Based on the data obtained from Scheglov A.I. and coauthors [79], Fedorov V.N. and others [84], the interspecies differences of mushrooms with regard to accumulated caesium make 100-1000. Also, there were found the differences in radionuclide distribution [85, 86] and accumulation by different ecological groups [87-90].

Radionuclide accumulation levels depend on both the biological characteristics of the species and the certain radioecological situation. Radiocaesium accumulation level is associated with the level of soil surface contamination by ^{137}Cs. However, it is necessary to point out that there is no clear correlation, since in some cases, one and the same species with the same level of soil surface contamination, are characterized by considerable variability of radiocesium content [91].

The considerable variability of the levels of accumulation in one and the same species complicates the assessment of the dose load on the human body at mushroom intake. Due to the fact that wild valuable and edible species from Boletacae, Amanitacae, Russulaceae and Tricholomataceae family accumulate considerable quantities of radionuclides, it is recommended to limit the collection and use of mushrooms at the territory of Polissia, including RNPP 30-km zone, what, first of all, is connected with “Chornobyl trail”.

Possible changes and disturbances of vegetation cover. Possible changes in forest communities

Forests perform the most important function in ensuring substance and energy circulation and are the most powerful stabilizing factor. In this regard, a great attention should be paid to forest management in the RNPP 30-km zone of the plant should be given great attention.

RNPP unit functioning under normal operation has practically no direct impact on forestry. Under BDBA scenario, there may be less direct impact on forestry activities and more indirect impact related to people resettlement and farm management termination. At the same time, natural vegetation is more resistant to changes occurred than planted vegetation.

The studies and geobotanical map allowed assessing the nature and extent of vegetation cover degradation and making their quantitative description. The geobotanical map was based on two principles of legend formation: 1) topological features of vegetation cover reflecting coenotic and ecological specifics; 2) real state of vegetation cover reflecting degree and nature of its transformation under the impact of human activities. Such principles allow both reconstructing a map of potential vegetation reflecting ecological specifics of the area, as well as assessing the scale of its transformation, damage under various possible impact scenarios, defining the measures to optimize the structure of vegetation cover and its protection.

The analysis of the map showed that many sections do not have rounded, but angular contours. This shows that it is the anthropogenic factor, which is leading in forming the structure of coenoses (felling and planting are carried out strictly by divisions, allotments; settlements are constructed according to relevant plans, agricultural land is tilled according to crop rotation, etc.). Only hydrogenic communities associated with direct impact of the water regime retain the features of natural boundaries.

Based on the studies, all phytocoenoses may be divided into four types: boreal, nemoral, hydrogenic, and agro-urban. Such a division is not strictly scientific and very conditional, since it was done not on one but on different grounds: agrocoenoses and urban complexes may be formed both in place of boreal and nemoral ones, etc., nevertheless, for this effort it is justified, since reflects the extreme degree of vegetation cover change where natural species are not preserved.

Construction of the geobotanical map and computer-based calculations using it resulted in obtaining relevant data and ratios of the areas of each allotment in the 10- and 30-km zones (Table 6).

Table 6 – Ratio of the areas of vegetation allotments in the 30-km zone

No. of allotment according to vegetation map	Area in the 10-km zone	% in the 10-km zone	Area in the 30-km zone	% in the 30-km zone
1	3 615.67	11.56	47 392.97	16.8
2	3 702.49	11.83	40 102.37	14.24
3	162.4	0.52	9 932.36	3.53
4	-	-	437.24	0.16
5	313.62	1.0	6 357.92	2.26
6	1 372.53	4.39	35 524.07	12.62
7	714.37	2.28	17 192.09	6.1
8	3 697.03	11.8	7 093.68	2.52
9	69.25	0.22	6 424.78	2.28
10	31.1	0.1	2 804.53	0.99
11	-	-	7 941.66	2.82
11a	-	-	307.36	0.1
12	197.93	0.63	4 851.71	1.72
13	78.82	0.25	1 055.21	0.37
14	13 604.42	43.5	75 723.32	26.9
15	109.14	0.34	640.87	0.23
16	3 459.92	11.06	15 803.56	5.61
17	144.91	0.46	1 880.15	0.66

According to the table, the boreal complex (allotment 1-4) is predominant in the 10-km (23.92%) and 30-km zones (34.77%) among natural ecosystems. Nemoral forests occupy a small area of 1% and 2.26%. The second place is occupied by alder forests and swamps in the 30-km zone

(12.62%), which in the 10-kilometer zone are replaced by meadows (14.43%). If in the 10-km zone grassy swamps occupy an area of 0.63%, then in the 30-km: 4.65%. The area of water bodies is small, respectively, 0.25 and 0.37%.

Natural vegetation in the 10-kilometer zone occupies almost a half of an area of 44.62%, and in the 30-km zone: two-thirds - 66.56%, which should be considered a very positive moment. Such a ratio of plant communities, natural and disturbed areas should be considered satisfactory.

Predictive assessment of possible contamination of vegetation cover by radionuclides under normal unit operation

It was defined that under normal operation of existing RNPP units, releases of radionuclides (^{137}Cs, ^{90}Sr, etc.), concentration of air and soil contamination is low, and it is almost impossible to mark it in the total contamination. It is quite possible to agree with the conclusion that radionuclide accumulation under NPP normal operation in plants will not exceed the permissible standards, but is currently determined by contamination with ^{137}Cs of Chornobyl origin, which has been thoroughly studied within the zone. Therefore, taking into account radionuclide accumulation by plants, sphagnum swamps are the most contaminated at this time and their highest concentration is found in sphagnum, European cranberries, as well as mushrooms, and less in blueberries.

Upon the mentioned above, it is necessary to protect the public in every possible way against the use of components of wetlands, primarily of mesotrophic sphagnum type, in particular, European cranberries, as well as of mushrooms. Considering that blueberry has a wider ecological amplitude, its contamination with radionuclides may vary considerably depending on specific local conditions (TC = 0.12 m^2·/kg).

TC (transition coefficient) is an indicator of the intensity of radionuclide transition from soil to plant. It depends on the taxonomic position of the species, life form, presence of symbiosis with mushrooms, need for K^+, Ca^{2+} and other cations, depth of root system. It is calculated for air dry mass and soil. Depending on ^{137}Cs accumulation intensity, TC is divided into very strong (TC> 0.1 m^2·/kg), strong (0.1 m^2·/kg> TC> 0.05 m^2·/kg), moderate (0.05 m^2·/Kg> TC> 0.01 m^2·/kg), weak ($10m^2 \cdot kg^{-1}10^{-3}$>TC>$1m^2 \cdot kg^{-1}10^{-3}$) and very weak (TC<$1m^2 \cdot kg^{-1}10^{-3}$) [91].

On that basis, blueberries, whose collection and purchase is currently conducted very intensively, should be strictly controlled for the content of radionuclides. Unfortunately, at present, such control is not implemented in situ; therefore, there are sources of blueberries, which contain radionuclides exceeding the permissible level.

In general, based on the analysis of changes in the background concentration of radionuclides with the distance from NPP units it may be assumed that NPP radiation mode under normal operation does not affect vegetation cover, does not cause any changes at the level of individual plant species.

Predictive assessment of possible contamination of vegetation cover under maximum design basis accident

Such assessments were made upon characteristics of the accident, whose data were presented by the Energoproekt Institute. Radioactive leakage through the containment at a height of 20 m for 10 hours was considered as this accident. Based on the calculations provided for radionuclide distribution, their greatest concentration is assumed near the units and corresponds to a level from 1 E + 07 Ki/day to 1 E + 09 Ki/day. In this case, short-lived isotopes decay and only long-lived ^{137}Cs, ^{90}Sr remain. They will determine contamination degree. The analysis of the distribution graphs of these radionuclides shows their decrease from 1E + 07 Ki/day in the area of the power units to 1.0E + 03 Ki/day at a distance of 30 km, as it was shown in the input data for assessing radioactive impact developed by the Kyiv Scientific Research and Design Institute Energoproekt. Such a uniform decrease of radionuclide concentration in the air may be significantly disturbed in biological components. This disturbance may be traced at two levels: landscape (biocenotic), as well as population and species. Due to specific nature of ecotopes (different soil humidity and acidity), the highest concentration of ^{137}Cs, ^{90}Sr radionuclides will be in mesotrophic (acidic, pH 4.5-5) sphagnum swamps, which are essentially a very isolated system. Here radionuclide concentration may reach 50-70% of their concentration in the air. Further, this indicator will decrease in the direction: spruce forests → pine forests → alder forests and grassy vegetation on dry sandy mounds (wastelands), where, due to mechanical soil composition (sandy, washing mode), radionuclide concentration will be not over 10% of background one and depending on weather conditions, time, and other factors, decrease. If functioning of the phytocoenoses of mesotrophic swamps and coniferous wet forests is aimed at binding, adsorption of radionuclides, then the phytocoenoses of eutrophic swamps, meadows and wastelands at their outflow beyond the biocoenosis. Thus, fluctuation of ^{137}Cs, ^{90}Sr radionuclide concentrations in phytocoenoses biomass may reach from 10 to 70% of background depending on environmental conditions, primarily soil humidity and acidity.

Radionuclide distribution at the population and species level may be characterized by large amplitudes, since significantly depends not only on ecological conditions of species growth, but also on their biological characteristics. At the same time, discriminator species accumulate them much less than background concentration in soils, and concentrators - vice versa. The greatest concentration, naturally, is typical for plants that adsorb them directly from the air (mosses and lichens), as well as for fungi and representatives of Ericales, associated with mycorrhizal nutrition. Their specific concentration may significantly (10-100 times) exceed the background one in soil. At the same time, according to the studies in the Chornobyl NPP zone, contamination with radionuclides does not affect the reduction of species ranges, population structure, species forming processes, i.e. is manifested only at the level of individual organisms.

Predictive assessment of possible contamination of vegetation cover under beyond design basis accident

Since regulatory documents in force in Ukraine do not contain specific requirements for environmental impact assessment under beyond design-basis accidents, and IAEA publications do not present recommendations on assessing such accidents, it is very difficult to develop the only option (or possible options) for such forecasts.

In case of a beyond design-basis accident and release of high concentration radionuclides, the role of vegetation cover is very significant in distribution (fixation), absorption and cycling of radionuclides.

It was defined that vegetation cover plays a very important role in radionuclide distribution, since it affects the transformation of air masses, deposition of aerosol elements, including radioactive contamination. Based on the formula to assess aerosol delay by vegetation

$$C_d = C \cdot P/Ao \quad (3),$$

where C_d is delay coefficient, C is radionuclide concentration in biomass (Bq/kg), P is biomass amount per area unit (kg/m^2), Ao is radiation density, concentration (Bq/m^2)

Forests with the largest biomass have the highest delay coefficient, and critical doses will reduce seed similarity by 50% [92]. It decreases from 100 to 50% from young pine forests to deciduous. Thus, pine forests the immediate vicinity of the NPP and 30-km zone should be considered as a positive phenomenon.

If there is a need for resettlement from the zone, it is this factor, and not radioactive contamination density, which is decisive in the process of vegetation cover successions that is considered regarding various types of economic activities.

RNPP impact on soil microflora

Algae, as components of different ecosystems, play an important role in the transformation and redistribution of radionuclides in the natural environment. Algae are the first link in trophic chains and take an active part in the migration and accumulation of radionuclides. The role of algae in soils is determined by their species and quantitative composition, as well as seasonal dynamics.

It is known that algae, especially blue-green belong to the organisms, which are the most resistant to radiation. Soil blue-green algae Microcolus vaginatus, Phormidium tenue, Synechococcus cedrorum withstand Co exposure up to 1230 kR/year, green Chlorococcum humicola alga: to 160 kR/year [91].

Thus, soil algae are organisms, which are the most resistant to radiation impact. Therefore, commissioning of RNPP-4 under normal operation and in case of emergencies will not affect the state of soil algal flora.

In general, microbiota participation in the processes of accumulation and redistribution of radionuclides in ecosystems is not well understood.

Assessing possible impact of power units on the animal world, definition of animal indicators for environmental assessments

Under normal operation of RNPP unit, no significant impact on the animal world of the RNPP 30-km zone is expected. A certain impact may be associated with an increase of recreational load on floodplain ecosystems of the Styr River. It should be noted that the maximum anthropogenic load is possible on the ecosystems nearest to Kuznetsovsk and RNPP, and just they, due to peculiar vegetation cover (pine forests) are characterized by depleted fauna and almost complete absence of rare and protected species.

It should be noted that the use of cooling towers and spray ponds instead of a cooling pond allowed minimization of NPP negative impact on the ecosystems and actual preserving the valuable floodplain of the Styr River with meadow, shrub and forest animal complexes. Floodplain ecosystems are characterized by a high occurrence of rare and protected species of animals: peevit, a number of protected species of dragonflies, lepidoptera, beetles, hymenoptera, etc.

Possible disturbances of food supply are mainly related to changes in vegetation cover structure, since a whole complex of animals is consortively associated with each plant species. Therefore, even minor changes in the ratio of certain vegetation types will inevitably affect species composition and the ratio of certain groups of insects, acarians and other groups of animals. However, significant disturbances are possible mainly in the meadow complex. For other plant associations, changes are less significant and do not cause significant rearrangements of faunal complexes.

RNPP unit commissioning will have an insignificant impact on the migration routes of birds and insects. Unit commissioning and operation under normal operation conditions may have an impact on animals due to the following factors:

1. An increase in the number of powerful light sources (lamps attracting insects at night; most often these are lepidopterans (hawk moths, owlet moths, geometer moths, lappet moths, grass moths, etc.), beetles (road beetles, may beetles, etc.), two-winged (flies, mosquitoes), hymenopterans (ichneumons), neuropterans, bugs. As a result, a large number of insects from habitats (from a distance of a few hundred meters to 2 or more kilometers) may fly away at night to RNPP area. This can adversely affect populations of a number of insect species, but will not lead to depauperization of species composition in the RNPP 30-km zone. This factor will have a positive impact on the number of nocturnal predators hunting near artificial light sources (some predatory beetles, arachnids, amphibians, etc.).

2. An increase of recreational and economic load on the ecosystems of the RNPP 30-km zone is associated with an increase in the number of personnel and total population. The area adjacent to the NPP is under heavy use.

No direct negative impact of RNPP on the communities of the meadow complex is foreseen. A certain negative impact on the meadow communities may be caused by two main factors: increase of recreational and grazing load. Locally, degradation of meadows in the 30-km zone is already observed because of overgrazing. At the same time, in order to preserve species diversity of entomocomplexes in a number of biocoenoses, moderate grazing is expedient, in particular, in wet grassy meadows. Here, under insignificant use of vegetation, species composition is expanded due to emergence of a number of representatives of the grasshopper superfamilies, as well as of the bush-crickets and some others.

It should be noted that the use of grass stand by hoofed mammals is uneven due to selective consumption of certain plant species. This results in forming mosaic multi-tiered community, which is rich in all groups of orthopterans and other invertebrate groups.

According to research results, for most of areas, pasture load should not exceed one head of large cattle per hectare. In this case, grazing will have a positive impact on species diversity of entomocomplexes and, respectively the whole community associated with it [93].

The maximum damage may be caused to floodplain ecosystems, which may quickly transform due to an increase in recreational load, as well as some other human activities. Other ecosystems are not subject to significant changes, so animal communities of these biotopes are little threatened.

Plowing lands (meadows, wastelands, etc.), deforestation adversely affect populations of a number of species, which ultimately may cause a certain reduction in the number of populations. Amphibians are particularly affected by this.

The fauna of mammals is significantly harmed by poaching, which primarily affects hunting and commercial species (martens, otter, badger, moose, wild boar, etc.).

The problem of zooindication in the environmental assessment of the impact of NPP units on the environment is very relevant and is actively studied by a number of scientific centers. A special attention is paid to the methodology of zooindication.

In most efforts on zooindication, complexes of soil invertebrates, nematodes, earthworms, spiders, microarthropods and ground beetles are most often subjects of research. The study of zoocomplex successions is of particular interest.

When studying ^{90}S effects on populations of soil protozoa, which are among the most radiosensitive organisms, it turned out that contamination effects are much more evident on them than on the populations of larger microarthropods with the same contamination level. In turn, populations of microarthropods react to radioactive contamination more sharply than populations of earthworms, and they, in turn are stronger than populations of mouse-like rodents.

Radioecological efforts, whose relevance has increased in recent years, is still very few. Indicator species and groups may belong to almost all systematic invertebrate taxa, faunistic and ecological complexes. In most cases, the search of indicators is carried out among soil and epigein animals (shell amoebae, enchitreid earthworms, isopods, diplopods, spiders, oribatid mites, collembolans, ground beetles, less often - other groups). Zoodiagnostics, which is inseparably related to zooindication of quality and condition of a studied object, is traditionally developed almost exclusively for soils.

It should be recognized that the issue of insect indicators of environment radiation contamination remains open and requires additional studies and generalization.

When determining a degradation degree of the entomocomplexes as indicator groups in the RNPP 30-km zone, it is advisable to use 2-3 order consumers. In this regard, braconids are tested and highly promising group [94].

Soil, epigean, and above-ground invertebrates constitute the majority of species composition, abundance, and biomass of animal population of terrestrial ecosystems, and play a leading role in the circulation of substances. The most important general efforts on the study of faunal-ecological structure and the role of animal population in the biogeocenotic processes in general are related to the soil fauna.

In 1949, M. Giliarov identified groups of soil animals regarding their relation to soil as a habitat. The first group includes inhabitants of water films on soil surface and soil cavities, i.e. practically aquatic animals. These are protozoa and small multicellular animals, such as rotifers and tardigrades. The second group includes inhabitants of cavities in soil and litter. These are small worms, acarians, springtails. Finally, the third group is soil inhabitants themselves, such as earthworms, larvae and insect imago, other large arthropods.

Oribatid mites (Oribatei) being one of the largest groups of soil invertebrates, take an active part in soil-forming processes. The study of oribatid has shown that different soils clearly differ in animal complexes, which reflect a degree of salinity, moisture, determine mechanical soil composition, as well as changes occurring under the impact of man-made pressure.

The impact of the same factors, including man-made, on the ecosystems of different organization levels is presented qualitatively differently. Therefore, in the bioindication of soil condition, it is necessary to transfer to the testing system or bioindication system that takes into account existence of various ecosystems in soil.

The analysis of soil fauna showed that certain species and groups are related to certain soils, horizons, habitat conditions and sensitively react to deviations in environmental conditions by changing species composition, quantitative representation and structure of communities, and therefore soil fauna may be effectively used in the system of environmental monitoring.

The results of the study of soil fauna in various biotopes of the RNPP 30-km zone are shown in Figures 1-5.

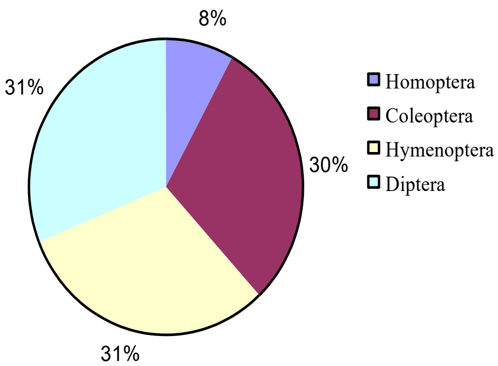

Figure 1 - The number of insects according to pitfall traps in meadow biotopes

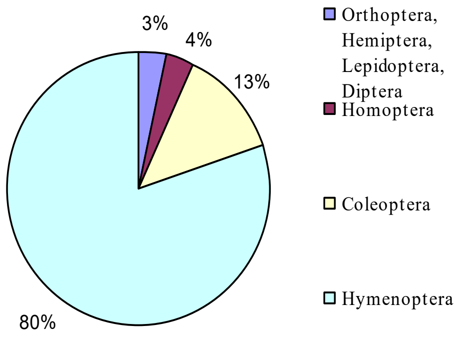

Figure 2 – The number of insects according to pitfall traps on city lawns

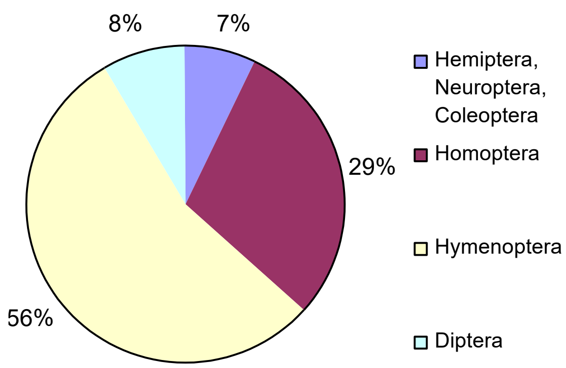

Figure 3 - The number of insects according to pitfall traps in pineta

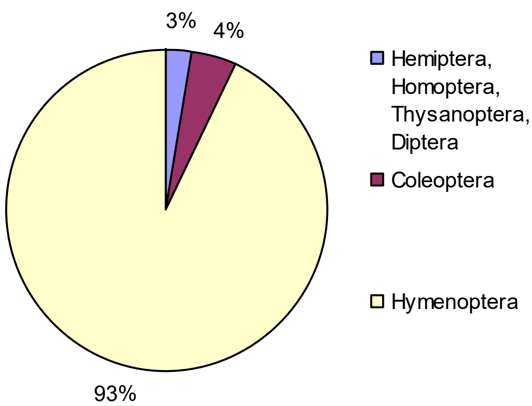

Figure 4 - The number of insects according to pitfall traps on wastelands behind cooling towers

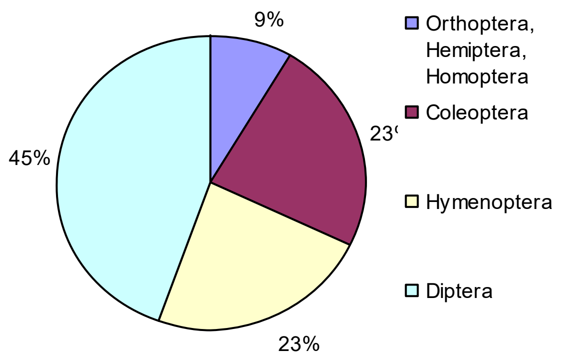

Figure 5 - The number of insects according to pitfall traps floodplain willow stand

Representatives of Hymenoptera, Diptera and Coleoptera groups dominated in all biotopes. The areas of floodplain willow stand and meadows differed regarding species diversity of soil insects. In other places, the dominance of Hymenoptera representatives (constituting 93% of all species in the areas of wastelands behind the cooling towers) was clearly observed. The obtained data (based on the results of pitfalll traps) are important to define further changes in soil fauna in terms of the dynamics of both representativity of certain groups and indicators of species diversity in general.

According to the studies of soil fauna, it may be concluded that species composition and species diversity of soil insects are associated mainly with the degree of soil humidity and species composition of the phytocoenosis. Therefore, possible changes in vegetation and soil humidity cannot but affect the structure of soil entomocomplexes, and due to this they are of considerable interest for biomonitoring.

POSSIBLE CHANGES IN POPULATION STRUCTURE OF AQUATIC PLANTS AND ANIMALS

Commissioning of new NPP units is associated with the solution of a wide range of issues on developing methods for qualitative and quantitative assessment of their impact on the ecosystem of water bodies [95-98]. The impact of NPP heated water discharge on the biota of water bodies is quite diverse: it is additional heat supply and resulting water temperature increase in some sections and a water body as a whole; changes in hydrological and hydrodynamic modes [99]; emergence of completely new biotopes due to the presence of various hydraulic structures, technical systems of piping and cooling units [100].

This complex of factors has both direct and indirect impact on the biota of all organization levels (from individual to biocoenosis), intensity of physical, chemical and biological processes (often multidirectional: adsorption-desorption, production-destruction, oxidation-recovery). At the same time, it is necessary to take into account that the impact may have both positive and negative effects.

A specific feature of the RNPP cooling systems is the absence of a cooling pond. In Ukraine, there are no analogues of discharges from the cooling and water supply system of such a powerful energy facility to a small natural water course, which is the Styr River. This makes it difficult to predict and draw analogies when assessing environmental consequences of the operation of 4 NPP units.

To assess possible changes in the hydroecosystems of water bodies and watercourses of the RNPP zone in unit 4 commissioning, an analysis of current state of the population of water bodies should be made, as well as a forecast of changes in habitat conditions for hydrobionts due to man-made factors.

According to the design documents, during unit 4 commissioning, blowdown water will be discharged from head conduits of the unit pump station, i.e. cooled water will be discharged. At present, blowdown is carried out from an open discharge channel, i.e. not cooled water is discharged with a temperature from 20ºC in winter, to 40ºC in summer. During unit 4 operation, water may be discharged with a maximum temperature to 33 ° C in particularly hot periods of summer. According to the design data for a low-water season of dry years with a 97% availability in the monitoring section water temperature will not exceed 25.5 ° C, and after full mixing: 24.5 ° C. Water temperature decrease in the river is about 2ºC at 100 m below blowdown water discharge.

In the cooling system, the additional water will be treated by liming to reduce total hardness, which will decrease from 5.8 to 1.8 mmol/dm^3. Blowdown water hardness is predicted to be at a level of 13.5 mmol/dm^3. The design data show that in the closed-circuit system, salt content will reach 1465.0 mg/dm^3, which is 4.4 times higher than the average values in the Styr River (333.0 mg/dm^3). In discharge water of industrial sewage (blowdown water, chemical water treatment drains), salt content will be even higher: 1566 mg/dm^3. However, due to dilution by river water, in the monitoring section after discharge, salt content will be 426.0 mg/dm^3, and after complete mixing: 363.0 mg/dm^3.

Thus, based on the design characteristics, the impact of various man-made factors on the hydrobiota will not increase during unit 4 operation, and according to some parameters, the impact will even decrease. However, not only these calculated parameters of the abiotic environment may determine development of hydrobionts.

A multiparameter analysis of all hydrobiological characteristics in close connection with abiotic factors of environmental is required [101].

In accordance with localization, structural and functional features, the organisms of water layer and those living at the bottom, solid substrates react differently to changes in environmental conditions. Therefore, it is advisable to divide impact assessment by subsystems: pelagic subsystem, which includes biocoenoses of plankton organisms and contour one, which includes benthos, i.e. a complex of organisms of loose soils, bottom sediments, and periphyton: a complex of organisms living in solid media, including man-made ones.

Pelagic subsystems (plankton)

Based on design features of the RNPP water supply and cooling system, several elements or units of pelagic groups of hydrobionts living in different conditions should be considered. These are planktonic groups (phytoplankton and zooplankton) of the Styr River section in front of NPP water intake, cooling pond functioning as a silt-detention basin of suspended particles in front of the additional water pump station, open channels of the main cooling system and closed sections of the water supply system, as well as Styr sections behind blowdown water discharge. With allowance for relatively small sizes, it is possible to draw certain analogies with cooling ponds of TPP and NPP, in which the main man-made factors are also temperature increase, flow turbulence increase, salinity increase, gas regime change.

It is defined that the impact of heated water discharge of TPP and NPP on the biota of water bodies is quite diverse, and the impact is both direct and indirect, since it includes all physico-chemical and biological processes, often multidirectional. The impact may have both positive and negative ecological effects.

RNPP-4 commissioning will be associated with the increase in water volume for cooling and evaporation compensation, increase in discharge of NPP industrial and household sewage and municipal wastewater. Although the content of chemicals in waters discharged into the river is mostly within the maximum permissible concentrations [102], they represent a certain risk for the flora and fauna of the Styr River. Such main risk factors [103] are the transformation of environmental, sanitary and toxicological indicators of water quality, such as oxidability (permanganate oxidability, dichromate oxidability), BOD_5, dissolved oxygen, forms of nitrogen and phosphorus, ions of copper, zinc, iron, petroleum products, synthetic surfactants and others. Polluted wastewater become toxic under high temperature, which leads to impairment of physiological functions and activity of hydrobionts, reducing their numbers and depauperization of species composition [99].

Taking into account the studies conducted in 2000, data of the NPP and Energoproekt Institute, numerous literature data, there is every ground to assume that after RNPP-4 commissioning, Styr chemical composition will be formed mainly in accordance with the regularities typical for the rivers of this soil and climate zone. According to salt composition, this will be hydrocarbonate and calcium water with moderate values of mineralization and total water hardness.

Discharge of blowdown and other wastewater containing significant amount of salts may cause local pollution. This will be especially noticeable during low-flow periods, as well as during dry years when the river goes to groundwater feed.

In winter, according to long-term data [104, 105], significant oxygen deficiencies were noted for the Styr River. Some improvement of gas regime may be expected in the river section located in the NPP zone due to disturbance of ice cover and active aeration. This phenomenon is noted in the Dnipro River downstream Trypilska HPP, in the Siverskyi Donets River: downstream the Luhansk HPP, in the Plissa River: downstream Smolevychi HPP and many others [106, 107].

In spring and summer, high water temperature leads to an increase of destruction processes and increase in the oxygen consumption for them. In addition, oxygen solubility decreases [96, 108]. In this regard, worsening of gas regime may be expected, especially in the low streamflow period, when the river is fed with ground swamp water.

Content and dynamics of biogenic (BS) and organic substances (OS) in rivers, in contrast to cooling ponds, are determined by several other conditions and reguliarities. While in off-channel and lake water bodies, intrabasin processes play a decisive role, other factors prevail in rivers: impact of groundwater (especially during low streamflow periods, both in winter and in summer); composition of surface runoff (spring flood and rainfall floods), entry of BS and OS with industrial and household sewage, as well as the level of quantitative development of hydrobionts and their functional characteristics.

Currently, the content of biogenic and organic substances in the Styr River in summer and autumn 2000, was not high and corresponded mainly to clear water. The maximum values of permanganate oxidation, nitrates and phosphates corresponded to class 3 (polluted water). At the same time, the content of organic substances, nitrates, phosphates in ISSS water, NPP open discharge channel of the nuclear power plant was 1.5–2.5 times higher than in river water.

These substances will be included in the biotic circulation of both the plankton and contour subsystems. At the same time, commissioning of RNPP-4 should not disturb the seasonal dynamics of biogenic and organic substances in the Styr River.

Bacterial plankton. The data obtained during survey of the Styr River and RNPP water supply systems showed that the total number of bacterial plankton in summer was within 3.9–7.3 million cells/ml, and in autumn: 5.4–9.0 million cells/ml. At the same time, an increase in bacterial plankton numbers was observed under the highest temperature. These results completely coincide with the results of long-term studies [100], which show that the abundance of bacterial plankton may fluctuate and it is higher in the areas of heated discharge impact (Table 7).

Table 7 – Abundance of bacterial plankton in different areas of Ukrainian cooling ponds in summer

Cooling pond	Water temperature, ºC	Abundance of bacterial plankton, mln. cells/ml
Kurakhove HPP	22–24	9.7–10.0
	29–31	13.3–19.5
Chornobyl NPP	24–25	3.5–3.8
	30–32	4.5–4.7

Since in the operation of 4 RNPP units, ISSS discharge water will not impact significantly the change of the thermal regime in the river at the discharge place, there is no reason to expect an increase in the development of bacterial plankton.

Phytoplankton of the studied water bodies in the RNPP area is qualitatively rich enough: 106 species and forms in the summer period and 87 species and forms in autumn. Diatoms and green algae played the main role in forming plankton communities, at the same time, approximately 80 species of algae were noted in the Styr River. Among them diatoms were represented the most.

Quantitative characteristics of phytoplankton in the Styr River in the RNPP area in summer fluctuated within 1.5–6.9 million cells/l, 0.4–1.2 mg/l. At the same time, below ISSS discharge and in open channels, phytoplankton abundance indicators were the highest.

In water bodies affected by heated discharge water [100], fluctuations in the abundance and biomass of phytoplankton algae are quite significant (Table 8).

Table 8 - Phytoplankton abundance and biomass in the cooling ponds of Ukraine

Cooling pond	Temperature, °C	Abundance, mln. cells/l	Biomass, mg/l
Chornobyl NPP	7–38	5.9-160.6	2.6–564.0
Kurakhove TPP	1–32	2.6–277.2	0.6–12.6
Zuiivka TPP	7–38	5.9–7878.5	1.1–18.3

According to studies in the Horyn and Viliia Rivers in the Khmelnitsky NPP region, phytoplankton abundance was 5.2–7.5 million cells/l, biomass: 1.4–4.0 mg/l.

Indicators of phytoplankton abundance and biomass in RNPP zone water bodies corresponded to those observed in the rivers of the Polissia region, as well as the lower limit for water bodies affected by heated discharges.

Phytoplankton communities being an integral part of hydrobiocoenosis, had a clear trend to increase qualitative composition and quantitative development from June to October. In summer, in the formation of phytoplankton complexes, green algae were advanced to the composition of the leading complex due to rich vegetation of chlorococcal algae. Blue-green algae played a significant role in the phytoplankton abundance, but did not reach mass development levels or the so-called "flowering", when one or two algae species reached high values of biomass suppressing the development of other aquatic organisms. Due to the vegetation of blue-green and chlorococcal algae, the value of diatoms in plankton decreased in summer, which, however, due to large cells, continued to play a prominent role in biomass formation. Naturally, in autumn, the role of diatoms in algal complexes increased again.

Possible changes in the nature of algal flora in RNPP water bodies in case of additional unit startup may be predicted as follows. Currently, heated water supply affects algae state in the river locally, i.e. downstream a few hundred meters. In autumn, there was a significant increase in the numbers of blue-green and chlorococcal algae, i.e. algae typical for summer phytoplankton, i.e. whose vegetation requires relatively high water temperatures.

In the summer period, when regular qualitative changes occur in phytoplankton composition, which are expressed in replacing the diatoms dominant in spring by blue-green and chlorococcal ones, this process may only be slightly enhanced by heated water supply in low-water years. The effect will be seen only directly below the discharge place, i.e. will be very local.

Zooplankton. Zooplankton composition of the Styr River was poor during the period of research; in summer, two species of rotifers, 8 species of cladocerans, 6 species and forms of copepods, Harpacticoida were noted, in autumn, the composition was also not rich, correspondingly 5, 8, 4 types and forms. At some stations, zooplankton organisms were not registered. This shows both their low abundance in the river (the organisms did not fall into 50–100 l of filtered water) and considerable heterogeneity of zooplankton distribution. Abundance indicators variated significantly. Thus, in summer, changes in abundance for certain stations was of 120–1680 specimen/m^3, in autumn, the range of number was of 30–250 specimen/m^3. Biomass values also varied widely: in summer, from 3.0 to 42.4 mg/m^3, and in autumn, from 0.06 to 1.54 mg/m^3**.**

Special interest is generated by river sections located below ISSS discharges, sewage treatment facilities. In the summer period, below ISSS discharges, zooplankton abundance and biomass were lower than in the monitoring section (lower boundary of the 30 km zone), however, it is difficult to relate this fact directly to the impact of discharges, since similar abundance indicators were noted, for example, in the silt-detention basin of NPP water supply intake. In autumn, the impact of heated discharges determines a significant increase in zooplankton biomass by 1–2 orders and peculiar zooplankton composition. In autumn, zooplankton biomass increase was also noted downstream of discharges from sewage treatment facilities (downstream the Babka village).

In summer, in the NPP water supply (silt-detention basin) and cooling (open channels) system, a richer species composition was noted, but abundance indicators were not higher than in the river. In autumn, zooplankton composition and abundance was very poor.

Probably, species composition of zooplankton in the RNPP zone will not significantly depleted.

Available data on the quantitative development of zooplankton in water courses in the KhNPP region also located in the Polissia area, show that in the rivers of this area zooplankton may have higher abundance and biomass indicators than in the Styr River. Thus, in the Horyn River, according to the summer period, abundance was 97200 specimen/m^3, in the Viliia River: 17100. Total biomass was 889.2 and 315.3 mg/m^3 correspondingly. During the autumn period, abundance and biomass indicators in these rivers decreased. Therefore, zooplankton biomass in the Horyn and Viliia Rivers was at a level of 6.4 and 19.4 mg/m^3 correspondingly.

Thus, despite the fact that the available data show very small indicators of zooplankton development in the Styr River and RNPP cooling system, situations are possible when abundance and biomass will be significantly higher. The impact of NPP discharges on zooplankton of the Styr River is quite local and significant negative impact is unlikely.

Blowdown water discharge through a tube outlet contributes to water aeration; this will impact positively on zooplankton in winter, under conditions of natural decrease in oxygen concentration. Despite the influence of water temperature, turbulence, repeated water passage through pumps, piping, cooling system (NPP discharge and supply channels) is not a lifeless water body without zooplankton. Regarding composition and abundance in general, zooplankton of the cooling system differed little from river zooplankton. During unit 4 operation, water hardness will be reduced in the cooling system. In general, this will not adversely affect zooplankton.

Regarding composition and abundance, zooplankton of the Bile Lake represent groups that are common to water bodies of the region. In the Bile Lake, composition and quantitative characteristics of zooplankton communities will not change if recreational load on the water body does not increase, which usually leads to eutrophication

Contour subsystems (benthos, periphyton)

In **microphytobenthos** and **phytoperiphyton**, the main part forming algocoenoses, to a greater extent than in plankton, were diatoms. In summer, floristic spectrum of microphytobenthos and phytoperiphyton was enriched with blue-green and green algae.

Algae forming microphytobenthos of the Styr River at st. 7, similarly to phytoplankton algae, responded to water entry from the industrial stormwater runoff with abundance and biomass increase. Bottom algocoenoses, to a greater extent than phytoplankton, react differentially to local pollution, in this case to heated water supply, therefore discharge impact was noted only in the immediate vicinity of the discharge and was limited to the area where water temperature was higher than in the river on the whole.

The main biotopes of benthic algae development are bottom areas located directly near water edge; therefore, phytobenthos development will be directly related to the change of river level regime. In low-water periods, water level will be decreased. This will cause destruction of near edge benthic algal communities. On the other hand, during low-water periods with a decrease of precipitation, terrigenous intake of mineral and organic suspended matters decreases, water transparency increases, which will improve conditions for vegetation of bottom algae.

Noticeable development of **macrophytobenthos** in the Styr River was not recorded within the studies of the Research Center for Fluid Mechanics. Only fragmentary findings of green filamentous algae were made, which did not play a noticeable role in river algocoenosis as a whole, although it was possible to expect their more abundant vegetation at the place of heated water supply. It is probable that with very low water availability, in the place of discharge, green macroalgae (first of all, Cladophora sp.) will vegetate in significant amounts near the edge.

According to the survey conducted in June and October 2000, **zooperiphyton** composition in all water bodies of the RNPP service water supply and cooling system and water bodies of the 30-kmr zone was quite rich: 72 species and groups (in summer) and 64 species and groups (in autumn). Seasonal changes of qualitative composition and zooperiphyton structure consisted in increasing the diversity of such groups as Chironomidae, Copepoda, decreasing the diversity: Cladocera, Ephemeroptera, Trichoptera. In October, representatives of Hirudinea, Gammaridae, Plumatella emarginata (Allm.) were not noted in zooperiphyton composition, and only in October, Colembola, Ceratopogonidae, Plumatella repens (L.) were met. Indicators of zooperiphyton abundance in the river during the study period varied significantly. In summer, changes in the number for certain stations were 688–14941 specimen/m^2. In autumn, zooperiphyton abundance varied within 667–53611 specimen/m^2. Significant fluctuations of zooperiphyton biomass were also noted: from 2.05 to 3559.85 g/m^2 (in summer) and from 0.028 to 345.497 g/m^2 (in autumn). The range of changes in zooperiphyton abundance for stations of the RNPP water supply and cooling system in the summer period was 4000–144167 specimen/m^2, in autumn: 7500–26707 specimen/m^2. In summer, biomass changed from 0.055 to 179.76 g/m^2, and in autumn from 0.007 to 145.66 g/m^2. The average level of zooperiphyton numbers in October was 1.8 times and biomass almost 9 times lower than in June, which is caused both by composition change and decrease in the abundance of zooperiphyton macroforms. The ratio of animals of different trophic status in summer and autumn in the zooperiphyton composition was almost at the same level: surface deposit feeders prevailed: 63–70 %; share of predators was 17–24 %, filter feeders: 4.7–5.6 %, and other: 5–7 %. Regarding biomass, in June, the share of filter feeders and surface deposit feeders was comparable (46 and 48%, respectively). In October, the share of surface deposit feeders dominated in the destruction processes: 94%. At the same time, the average level of destruction in zooperiphyton decreased by almost 11 times from June to October.

Analysis of representativity of certain groups of macroorganisms in Styr River zooperiphyton showed that a significant share of its composition was composed by insect and beetle larvae (77 % of species), at stations both above and below the ISSS discharge, there were such representatives of macrozooperiphyton as sponge (Spongilla lacustris L.), pearlweed (Plumattela emarginata). Zebra mussel (Dreissena polymorpha), which is a typical zooperiphyton component in most of the studied cooling ponds in Ukraine was found in the abandoned loop of the Styr River downstream the Kolka village. This shellfish is a common species in Prypiat River basin, therefore, its presence in the RNPP water supply systems is quite likely.

The presence of these zooperiphyton species and groups, as well as development level of filter feeders-sedimentators shows currently favorable conditions for their vital activity. In unit 4 commissioning based on the design characteristics, the impact of various man-made factors on the hydrobiota will not increase significantly, and regarding some parameters, the impact will even decrease. We should expect improved conditions for the development of zooperiphyton macroforms in such biotopes as a silt-detention basin of water supply intake, discharge and supply channels, which may increase the number of their habitats and increase their abundance.

Increasing the diversity of microbiotopes due to the development of macroforms (such as sponges, zebra mussels, pearlweeds) will have a positive effect on increasing species richness and abundance of meso- and microzooperiphyton. Compared to the zooperiphyton composition in the previously studied cooling ponds (about 100 species), one can say that there is a potential to increase species richness of the zooperiphyton in the structures of the NPP water supply and cooling systems and Styr River.

Low-water years may significantly affect zooperiphyton diversity and abundance. Water level decrease will cause uncovering of substrates populated by zooperiphyton and death of the attached forms. In the presence of suitable substrates, moving forms of zooperiphyton can migrate from the near-edge zone to great depths. Since currently, attached zooperiphyton macroforms are mainly represented by sponge colonies, whose biomass has reached over 3 kg/m^2 in June 2000, significant increase of zooperiphyton biomass in sponge biotopes in low-water years may be predicted.

Zoobenthos of water bodies and water courses of the RNPP zone is quite diverse and in the summer period of 2000, there were 114 species and forms of invertebrates of 19 taxonomic groups, and in the autumn period: 55 species of 15 groups.

In river conditions, an important factor for zoobenthos development is flow rate and soil quality. Therefore, river biocoenoses and biocoenoses of silty soils differed both regarding quality and quantity. Fluctuations in zoobenthos amount of the Styr River main bed in summer were 1617–5900 specimen/m^2, biomass: 0.34–36.62 g/m^2 with the dominance of oligochaetes, mainly Enchytraeidae. In silty areas, they amounted to 2300–32800 specimen/m^2 and 3.60–97.65 g/m^2 due to the development of tubificid worms, bloodworms, and gastropods. In the Styr River, the level of zoobenthos development was at a level similar to the indicators of other Polissia rivers, for example, located in the KhNPP 30-km zone. In the Viliia River, zoobenthos abundance indicators were 3067 specimens/m^2 and 4.43 g/m^2 with oligochaete domination, and in the Horyn River, these indicators were respectively 19333 specimens/m^2 and 1037.51 g/m^2 due to development of tubificidae, gastropods and bivalve mollusks.

In summer, the impact of increased temperature (up to 34 °C) and flow turbulence in the swash zones located directly near ISSS discharge had a negative impact on zoobenthos development. Only juvenile tubificidae were noted here with insignificant abundance indicators (1300 specimens/m^2 and 0.46 g/m^2). With a distance from discharge and a temperature decrease to 26 °C, zoobenthos biomass remained insignificant (0.37 g/m^2), but the number of Enchytraeidae oligochaetes increased and reached the maximum values in the studied area of the Styr river main bed. In autumn, the heated area was characterized by average abundance values, biomass increased to 8.68 g/m^2 due to development of caddis fly larvae.

Thus, the impact of blowdown water discharge in summer is negative only for zoobenthos biocoenoses located in the immediate vicinity of discharge, and in autumn, on the contrary, temperature increase contributes to a higher development of zoobenthos compared to other river sections.

In unit 4 commissioning, discharge water temperature and volume will not change significantly; therefore, no significant changes should be expected in zoobenthos communities. In this case, the local soil erosion may be a more important factor, since high flow velocities adversely affect the development of benthic organisms and contribute to their physical demolition. A decrease of flow velocity also adversely affects zoobenthos development leading to increased siltation, deterioration of the oxygen regime, and contributes to alluviation [109].

Thus, at this stage, the impact of discharge on bottom biocoenoses is local and insignificant, and commissioning of new capacities will not lead to fundamental changes in zoobenthos. In dry periods, swash zones in the river will be drained, whose population may migrate or undergo dewatering by digging in soil.

POSSIBLE IRREGULIARITIES IN GROUND BIOCENSOSIS; JUSFTIFICATIONS OF MEASURES TO PREVENT DEPAUPERIZATION AND DEGRADATION OF VEGETABLE COMMUNITIES AND POPULATIONS OF ANIMALS

Possible irregularities of phytocoenoses, justification of measures to prevent depauperization and degradation of plant communities

The area of community change depends on one or another way of external impact. Such are ploughing, reclamation, recreation, grazing, and haymaking.

Ploughing. This type of anthropogenic impact regarding impact area and intensity is the most powerful and destructive for vegetation. In the 10-km zone, there are 43.5 % of the ploughed territory and in the 30-kilometer zone: 26.9 %. As a result of ploughing, plant communities completely lose their peculiarities, structure and are replaced by segetal communities formed by annual plants. In comparison with natural ones, they accumulate less energy, less participate in the circulation of substances, and are less stable. In case of radionuclides entry, the latter tend to weakly bind in the biosystem, penetrate soil and easily wash it out, taking into account that the sod-podzolic soils of light mechanical composition predominate here. In the event of an accident when people are resettled, the most significant successions occurs here and the restoration of natural communities depending on the environmental conditions occurs within 20-100 years. During this time, a large percentage of radioactive elements have already been taken outside the ecosystem.

Felling. Under the impact of felling, depending on specific environmental conditions, it is possible to predict the following possible changes. Dry pine forests will be replaced by wastelands (lichens (Cladonia)), creeping thyme (Thymus serpyllum L.), gray hair grass having a weak projective cover, which will lead to development of deflationary processes. Fresh pine forests are replaced by poor meadows of matgrass with low feeding quality. The obtained soil humidity calculations show that for the region pine licheous forests are practically capable with pine age increase to be replaced by pine forests with green mosses and blueberries reflecting the optimum for this zone. Intensive felling can cause disappearance of relict spruce forests, if not to ensure timely renewal of spruce, since the ecological amplitude of spruce forests is the most narrow by all ecological factors.

Optimum ecological conditions are typical for deciduous forests, which under the impact of repeated felling are replaced in the direction of replacing common oak by European hornbeam. Therefore, it is expedient to expand cultivation of oak forests in the observation area. Alder swamps are characterized by quite normal regeneration after felling. Clear felling greatly changes the natural ecosystems, their structure, stability. Young tree planting up to 20 years is characterized by a reduced possibility of radionuclide fixation in the ecosystem, from 20 to 60 years with an intensive growth of the tree layer continuum, they are accumulated in the tree layer and only in 60 years, accumulation of radionuclides within this ecosystem is possible.

Grazing, haymaking, recreation cause the replacement of typical forest communities by grassy meadows. Such a replacement leads to salt accumulation and soil acidity increase. These indicators contribute to radionuclide accumulation in biomass, most of which is alienated annually, so radionuclides are taken out of the ecosystem.

Urbanization. The most significant and powerful external factor associated with the direct construction of Rivne NPP and residential areas of Kuznetsovsk. Due to forming such urban complexes and related communications, the area of man-made forests, ruderal communities, etc., which also have a very low resistance in comparison with natural ones, has increased. The situation will not change qualitatively due to commissioning of a new power unit,

Recreation. The indirect influence of Rivne NPP operation caused construction of the communication system (roads, hydraulic structures, bridges), which significantly affected the use of plant resources, increased recreation impact. Currently, recreation is one of the leading factors affecting the environment. In the vegetation cover, this is shown by forming grass cover in coniferous, mixed and, partly deciduous forests. This is most typical of the forests adjacent to Kuznetsovsk and Rafalivka, as well as other settlements.

Reclamation. This type of impact significantly changed the natural picture of Polissia as a whole. In the area of Rivne NPP, reclamation traces are also visible due to the need to regulate water regime, although this is not related to NPP operation. Swamp drainage led on the one hand to the expansion of areas occupied by dry pine forests, deflation processes, and on the other - lowering of the groundwater level. This contributes to the strengthening of radionuclide migration beyond this ecosystem.

Fires. Traces of fires were recorded in various forestry areas. The most vulnerable are pine lichenous and green moss forests. After fires, there is an expansion of nitrophilic elements: greater celandine (Chelidonium major L.), stinging nettle (Urtica urens L.), dog nettle (Galeopsis ladanum L.), etc. Disturbance of ecosystems by fires also leads to increased radionuclide migration and their washing out.

Based on the mentioned above, it may be concluded that absolutely all factors associated with human economic activities, to a variable degree lead to such disturbances of ecosystem structure that prevent radionuclide accumulation and contribute to their migration, and their taking out this ecosystem.

In the 30-km zone, there are very interesting, especially vulnerable ecosystems, for example spruce forests, areas of pine forests characterized with very rich flora, rare species, their unique combination, which currently have no the conservation status and are intensively used. They first need the conservation status.

Along with monitoring of the water regime, radionuclide content, etc., it is necessary to set up monitoring areas to monitor the dynamics of vegetation cover, especially in the areas with rare species.

Assessment of possible changes in phytocoenoses resulting from changes of surface and groundwater level, hydrochemical composition

To assess such changes, we used the author's phytoindication technique, as well as the ordination analysis technique, which allows evaluation of the relationship between changes in various factors [60].

During the work, such indicators as humidity (Hd), acidity (Rc), carbonate content of soil (Ca), salt (Tr) and nitrogen content (Nt) were evaluated. For each community type, relevant indexes expressed in points, their average values were calculated, and ordination matrices were formed based on which possible changes were predicted.

The following conditions are the most optimum for this territory:

1) soil humidity: 12 points (fresh forest-meadow with full spring drench, in which moisture deficiency is observed only in the late summer; ground water is from 5 to 10 m) (Figure 6);

2) soil acidity: 7 points (weakly acidic sod-podzolic soil, pH 5.5-6.5) (Figure 7);

3) trophicity (total salt content: 5 points (soil poor in salt (95-150 mg/l), podzolic soil) (Figure 8);

4) nitrogen content: 4-6 points (soil poor in mineral nitrogen, 0.05-0.3 %) (Figure 9);

5) carbonate content: 4-5 points (soil poor in carbonate due to overlapping of chalk deposits by quaternary silicate rocks) (Figure10).

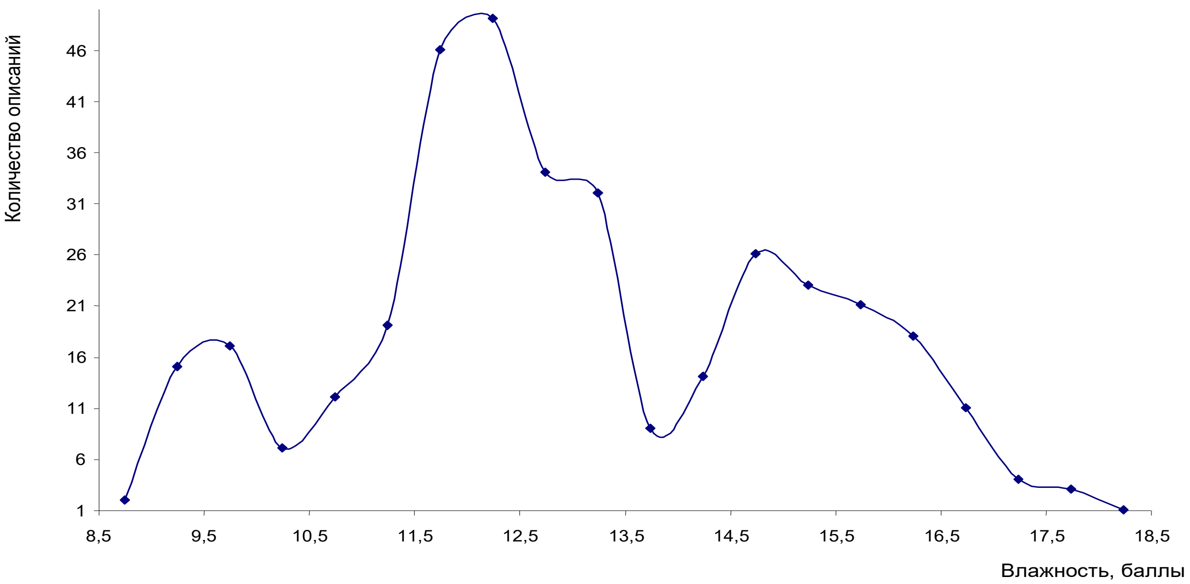

Рисунок 6 - Распределение количественных показателей влажности почвы (Hd) на пробных площадях в 30-километровой зоне РАЭС

Figure 6 – Distribution of quantitative indicators of soil humidity (Hd) on sample plots in the RNPP 30-km zone

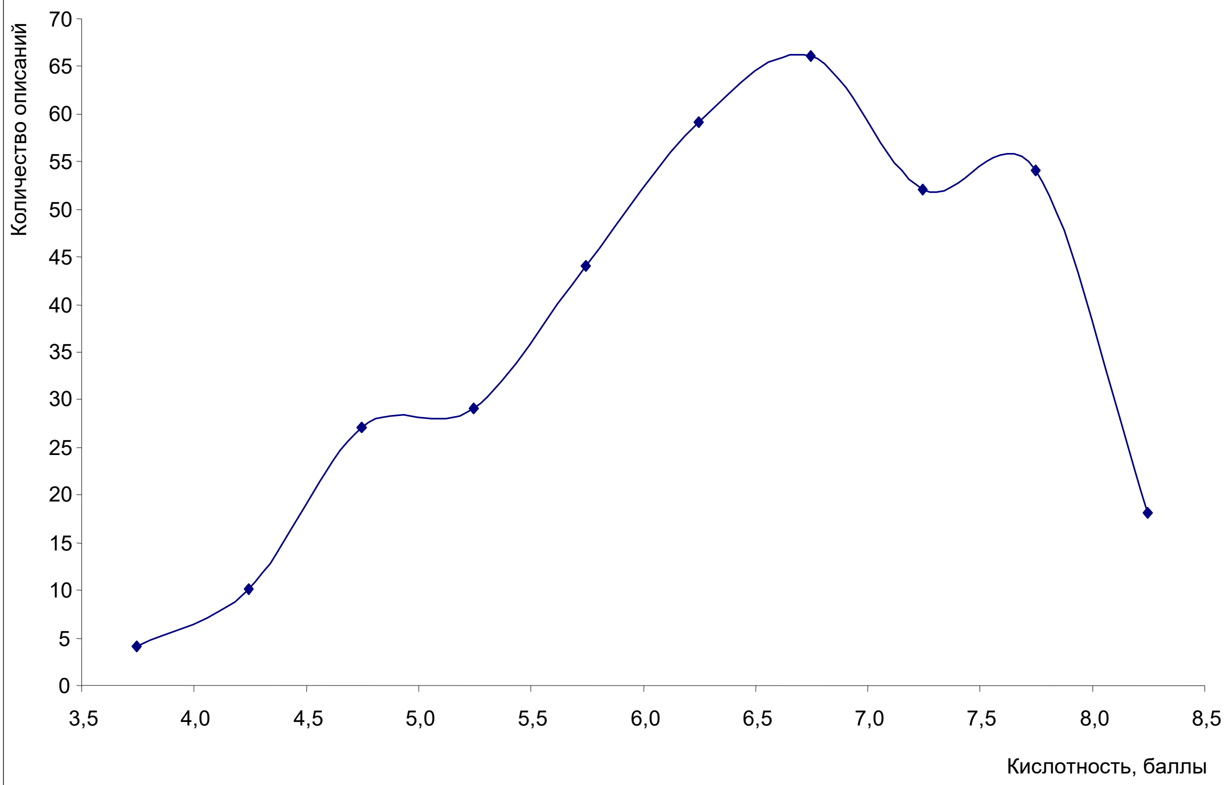

Рисунок 7 - Распределение количественных показателей кислотности почвы (Rc) на пробных площадях в 30-километровой зоне РАЭС

Figure 7 – Distribution of quantitative indicators of soil acidity (Rc) on sample plots in the RNPP 30-km zone

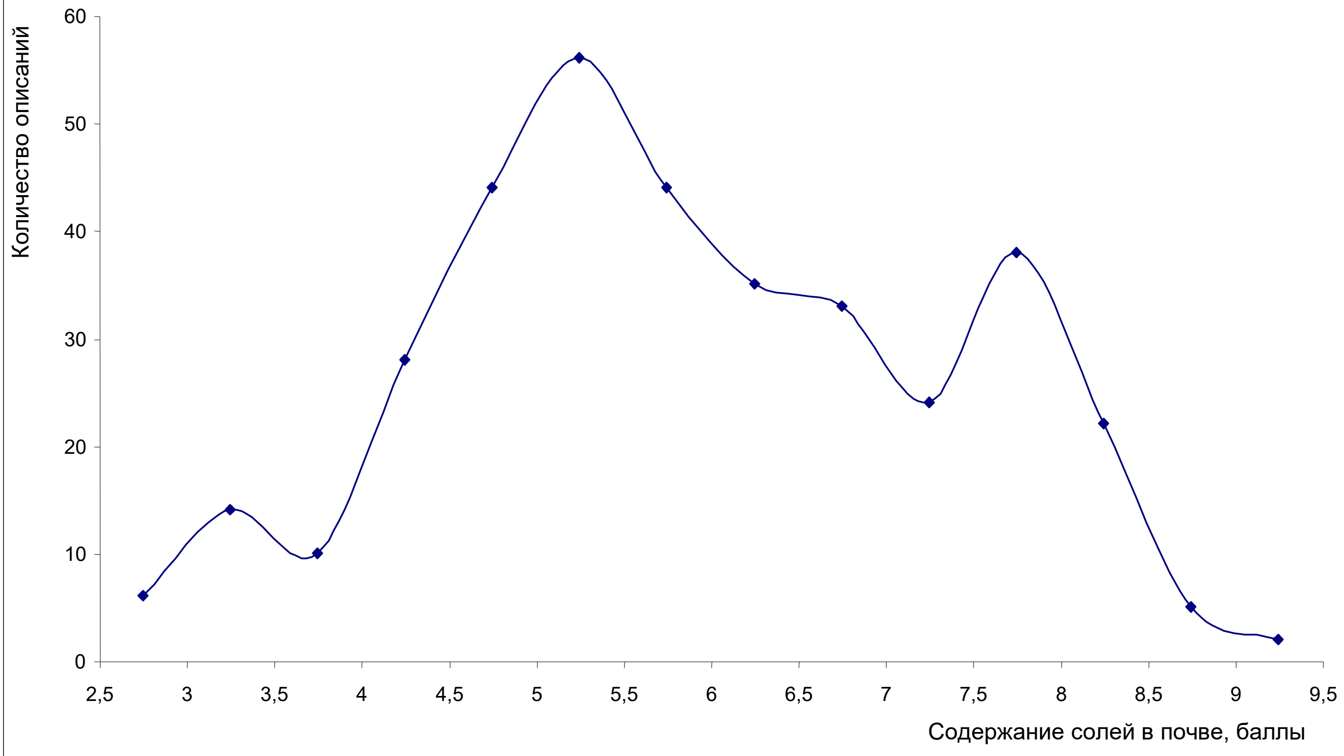

Рисунок 8 - Распределение количественных показателей содержания солей в почве (Tr) на пробных площадях в 30-километровой зоне РАЭС

Figure 8 – Distribution of quantitative indicators of salt content (Tr) in soil on sample plots in the RNPP 30-km zone

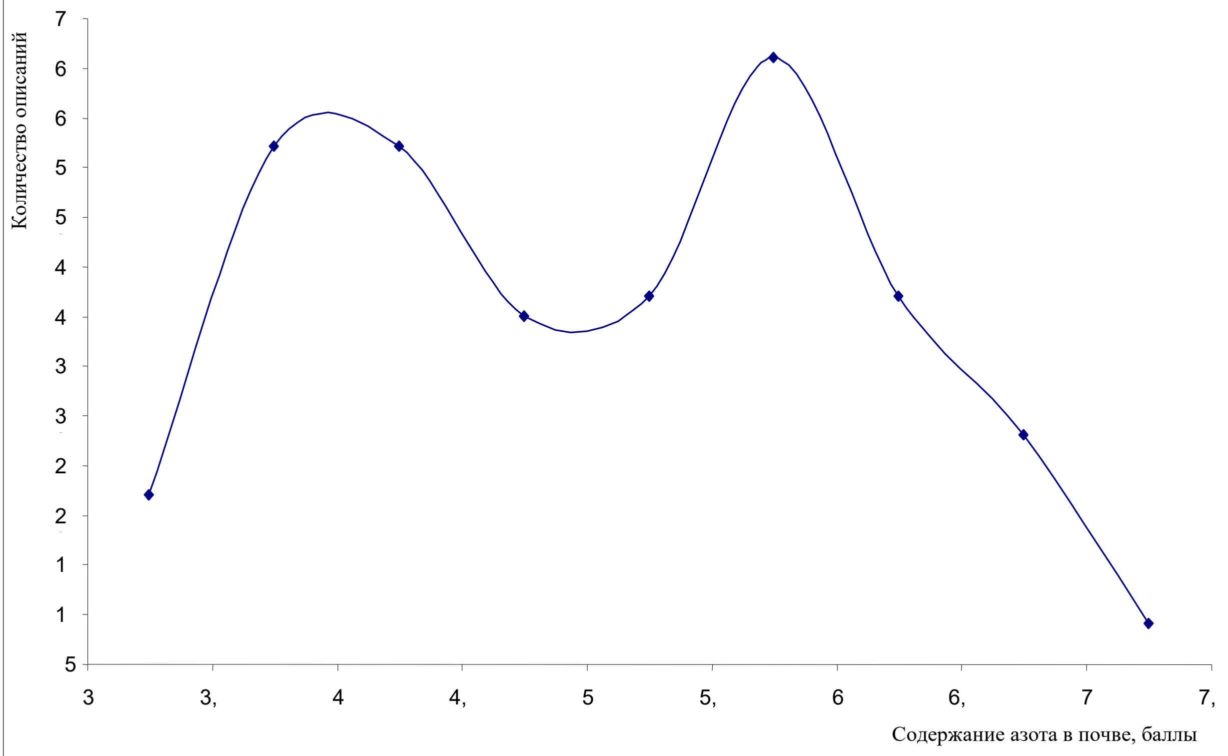

Рисунок 9 - Распределение количественных показателей содержания азота (Nt) в почве на пробных площадях в 30-километровой зоне РАЭС

Figure 9 – Distribution of quantitative indicators of nitrogen content (Nt) in soil on sample plots in the RNPP 30-km zone

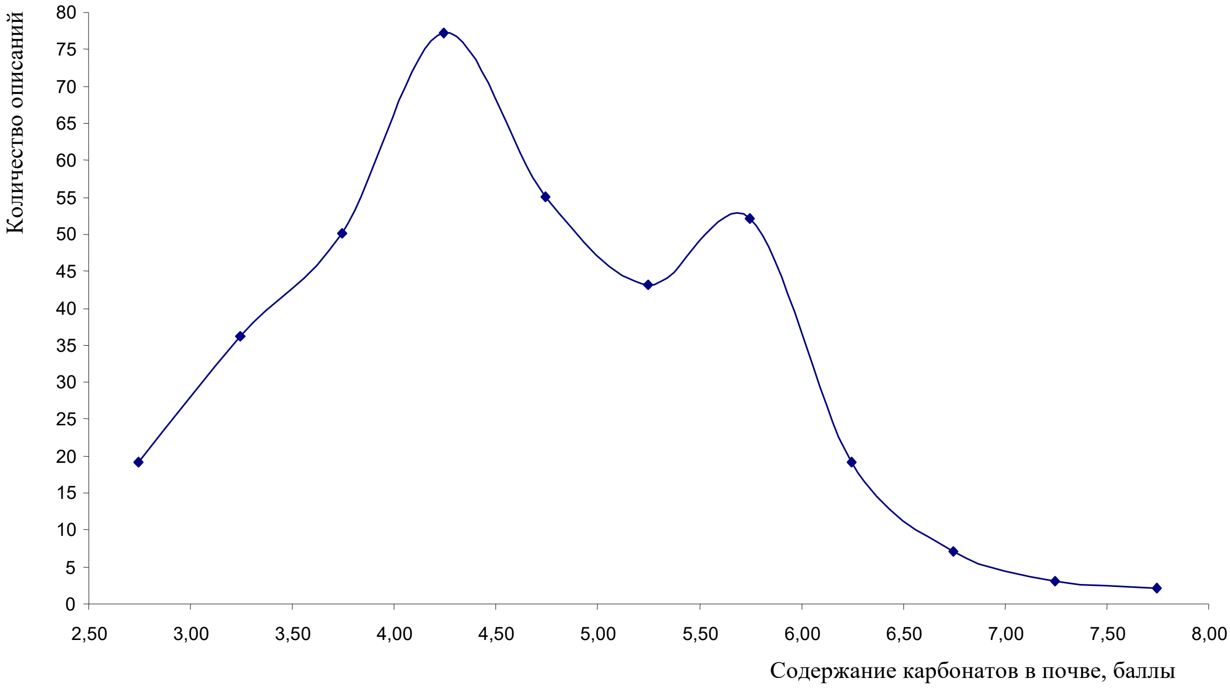

Рисунок 10 - Распределение количественных показателей карбонатов в почве (Са) на пробных площадях в 30-километровой зоне РАЭС

Figure 10 – Distribution of quantitative indicators of carbonate content (Hd) in soil on sample plots in the RNPP 30-km zone

The analysis of ordination matrices showed that between changes in soil acidity (Rc) and salt content (Tr) (Figure 11), carbonate content (Ca) and acidity (Rc) (Figure 12), nitrogen content (Nt) and acidity (Rc) (Figure 13), nitrogen content (Nt) and humidity (Hd) (Figure 14), carbonate (Ca) and salt (Tr) content (Figure 15), nitrogen (Nt) and salt (Tr) content (Figure 16) there is a straight-line correlation and between the change of soil humidity (Hd) and carbonate content (Ca) in it (Figure 17) there is an inverse relation. Although there is a relation between the change of humidity and salt content in soils (Figure 18), humidity and acidity (Figure 19), it is not so clear and not strictly deterministic. At the same time, relation between carbonate and nitrogen content in soils (Figure 20) was not defined.

As you know, the leading environmental factors in the distribution of plant communities are soil humidity and trophicity. Soil humidity varies in a wide range from 9.0 (meadow-steppe type with moderate spring drench with atmospheric precipitation on wastelands and dry pine forests with hidden podzol soils) to 18 points (swamp type with flooding regime), which contributes to intensive peat accumulation under mesotrophic, alder and eutrophic swamps. This represents 39% of the total scale. When thee hydrologic regime changes, the following successions of grass communities are formed: wasteland → meadows → eutrophic swamps and forest communities are formed: dry → fresh pine forests → spruce forests → mesotrophic swamps.

Soil acidity (Rc) ranges from 4 points (pH 4.5 under mesotrophic swamps and pine forests) to 8 points (pH 6.5 under eutrophic swamps), which is 31 % of the scale. With a change in acidity, the row from mesotrophic to alder and eutrophic swamps is most clearly manifested.

Salt content (Tr) in soil also varies in a very wide range from 3 points (poor heavily leached soil under mesotrophic swamps) to 9 points (salt-rich eutrophic swamps and meadows). This range takes up 32 % of the total scale. With a change in soil salt regime, formation of two rows of communities is observed: dry pine forests → wastelands → meadows → eutrophic swamps and spruce forests → alder forests → eutrophic swamps.

Carbonate content (Ca) in soils has a wide range from 2.5 (carbonate-free soils) to 7.5 points (enriched with carbonates), which is 38 % of the scale. This is due to occurrence of carbonates here, which in some places come to the surface or overlap with considerable sand masses of silicate origin.

Nitrogen content (Nt) in soils ranges from 2.5 (nitrogen-free soil under wastelands) to 7 (sufficiently nitrogen-rich soil under alder, eutrophic swamps and spruce forests). Although this indicator is the highest and covers 41 % of the scale, it depends on soil humidity, its acidity and salt content. As can be seen in the ordination matrix, this indicator is not differentiating for the majority of coenoses.

The analysis of the data obtained showed that the most differentiating factors for which the amplitudes are least overlapped are soil humidity and salt content. At the same time, practically each community type is characterized by a special combination of indicators, except dry pine forests overlapping with wastelands, hornbeam-oak and spruce forests overlapping both with each other and with fresh pine forests. If regarding humidity and carbonates, the amplitude of fresh and wet pine forests completely overlaps the amplitudes of spruce and hornbeam-oak forests, then regarding carbonates and nitrogen, they differ.

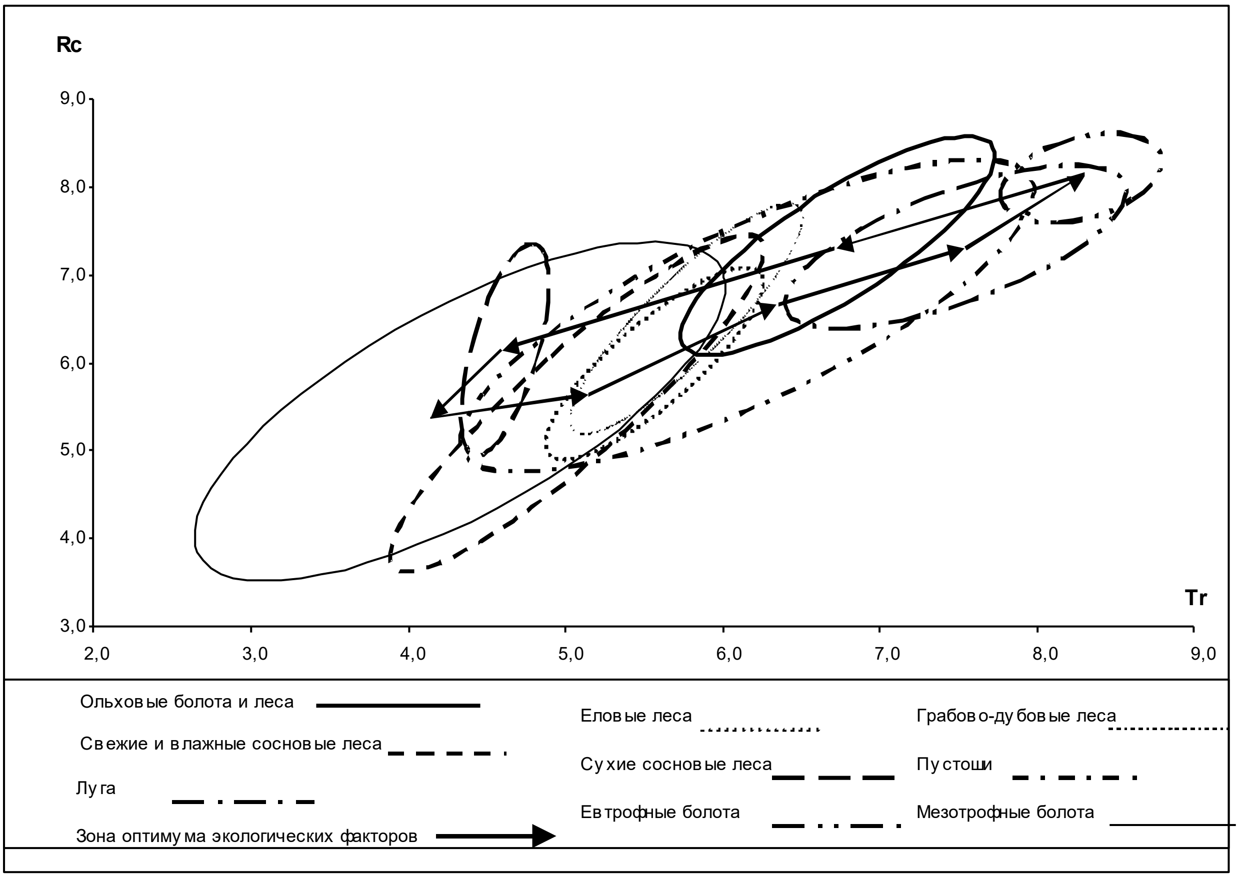

Figure 11 – The dependence between the change in acidity indicators and salt content in soil for different communities in the 30-kilometer RNPP zone (in points)

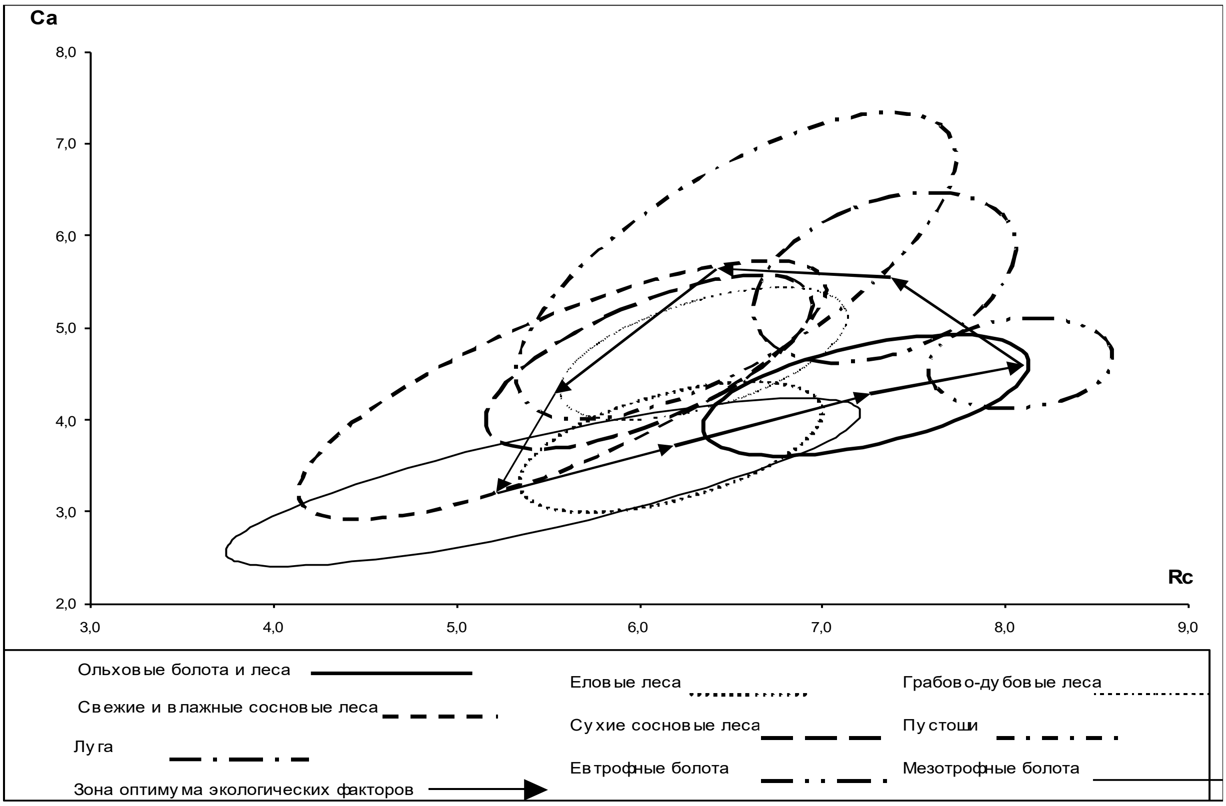

Figure 12 – The dependence between the change in acidity indicators and carbonates in soil for different communities in the 30-kilometer RNPP zone (in points)

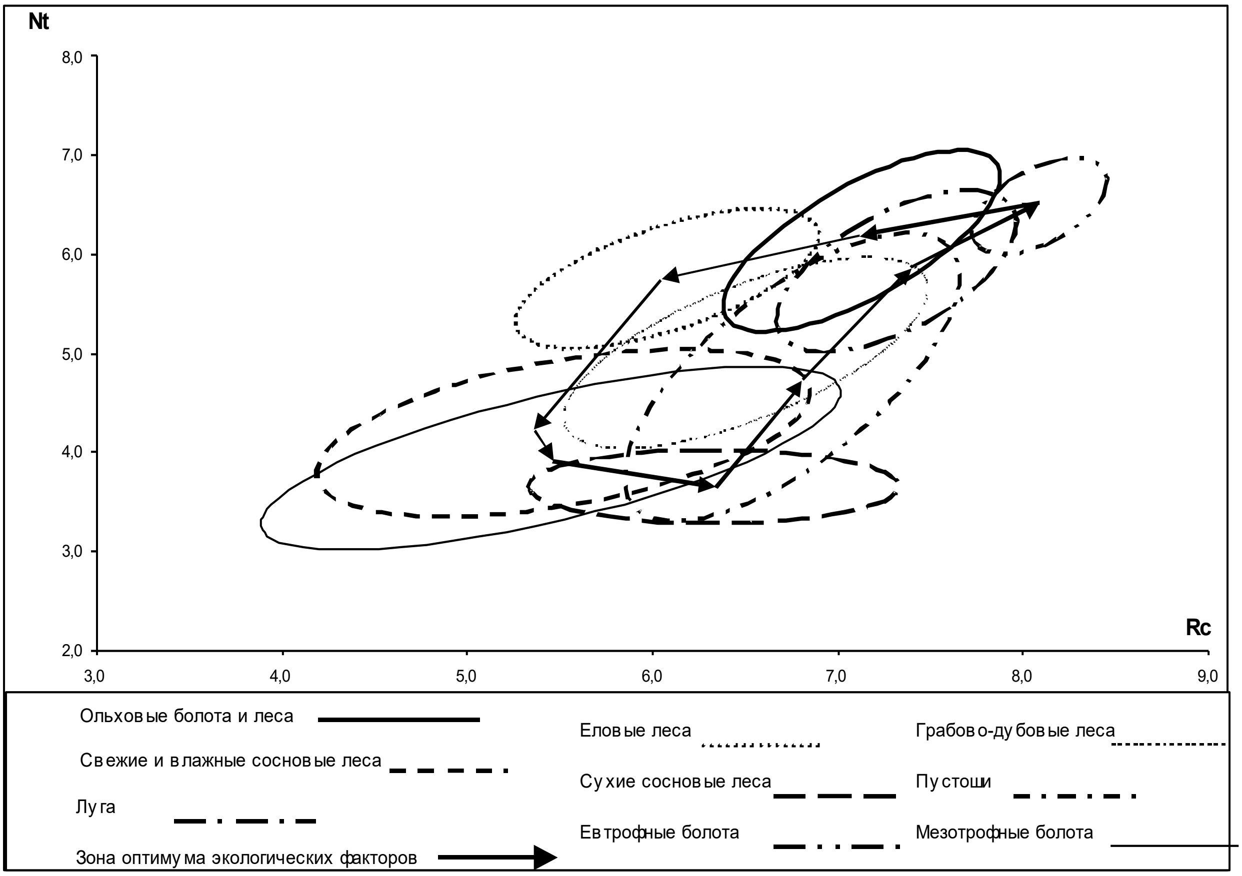

Figure 13 - The dependence between the change in acidity indicators and nitrogen content in soil for different communities in the 30-kilometer RNPP zone (in points)

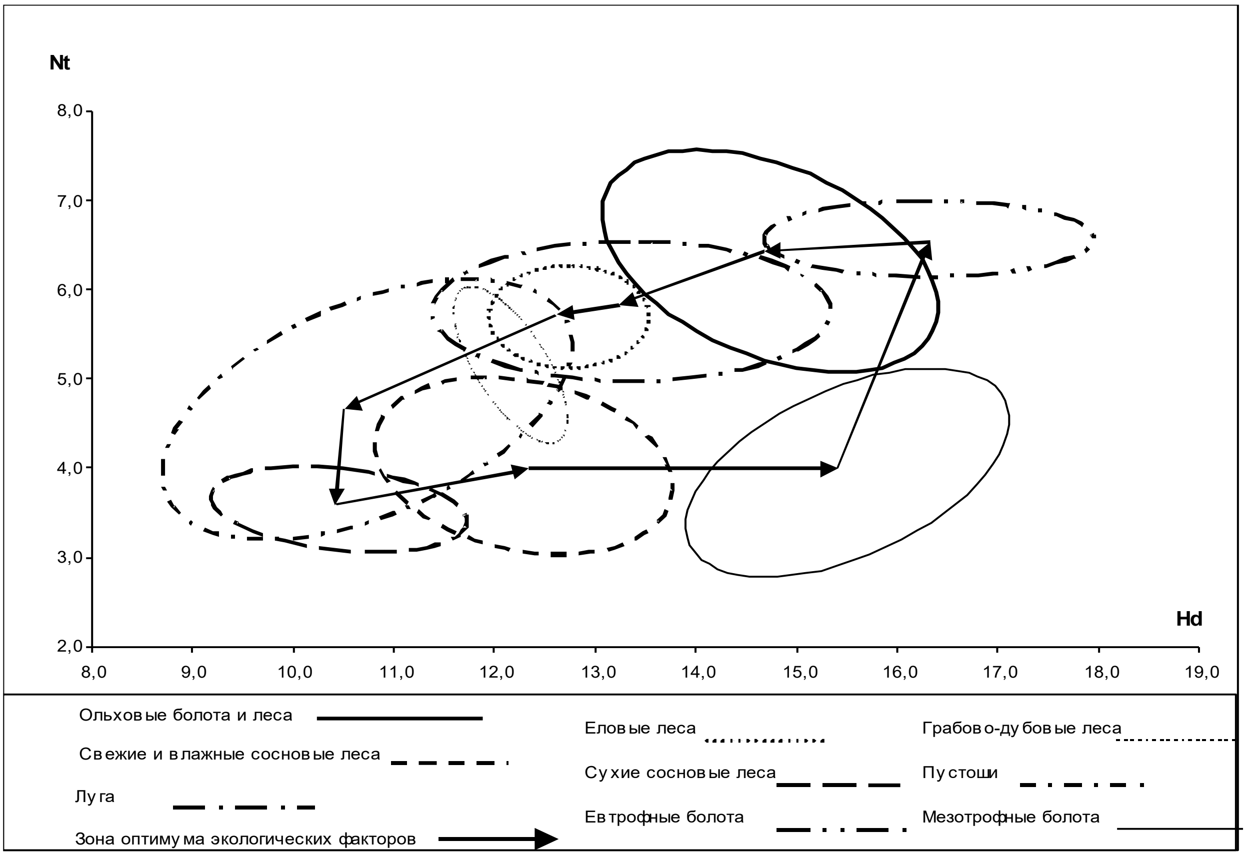

Figure 14 - The dependence between the change in humidity indicators and nitrogen content in soil for different communities in the 30-kilometer RNPP zone (in points)

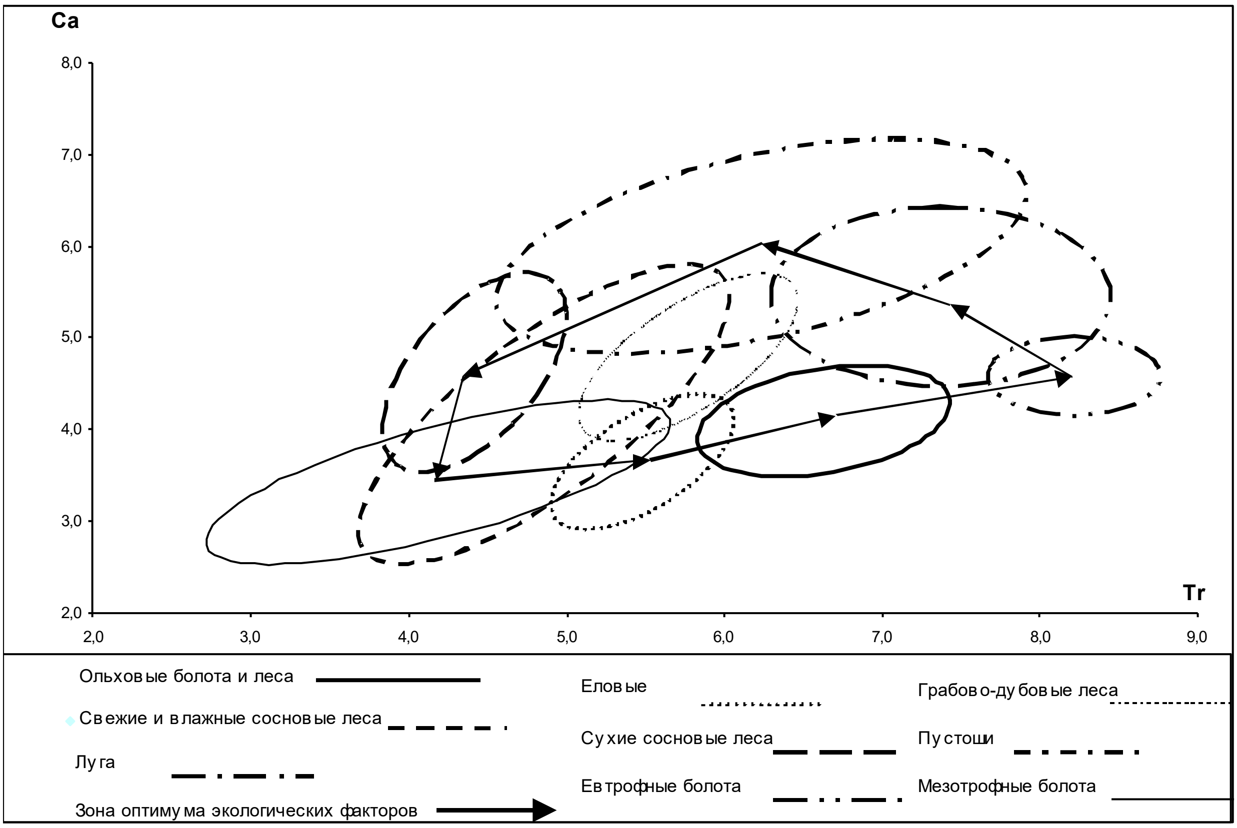

Figure 15 - The dependence between the change in indicators of salt and carbonate content in soil for different communities in the 30-kilometer RNPP zone (in points)

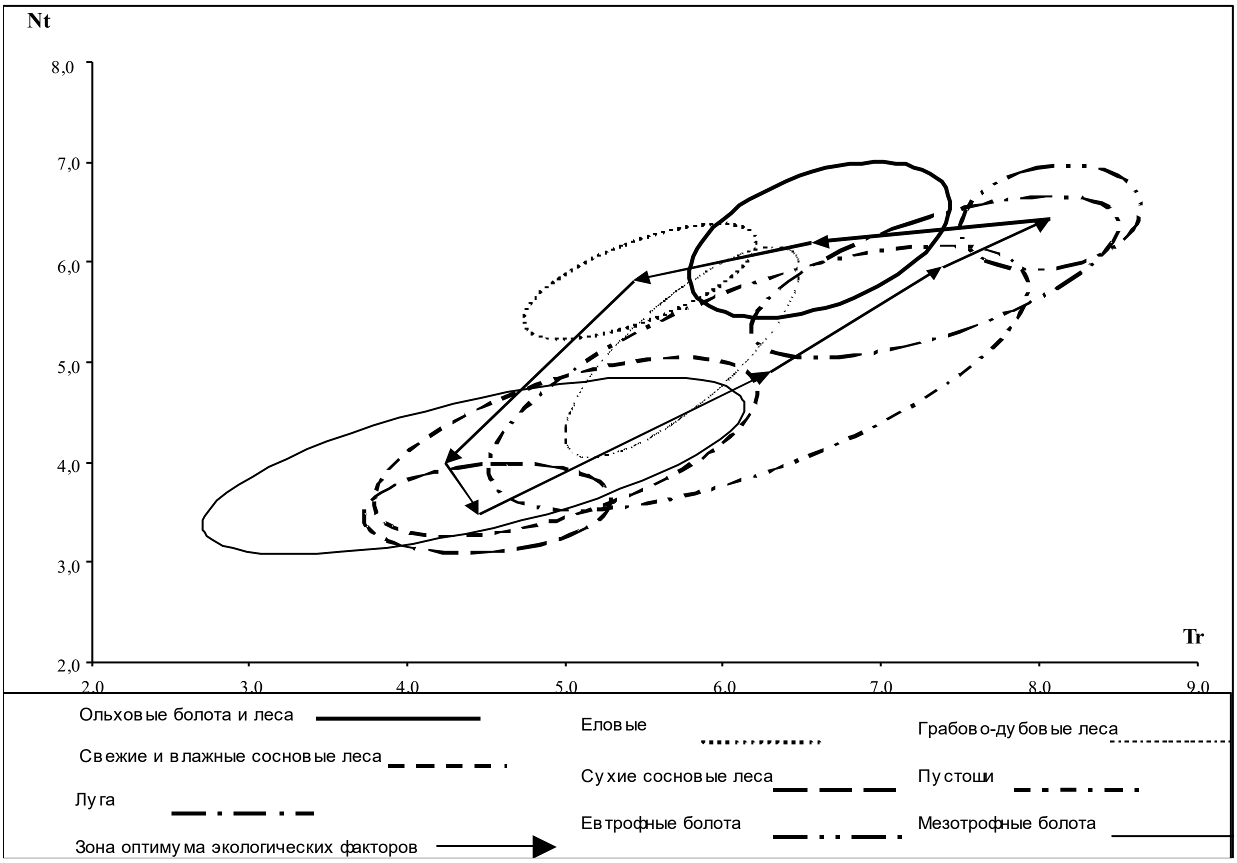

Figure 16 - The dependence between the change in indicators of salt and nitrogen content in soil for different communities in the 30-kilometer RNPP zone (in points)

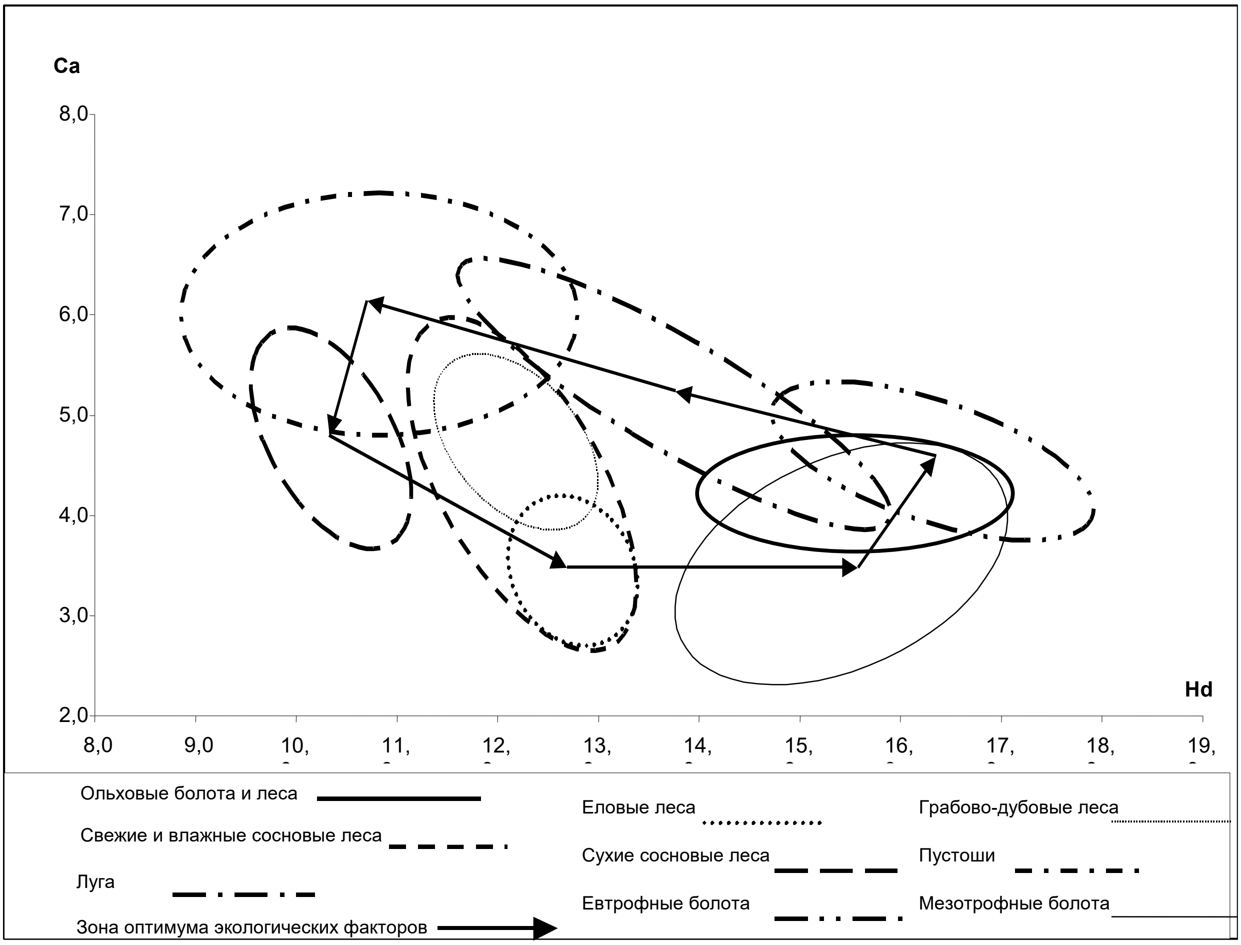

Figure 17 - The dependence between the change in humidity indicators and carbonates in soil for different communities in the 30-kilometer RNPP zone (in points)

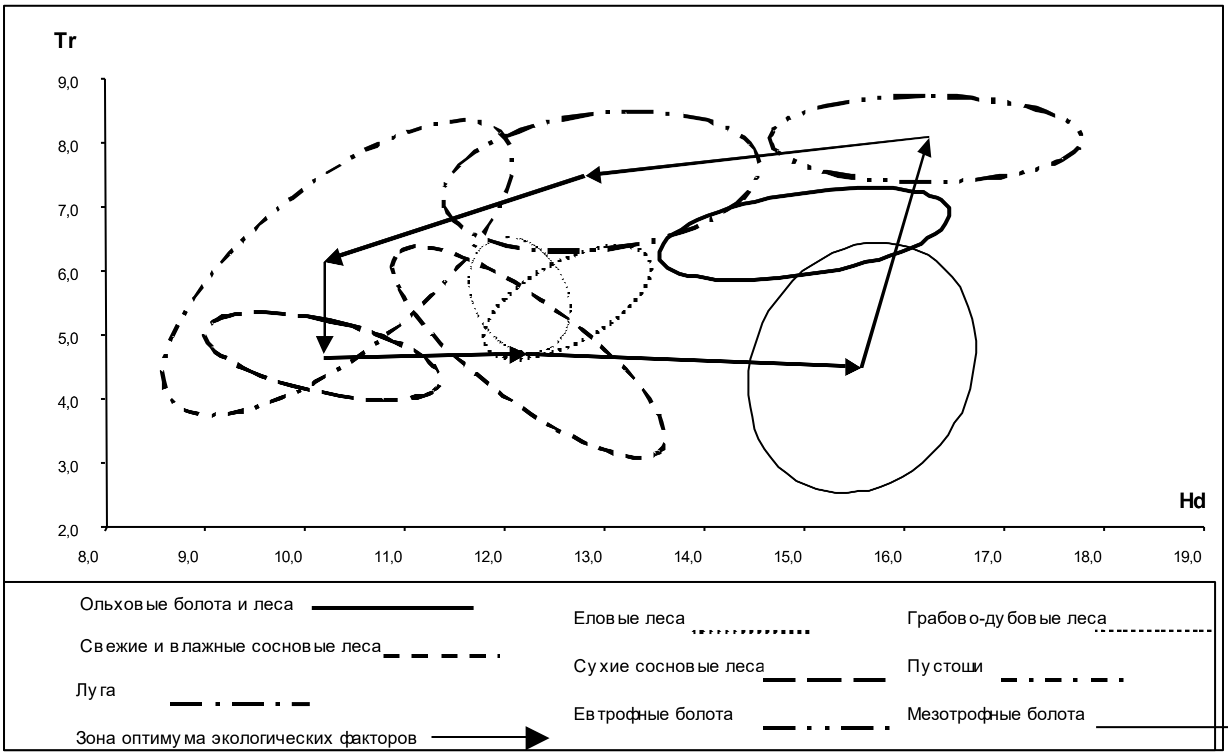

Figure 18 - The dependence between the change in humidity indicators and salt content in soil for different communities in the 30-kilometer RNPP zone (in points)

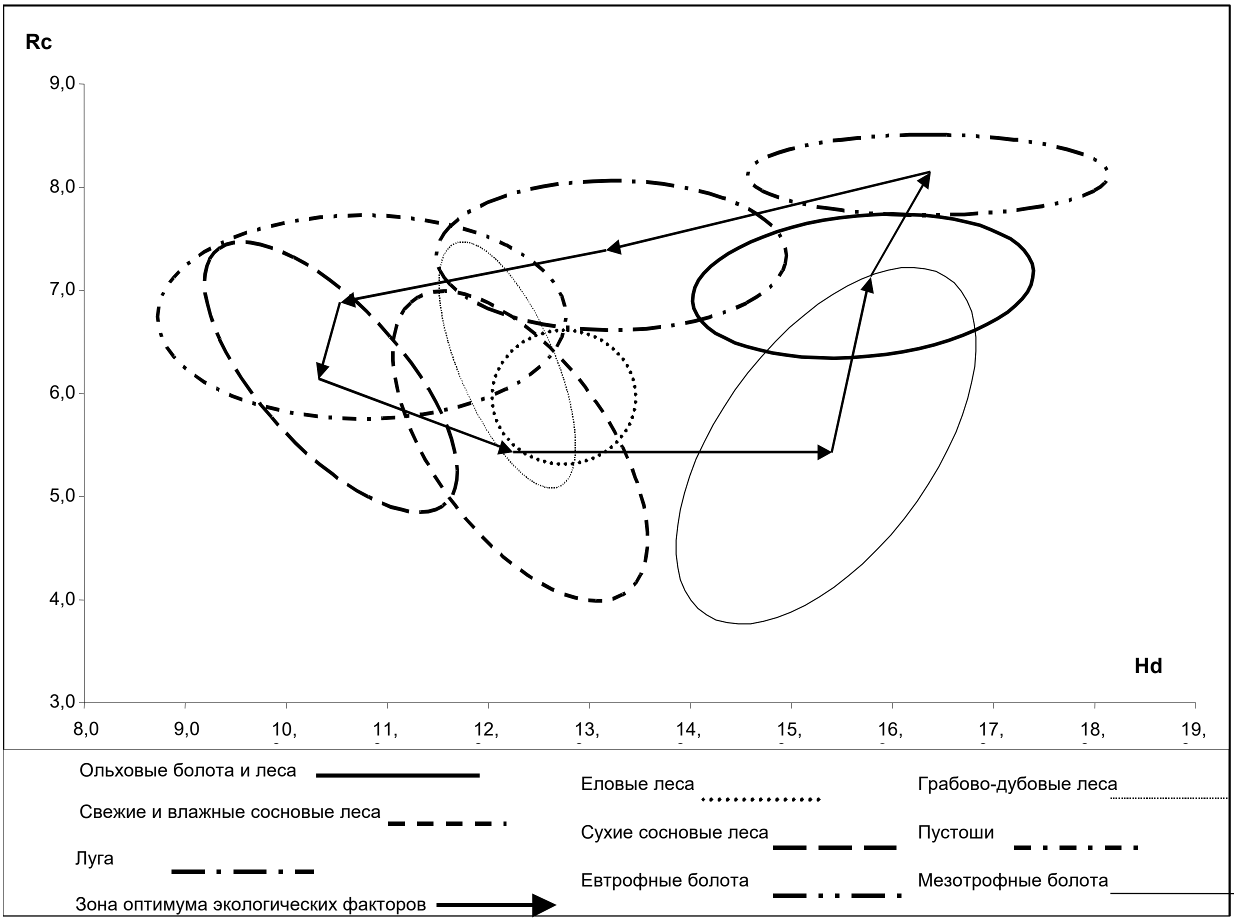

Figure 19 - The dependence between the change in humidity and acidity indicators of soil for different communities in the 30-kilometer RNPP zone (in points)

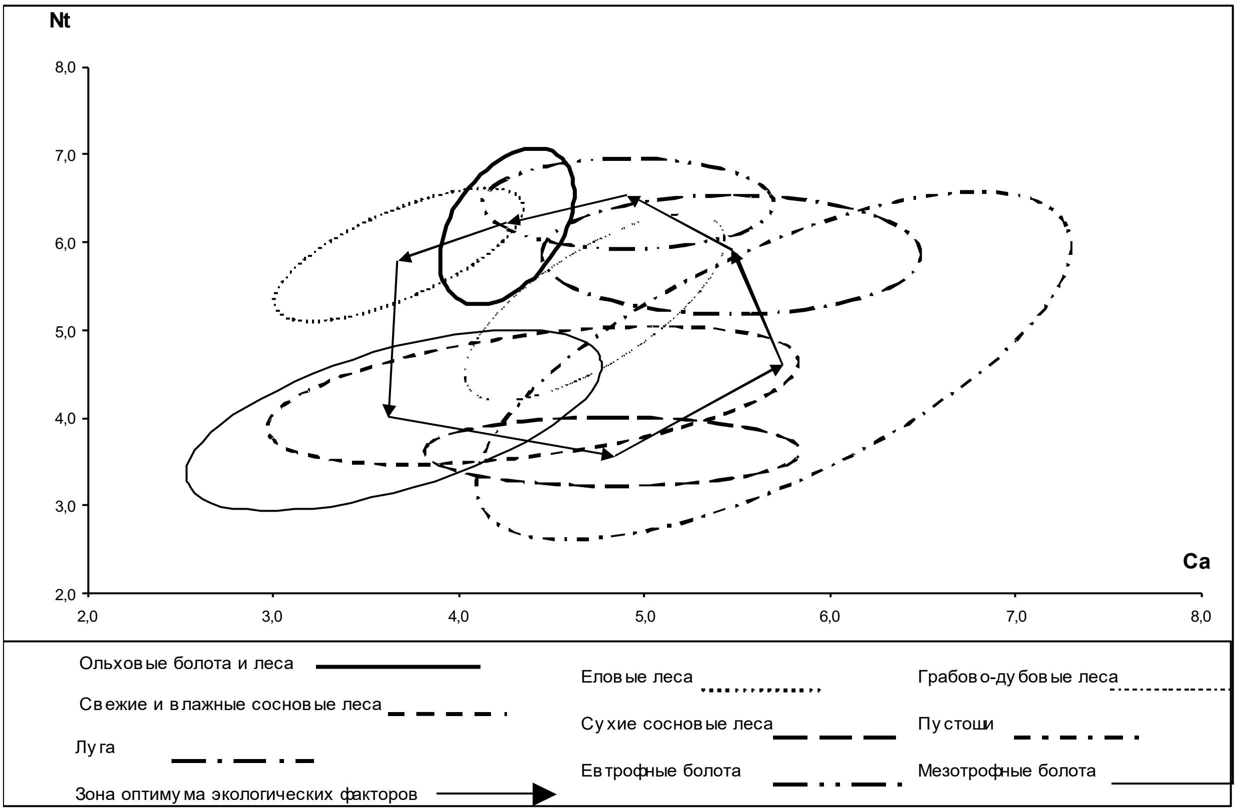

Figure 20 - The dependence between the change in indicators of carbonate and nitrogen content in soil for different communities in the 30-kilometer RNPP zone (in points)

Thus, among these five basic factors, there are always some that are determinative for the existence of certain vegetation types.

Construction of ordination matrices in terms of changes in various factors, in particular, their average (optimum) indicators, show the following. The closer ecological fields are to the optimum, the more they overlap, the stronger edificators form these communities, their stability is higher (i.e., the ability to preserve structure in these specific conditions) and lability is less due to internal coenotic structure, such communities may be replaced by one another. The farther from the optimum, the less competitors, the more extreme conditions and competition plays a smaller role. If the amplitudes do not overlap, then this means that this community cannot be replaced by another, it preserve its structure or disintegrates, i.e. it is stable in these specific conditions and for its change, changes in external conditions are needed.

The nature of fields also shows that acidity-trophicity field and nitrogen content are characterized by the narrowest amplitude. It means that these factors in this territory limit the distribution of communities as a whole. When these indicators change, the most significant changes in vegetation cover could occur.

The analysis of the data obtained makes it possible to predict the change of communities with a decrease or increase in one or another factor. Spruce forests, hornbeam-oak forests and fresh pine forests are the most stable, preserving their structure in this combination, but if they are destroyed they are not able to recover quickly i.e. have low lability.

Mesotrophic swamps are the most ecologically isolated, and they can be changed only in case of drastic melioration. The communities of dry acidic poor ecotopes (dry and fresh pine forests, wastelands, mesotrophic bogs) have the least ecological stability. In case of an extreme external impact, they can change dramatically, and if soil indicators are changed, they do not recover at all.

The most stable to recreation are B_3-C_3 forests, i.e. differing in optimum conditions. With an increase of dryness or humidity, trophism, that is, closer to extreme conditions, recreational stability decreases. Pure dry pine forests $A_0$are the least stable, since under the influence of recreation, due to sand mobility, grass layer quickly disappears, tree stand has low bonitet (V-Va), and its disturbance causes thinning, i.e., they have low lability. Although perhumid ecotops are not stable to the impact of recreation, but unlike dry ones, they may be restored quickly, i.e. they have high lability.

Assessing the threat of loss or suppression of rare species listed in the Read Book of Ukraine

The populations of 37 rare species, 23 of which are listed in the Red Book of Ukraine [59] are represented by various numbers, densities and are characterized by a certain dynamics due to human economic activities.

It is necessary to note that radioactivity changes even in case of emergency releases will not impact the reduction or disappearance of rare species, since this impact is manifested at the organism level and does not cover population or species levels.

However, various types of anthropogenic impact or, in the event of an accident, cessation of economic activities may significantly affect the state of populations.

The most of the species, in particular typical for mesotrophic swamps and non-moral forests may reduce their numbers while increasing the anthropogenic factor (drainage, recreation, etc.). This are Chamaedaphne calyculata, diecious sedge (Sarex dioica L.), creeping sedge (Carex chordorrhiza Ehrh.), English sundew and oblong-leaved sundew, Epipactis palustris, small-fruited cranberry, whortleberry willow, downy willow, marsh scheuchzeria, etc.

Forest species are very sensitive to the impact of clear felling and may disappear in tree stand lightening (oak fern, stiff club-moss). A number of forest species may withstand lightening (sanitary felling), but disappear in case of complete deforestation (foxfeet, fragrant daphne, dark-bark birch (Betula obscura A. kotula), turk's cap lily, common neottia, butterfly orchid (Platanthera bifolia (L.) Rich.)

Quill wort (Isoëtes lacustris L.) is very interesting and rare for Ukraine. It was previously known in Ukraine from two lakes (Sopachiv and Voronky), but in recent years it has been found in the Volyn region. Its presence in the 30-kilometer zone (Voronky Lake near Voronky village) is under threat due to increased recreation, rest and, as a result water pollution and eutrophication. Due to establishing the Rivne nature reserve, implementing the reserve status for the White Lake may mean strengthening of the recreational load on the Voronky Lake that may cause extinction of this rare species.

Along with reducing populations of the most rare plants, some species have expanded their populations in the past decade and anthropogenic impact has contributed to this. Thus, spreading St. John's wort was known only from two points of the Volodymyretskyi region but our studies have shown that its populations are more numerous and they expand their areas under the impact of intensive grazing. At the place of performed felling, on bare sands, along roads, Lithuanian campion, barren myrtle, Polissia fescue expand their positions. At the place of felling, recreation, along forest paths, the following was noted: bulbous rush, bog clublike, which thus avoid competition. However, the percentage of the last species is much less than of the first ones. In this regard, a paragraph on monitoring of their populations should be included in the monitoring research program. It is also necessary to expand the network of existing reserved objects.

The impact of power units on reserved objects

According to the State Administrations of Ecological Resources in the Volyn and Rivne regions, in the 30-km zone of RNPP there are 47 objects of the natural reserve fund of different reserve degree with a total area of 29733 hectares. This amounts to 10.5 % of the the observation area, which is almost three times higher than the national indicator (3.9 %). Reserved objects belong to such categories: reserve (branch), special nature reserve (national and local significance), natural sanctuaries of local significance, reserved natural boundaries.

Since the change in the properties of biological systems (both at population and at cenotic organization level) due to radiation exposure is not manifested, if it does not cause direct death of organisms, i.e. does not exceed a certain threshold. Therefore, the operation of Rivne NPP units, and consequently periodic release of radionuclides into the environment, will not cause transformation of protected ecosystems or death of botanical rarities.

The main factor in changing and reducing stability of reserved ecosystems is recreation. This impact leads to soil compaction, deterioration of its water-air regime, worsening of regeneration of trees, number of herbage plants and formation of grass stand of soddy cereals. The strongest recreational impact will be experienced by the reserved objects located near settlements, especially large ones (Kuznetsovsk, Manevychi, Rafalivka, Volodymyrets). This concerns the branch of the Biloizerskyi Rivne nature reserve, Vorontsovskyi special nature reserve, Dzherelo special nature reserve and others.

Thus, it may be stated that the nature reserve network of the RNPP 30-km zone is well developed, but regarding coverage of plant rarities it is not optimum. It is necessary to increase the share of reserved objects assigned to protect rare for Ukraine pine juniper forests, pine ledum forests, botanical rarities.

Commissioning of a new power unit in general will not cause the transformation of reserved ecosystems. They may impact only the amount of medicinal raw materials protected in several reserved objects. Possible increase of recreation impact on reserved ecosystems should be regulated by protection regimes.

Possible disturbance of fauna in the 30-km zone

Under normal operation there will be no noticeable impact on the animal world in the RNPP 30-km zone. Only a further increase in the recreational load on the Styr floodplain may have a certain effect. Due to peculiarities of the vegetation cover, pine forests adjacent to the NPP and Kuznetsovsk are characterized by a depleted fauna, insignificant number of rare and protected species. MDBA cannot have a significant impact on rare and protected species of animals whose number is very insignificant in pintums.

In a beyond design-basis accident, changes in the animal world will be caused by changes in economic activities. This will lead to a major reconstruction of phytocoenoses (reduction of recreational and grazing load, extensive wastelands, etc.).

Under MDBA and BDBA, accumulation of radionuclides will be observed in food chains, which can cause negative changes in the structure of higher trophic levels and disbalance of genetic constitution of populations, increase of mutational background and long-term genetic consequences, as well as increase in microevolution processes.

Assessing the threat of loss or suppression of rare species of vertebrate animals listed in the Red Book

The list of species of vertebrates included in the Red Book of Ukraine:

Reptiles

1. Smooth snake - *Coronella austriaca*

Birds

2. Black stork - *Ciconia nigra*.
3. White-eyed pochard -Aythya nyroca
4. Goldeneye -Bucephata clangula
5. Merganser -Mergus merganser
6. Spotted eagle - *Aquila.pomarina*
7. Greater spotted eagle-Aquila clanga
8. Dove-hawk - *Circus cianeus*
9. Snake eagle - *Circaetus gallicus*
10. Crane - *Grus grus*
11. Marsh sandpiper -Tringa stagnatilis
12. Great gray shrike -Lanius excubitor

Млекопитающие:

13. Otter – Lutra lutra.
14. Steppe polecat –Mustela eversmanni.
15. Brock – Meles meles.
16. Small water shrew – Neomis anomalis.
17. Garden dormouse – Eliomys guercinus.
18. Common barbastelle – Barbastella barbastella.

RNPP normal operation does not cause significant damage for almost all of the above species of animals. A certain negative impact on the population of “red book” species may be caused by related human economic activities in the 30-km zone. However, at the same time, significant destruction of animal populations, their biotopes or complete liquidation of habitats is not expected.

Rare species of insects in the RNPP 30-km zone

In the surveyed area, 18 species of insects listed in the security lists - the Red Book of Ukraine (RBU) and the European Red List were identified. Among them, 7 species are not specified in the Red Book of Ukraine for the Rivne region.

1. Emperor dragonfly (Anax imperator Leach). Rare category: RBU category III. The species is common in the RNPP zone. In the Rivne Nature Reserve in the vicinity of the Bile Lake, this ragonfly was found in large numbers (up to 10-12 specimens per 100 m of the recording route). Hunting males and females were observed on wide forest glades at a considerable distance (up to 800-900 m) from breeding place. The main factor adversely affecting the number and population structure of emperor dragonfly is water pollution. The imago and larvae of this dragonfly are active predators capable to accumulate harmful substances (including radionuclides) in food chains.

2. Black-winged damselfly (Calopterix virgo L.) Rare category: RBU category III. This is one of the most beautiful insects of Ukraine. For the Rivne region, this species is not specified in the Red Book of Ukraine. In the RNPP 30-km zone, this species is rare and is relatively in small numbers. Their larvae can develop only in water bodies with pure oxygen-rich flow water. As a rule, dragonflies do not migrate far from breeding places. Adult insects and larvae are predators. They can accumulate harmful substances, including radionuclides in food chains. First of all it concerns the larvae living in water. The main factor limiting the number of this species is water pollution.

3. Green large dragonfly (Aeschna viridis Ev.). Rare category: category I in the European Red List. In the surveyed area, this is a usual not numerous species. Larvae and adult insects are predators. The former attack many aquatic invertebrates, as well as fries and frog larvae. Adult dragonflies usually stay near water bodies. They hunt flying insects from many groups, including smaller dragonflies. In the vicinity of the Bile Lake, we observed a case of attacking a flying predatory carabid beetle (Carabidae) by a green large dragonfly. Like the above species, this dragonfly can accumulate harmful substances, including radionuclides by food chains. The main factors affecting the number of green large dragonflies are availability of water bodies suitable for larvae development and degree of water pollution in breeding places.

4. Forest caterpillar hunter (Calosoma sycophanta L.). Rare category: RBU category II and category V in the European Red List. For the Rivne region, this species is not specified in the Red Book of Ukraine. In the RNPP area, it is rarely seen. It lives in forests with a large oak presence. It keeps a hidden way of life. Beetles and larvae are voracious predators. They eat very furry caterpillars (gipsy moth - Lymanthria dispar L., brown-tail moth - Euproctis chrysorrhoea L. and other lepidopterids), which, incidentally, are reluctantly eaten or not eaten by many birds. Beetles live for about two years, during which they eat within several hundred large and small caterpillars. Like other predators, forest caterpillar hunter can accumulate harmful substances by food chain. The highest probability of harmful substance accumulation in the organism of forest caterpillar hunter is in May - June, i.e. during the period of the most intensive beetle feeding. The main factors determining the abundance of forest caterpillar hunter are chemical forest treatment with pesticides and dynamics in the number of lepidopterids (food items), primarily gipsy moth.

5. Hermit beetle (Osmoderma eremita Scop.). Rare category: RBU category II. For the Rivne region, this species is not specified in the Red Book of Ukraine. Hermit beetle is extremely rare in the RNPP area. It lives in forests with old hollow oaks. Larvae develop in rotten wood of tree cavities. Beetles feed on sap of damaged trees. The main factors affecting the number of this species are

sanitary felling destroying the beetle's breeding places (old hollow trees), and chemical forest treatment.

6. Stag beetle (Lucanus cervus L.). Rare category: RBU category III. For the Rivne region, this species is not specified in the Red Book of Ukraine. In the surveyed area, stag beetle may be seen locally: in places with old deciduous trees (primarily oaks). Larvae develop in hollows of willows, stubs. Beetles fly in June - July. The number of stag beetles is relatively low. Despite this, the species is well known to the local public. The main limiting factors are the same as for hermit beetle.

7. Musk beetle (Aromia moschata L.). Rare category: RBU category III. In the RNPP area this species is common but not numerous. Larvae develop in old willows, rarely in poplars. Beetles fly from June to August inclusively. The number of musk beetle is affected by natural enemies (parasites and predators), as well as sanitary felling. Nothing threatens well-being of this species in the zone.

8. Swallowtail (Papilio machaon L.). Rare category: RBU category II. In the surveyed area, this species is common but not numerous. May be seen on mixed grass mesophytic meadows and in agrocoenoses. Some butterflies were indicated on the outskirts of Kuznetsovsk from the Styr River side and even on the central street of the town. Butterflies of this species can migrate for many kilometers from breeding places. Although both natural and anthropogenic factors impact the number of swallowtail, the population of this species in the zone is quite stable.

9. Rite swallowtail (Iphiclides podalirius L.). Rare category: RBU category II. In the surveyed area, this species was rare and had a low population. It was noted mainly in settlements. This is explained by the fact that caterpillars of rite swallowtail develop mainly in gardens. The species is trophically associated with trees and shrubs from the Rosaceae family. The number of rite swallowtail is negatively affected primarily by chemical treatments of gardens.

10. Poplar admiral (Limenitis populi L.). Rare category: RBU category II. In the RNPP area, this is a relatively rare not numerous species, despite a very good forage base (caterpillars are fed on poplars and aspens). Butterflies fly from late May to mid July. It may be seen more often on glades and forest roads, mainly in wet places. Sometimes poplar admirals fly to the highway passing in the forest, where they are at great risk of death from vehicles (we found a dead butterfly on the road 8 km from Kuznetsovsk on the way to Rafalivka). It should be noted, however, that chemical treatments in breeding places and massive catch of butterflies by entomologists represent the greatest threat for populations of poplar admirals.

11. Large purple emperor (Apatura iris L.). Rare category: RBU category II. For the Rivne region, this species is not specified in the Red Book of Ukraine. In the surveyed area, this is a relatively rare and not numerous species. Caterpillars develop on willow and aspen. Butterflies fly from late June to early August. They are most likely to be seen in wet areas of forest roads. Often they may be together with poplar admiral. Large purple emperor is one of the most beautiful butterflies of Ukraine. In this regard, it is very attractive for collectors. The number of this species is also adversely affected by chemical treatments and deforestation.

12. Large tortoiseshell (Nymphalis xanthomelas Exper). Rare category: RBU category III. For the Rivne region, this species is not specified in the Red Book of Ukraine. In the RNPP area, large tortoiseshell is relatively rare and not numerous. Caterpillars feed on leaves of some willow species. Butterflies fly in June - July. They can be found on the edges of deciduous and mixed forests. In the vicinity of Kuznetsovsk, we observed flying. Treatment and deforestation as well as massive catch by collectors represent a threat to the species.

13. Large copper (Lycaena dispar Hw.). Rare category: category E in the European Red List. In the surveyed area, this is a very common, but not numerous species. It may be seen on meadows. The most common in floodplains. Caterpillars are fed on sorrel. Habitat destruction (plowing of floodplain meadows) and overgrazing have a negative impact on the population of this species.

14. Autumn silkworm moth (Lemonia taraxaci Den. Et Schiff.). Rare category: RBU category II. For the Rivne region, this species is not specified in the Red Book of Ukraine. In the surveyed area, it is known by the only discovery in the Styr River floodplain near Kuznetsovsk. Probably, it has a small population here. Caterpillars feed on dandelion. Butterflies fly in September - October. Chemical treatments and overgrazing meadows may be the main negative factors for the population.

15. Blue underwing (Catocala fraxini L.). Rare category: RBU category II. In the surveyed area, this species is noted by single discoveries (Rafalivka, Kuznetsovsk), but we assume that the species is relatively common here. Caterpillars feed on poplar, aspen, birch, alder, oak and some other species. Butterflies fly from mid July to October. They are nocturnal and fly to artificial light sources. This feature may adversely affect survival of imago and structure of the population in places with a large number of strong light sources. However, chemical treatment is the main threat for this species.

16. Moss carder-bee (Bombus muscorum F.). Rare category: RBU category II. In the RNPP area, this is a very common, but not numerous species. More common in sphagnum swamps and meadows. Well-being of the population of this species primarily depends on the availability of suitable nesting places. In Polissia, the main negative factor for moss carder-bee is swamp drainage. Chemical treatment of forests are also a great danger for this species.

17. Violet carpenter bee (Xylocopa violaeae L.). Rare category: RBU category II. In the RNPP area this bee is comparatively common, but not numerous. Most often it may be noted in settlements where it is easier to find a suitable place for nesting. Bees often fly to flowering gardens and sometimes fly into residential areas. In the latter case, as a rule, they die. This is shown by survey findings. Chemical treatment and conditions for nesting (presence of dry trees or cavities suitable for nests) affect the population of this species most of all.

18. Red forest ant (Formica rufa L.). Rare category: V category in the European Red List. In the NPP area, it is common and numerous in some places. It lives in coniferous and mixed forests. Red ants are active predators. They are of great importance in the regulation of the number of many leaf and needle-eating pests. The main factors affecting the anumber of this species are chemical treatment of forests by pesticides, destruction of habitats (clear felling of tree stands), and destruction of anthills by local residents to extract ant eggs. Ruined anthills are quite common in the vicinity of Kuznetsovsk and other settlements.

Thus, the operation of RNPP units does not represent a direct threat to rare species of animals.

APPROVED
Director of NT Engineering
_______________R. V. Maraikin
"05" December 2018

REPORT
ON
SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 4
Assessment of impact on the social
and anthropogenic environment

Version 2

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ABSTRACT

Volume 4 of this Report contains 102 pages of text, 10 figures, 46 tables. The assessment subject is the operating power units, facilities and structures that are part of the process system at the NNEGC Energoatom SS Rivne NPP site, as well as their environmental impact in the area near SS Rivne NPP.

The sections of this Report contain the assessment of SS Rivne NPP impact on the “Social Environment” and “Anthropogenic Environment” taking into account the entire set of works needed for operation of SS Rivne NPP, which is based on the results of implementation of environmental protection measures, long-term results of monitoring and comparison of the NPP neighbouring environment condition before commissioning and during operation of power units.

Book 4 provides a general description of basic social and anthropogenic environment indicators in the area near SS Rivne NPP:

– Section 1 contains a general description of SS Rivne NPP.

– Section 2 provides information on various aspects of the social environment, including: demographic analysis; type and arrangement of residential and public construction, its utility networks; assessment of population health in the area near SS Rivne NPP; assessment of impact of the existing SS Rivne NPP site facilities on population; measures to prevent deterioration of living conditions and health of the local population, and compensatory measures.

– Section 3 assesses impact of economic activities on industrial, agricultural, civil buildings, architectural, historical and cultural landmarks, recreation areas, cultivated landscapes, above-ground and underground structures and other elements of anthropogenic environment within the area affected by economic operations of SS Rivne NPP, and justifies measures to ensure their operational reliability and preservation.

The Report is executed in accordance with the requirements for the composition and content of the environmental impact assessment documentation.

This Report provides environmental feasibility justification for the economic activities of the existing SS Rivne NPP site facilities, as well as determination of social and anthropogenic safety requirements for future activities.

Keywords: SS Rivne NPP, SS RNPP, SOCIAL ENVIRONMENT, POPULATION, DEMOGRAPHICS, ANTHROPOGENIC ENVIRONMENT, IMPACT, MONITORING, PROTECTION MEASURES.

Report distribution terms: in accordance with the Agreement.

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LIST OF LEGENDS, SYMBOLS, UNITS OF MEASUREMENT, ABBREVIATIONS AND TERMS

Abbreviation	Name
NPP	Nuclear power plant
NCP	Nuclear cogeneration plant
ARSMS	Automated radiation state monitoring system
WANO	World Association of Nuclear Operators
VVER-440	Water-water power reactor with a rated power output of 440 MW
VVER-1000	Water-water power reactor with a rated power output of 1000 MW
HLP	Health losses in child population
WHO	World Health Organization
SS Rivne NPP	Separated Subdivision Rivne Nuclear Power Plant
ARI	Acute respiratory infections
GTU	Gas treatment units
HQ	Head Quarters
SEZA	State Agency of Ukraine on Exclusion Zone Management
PR	Permissible release (maximum release level)
PSF	Preschool facilities
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
IRS	Ionizing radiation source
LLR	Long-lived radionuclides
PC^{inhal}	Permissible air concentration of radionuclides in the air
PC^{ingest}	Permissible drinking water concentration of radionuclides
DK UkrDO Radon	State Corporation “Ukrainian State Corporation Radon”
PI^{inhal}	Permissible intake of radionuclides through the respiratory system
PI^{ingest}	Permissible intake of radionuclides through the digestive system
SE NNEGC Energoatom	State Enterprise “National Nuclear Energy Generating Company Energoatom”
DR-97	Permissible concentrations of ^{137}Cs and ^{90}Sr in food and water
SSE CEMRW	Central Enterprise for the Management of Radioactive Waste State Specialized Enterprise
SSE ChNPP	State Specialized Enterprise Chernobyl Nuclear Power Plant
CYSS	Children’s and youth sports school
VCL	Vital capacity of lungs
PPE	Personal protective equipment
MM	Mass-media
OZ	Observation zone
ID	Immunological deficiency
IRG	Inert radioactive gases
PHI	O. M. Marzeiev Institute for Public Health of the National Academy of Medical Sciences of Ukraine
CUF	Capacity utilization factor
PC Vector	Production Complex Vector
BP	Bottom products
DPRK	Democratic People’s Republic of Korea
C/P	Checkpoint

Abbreviation	Name
RW CT	Comprehensive treatment of radioactive waste
SRW TC	Solid radioactive waste treatment complex
MPD	Maximum permissible dose
LD_{extrem}	Limit external dose equivalent for hands and feet
LD_{lens}	Limit external dose equivalent for crystalline lens
LD_{skin}	Limit external dose equivalent for skin
PTL	Power transmission line
IAEA	The International Atomic Energy Agency
MDA	Minimum detected activity
MoH of Ukraine	Ministry of Health of Ukraine
MDBA	Maximum design basis accident
IWG	Interdepartmental working group
MDE	Maximum design earthquake
URC	Unknown radionuclide composition
LLW	Low-level waste
NRBU-97	Norms of Radiation Safety of Ukraine, 1997
NT Engineering	NT Engineering Limited Liability Company
n/a	Not available/applicable
PBH	Positive biological history
H&S	Fundamentals of health and safety
EIA	Environmental impact assessment
EIA	Environmental impact assessment
RSA	Regional state administration
PSH	Positive social history
PR_i	Permissible release
SG	Steam generator
EDR	Exposure dose rate
EF	Earthquake factor
SPM	Scheduled preventive maintenance
PD_i	Permissible discharge
VS	Vocational school
RNPP	Rivne Nuclear Power Plant
RNPP-1	Power Unit No. 1 of Rivne NPP
RNPP-2	Power Unit No. 2 of Rivne NPP
RNPP-3	Power Unit No. 3 of Rivne NPP
RNPP-4	Power Unit No. 4 of Rivne NPP
RW	Radioactive waste
SES	Sanitary and epidemiological service
SPZ	Sanitary protection zone
PRM	Personal radiation monitor
sett.	Urban type settlement
CIS	Commonwealth of Independent States
MHI	Mean Health Indicator
USSR	Union of Soviet Socialist Republics
SNF DS	Dry storage for spent nuclear fuel
SNiP	Construction norms and rules

Abbreviation	Name
TPP	Thermal power plant
ToR	Terms of Reference
NT-Engineering LLC	NT-Engineering Limited Liability Company
OTS	Operation technical support
U/S	Ultrasound scanning
I&PR	Office of Information and Public Relations
MOS	Medical and obstetric station
PHF	Public health fund
MS	Medical station
CDH	Central district hospital
SNF CS	Centralized storage for spent nuclear fuel
ChNPP	Chornobyl Nuclear Power Plant
NRS	Nuclear and radiation safety
NF	Nuclear facility
E	East
N	North
S	South
W	West
MSK-64	Earthquake recurrence scale
RNPP Doses	Software platform for population dose calculation based on actual releases and discharges
RODOS	European system for decision-making support in case of radiation accidents
SOARS	Software platform for dose calculation for all settlements in the OZ in case of accidents

INTRODUCTION

The service of SS Rivne NPP site environmental impact assessment has been provided in accordance with Agreement No. 347 dated 27 March 2018 between the State Enterprise "National Nuclear Power Generating Company Energoatom" (SE NNEGC Energoatom), its Separate Subdivision Rivne Nuclear Power Plant (SS Rivne NPP) and NT Engineering Limited Liability Company.

Environmental impact assessment (EIA) documents are developed to assess the environmental impact of SS Rivne NPP operation based on the results of environmental protection measures, long-term results of monitoring and comparison of the NPP neighbouring environment condition before NPP commissioning and during operation.

EIA provides environmental feasibility assessment of economic activities of the operating SS Rivne NPP site facilities, as well as determines environmental safety requirements for future activities.

EIA was prepared with a focus on social environment studies based on synthetic sociological properties, e. g. population life pattern and quality, as well as on studies of society structure, which is an integrated outcome of life pattern and quality.

The key point of social society determination is assessment of population that resides in an area, its size and make-up.

Social environment analysis began with establishing the size and quality of population in the area under study. For this purpose, all population groups, directly or indirectly affected by the project, were determined.

These population groups include:

- residents of the area engaged in construction works or facility operation, with family members;
- manpower engaged in design works from other places;
- persons who face changes in their life patterns due to implementation of the project;
- project consumers.

The purpose of this segmentation is defining population groups that face the greatest impact during operation of SS Rivne NPP. It is normally based on ethnic and demographic profile, sociocultural level and social organization. Population is largely heterogeneous in terms of ethnicity, occupation, education, family status and attitude toward the nuclear power plant. Defining the actual ethnic boundaries in the context of industrialisation and integration is exceedingly difficult. Even though the current stage of ethnicity development suggests there are integration trends in the social life, and association of people and groups based on citizenship prevail over ethnic association, we'll consider population analysis approaches in terms of acceptability. For example, it is ethnicity that predetermines the family household composition, involvement of women in public production, number of children in families, etc. Presence of families with multiple children, where women normally don't work, increases the share of dependent persons in total population of the region. These aspects should be taken into account differently for projects being implemented.

Assessment of demographic processes, which rank among the most stable processes since they are formed for decades due to a variety of factors (natural and climatic, social and economic, historical and religious), is vitally important. The depth of demographic studies ranges from "statistical study of population" to "study of communities". Ethnographic structure of population is commonly described by sex, age, ethnographic group affiliation, level of health, education and geographic distribution. This structure may be extended with the following demographic behaviour parameters: family status, number of children and family type. Demographic studies involve cultural traditions, employment pattern, income level, and housing conditions. Demographic analysis may establish availability of jobs, level of intergenerational competition, social mobility and migration flows.

The main task of the authors of this book is assessing the impact of certain most critical ethnic, demographic and sociocultural factors on the economic growth structure and rates, consumption structure, attitude towards work, or preferred occupations.

Demographic process indicators may include:

- population size, incl. shares of urban and rural population;
- life expectancy at birth;
- migration;
- increase in urban population;
- population decline.

EIA has been executed in accordance with "Recommendations on the content of environmental impact assessment documentation", DBN A.2.2-1-2003 "Composition and content of environmental impact assessment documentation (EIA)" and Guidelines for the development of environmental impact assessment documentation (supplement to DBN A.2.2-1-2003).

The benefits of nuclear power as compared to other power types include high calorific value of nuclear fuel (2 millionfold compared to oil and 3 millionfold compared to coal), better economic performance, lower environmental contamination. Moreover, no combustion reactions that involve oxygen occur during nuclear reactor operation, while 5 times as much oxygen is combusted by other power industries as is consumed by all living beings. In addition, raw material resources for nuclear fuel are about 20 times the organic fuel resources of all types [1,2].

The majority of nuclear energy supporters consider that all efforts should be focused on fighting population's mistrust toward nuclear safety.

Nuclear power is a reliable source of energy supply that plays a leading role in ensuring the energy needs of Ukraine. It is especially essential considering the economic crisis in the country, insufficient amounts of natural fuel resources, lack of funds available for modernizing the equipment of thermal and hydroelectric power stations, as well as for the development of alternative energy sources. Electricity production by NPPs contributes to keeping the wholesale tariff on electricity at an acceptable level and reduces the emission of greenhouse gases into the atmosphere. NPPs produce almost 50 % of the electricity consumed in the country, which is equivalent to burning about 40 million tons of coal per year.

One of the main principles of state policy in the field of nuclear energy and radiation protection in Ukraine is the priority of protecting people and the environment from the negative effects of ionizing radiation and ensuring nuclear energy safety. In particular, in accordance with the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" [3], Article 8, "observance of norms, rules and standards on nuclear and radiation safety is obligatory for any kind of activity in the field of nuclear energy".

Over the last five years, large quantity of new equipment and automatic controls, mainly produced by domestic manufacturers, as well as an improved lightning protection system have been installed at SS Rivne NPP. Commissioning of a recently-built 750 kV PTL "RNPP - Kyivska Substation" resulted in reduced dispatch restrictions at the power plant, improved busbar output capacity of Rivne NPP, and allowed power transmission to regions suffering from power shortages, followed by increased operating reliability of the entire country's integrated power system.

SS Rivne NPP site environmental impact assessment is executed in 7 volumes.

Book 4 provides description of basic social and anthropogenic environment indicators in the area near SS Rivne NPP and assessments of impact on population and elements of anthropogenic environment by the NPP.

1 SS RIVNE NPP GENERAL DESCRIPTION

The reliability and efficiency of power generation by nuclear power plants are recognized The reliability and efficiency of power generation produced by nuclear power plants are recognized worldwide. Considering the instability of world markets and rising prices for gas, oil, coal, the importance of nuclear power to fulfil the needs of the manufacturing sector and the population by providing relatively cheap electricity is ever increasing.

SS Rivne NPP is a separate subdivision (unit) of the State Enterprise “National Nuclear Energy Generating Company Energoatom (SE NNEGC Energoatom). SE NNEGC Energoatom carries out activities in accordance with its Articles of Association and is subordinate of the Ministry of Fuel and Energy of Ukraine, which forms the state policy in the field. In accordance with the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” adopted by the Resolution No. 1268 of the Cabinet of Ministers of Ukraine dated 17 October 1996 “On the Establishment of the National Nuclear Power Generating Company Energoatom” [5,6], SE NNEGC Energoatom is assigned with functions of an operating organization responsible for the safety of all nuclear power plants in the country.

Being one of the four operating NPPs in Ukraine, Rivne Nuclear Power Plant is the largest enterprise in the region. Each year, the power plant supplies about 19 billion kilowatt hours of electricity to the country’s integrated power system and adds almost UAH 25 million to local budgets for social and economic compensation to the population of the observation zone.

Rivne NPP is located on the Stir River in the northeastern part of the Rivne Region, 80 km from the regional centre, in the Volodymyrets district. Rivne NPP is nearest NPP to the neighbouring countries located approximately 60 km from the border with the Republic of Belarus and 130 km from the Republic of Poland.

Rivne NPP is located in western Polissya, in the north-west of the Rivne Region, near the Stir River. The site choice was preconditioned by several reasons: low fertility of sandy land and great distance from densely populated areas. In 1973, the density of population in this territory was 55 persons/km^2, while today’s population in Varash is 3,684 persons/km^2.

SS Rivne NPP uses the following resources for the production needs:

- NPP territory - 482 hectares;
- industrial site territory - 215 hectares;
- special use permit to collect fresh water from surface water reservoirs in the amount of 73,164 thous. m^3 per year;
- auxiliary electric power: 8 % of the total electric-power generation.

According to SNiP P-7-81 “Construction in Seismic Areas” [5], the industrial area of SS Rivne NPP is located in the P3-5, MR3-6 zone. NPP was designed taking into account two levels of seismicity (P3) - magnitude 5 and the maximum estimated earthquake (MRZ) - magnitude 6. The recurrence of earthquakes according to the MSK-64 scale is 1 time in 5000 years [6].

SS Rivne NPP industrial site is located in a moderate climate zone characterized by mild and humid winters, relatively cold and rainy summer, wet autumn and unstable weather during the season transitions.

The terrain is even and open to the wind, which provides good ventilation of the site.

Power delivery to the power system is carried out via:

1 - 750 kV lines;

4 - 330 kV lines;

5 - 110 kV lines.

NPP process water supply is of circulating type, feeding from the Styr River. The Rivne NPP power units cooling system does not include cooling ponds. The entire power units cooling system is designed to use six cooling towers and spray pools. Heat is removed from circulating water via 6 cooling towers with a productivity of 100,000 m^3/h each. Spray pools are used to remove heat from critical consumers.

Each year, SS Rivne NPP generates about 13 % of the total electricity amount generated in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Varash town and Zabolottia village. The design CUF capacity utilization factor is 74.2 %.

See Table 1.1 for information on products (finished and semi-finished products) annually supplied by the enterprise to consumers or services provided in accordance with the accounting data.

Table 1.1. Products of SS Rivne NPP

No	Product (service) type	Annual capacity
1	Electric energy	19 billion kW×h

SS Rivne NPP uses the following resources for the production needs:
- NPP territory;
- industrial site;
- circulating water use;
- evaporation of water for cooling purposes;
- auxiliary electric power;
- diesel fuel (for emergency power supply, etc.);
- lubricants (for turbines, etc.).

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:
- protection safety systems;
- localizing safety systems;
- auxiliary safety systems;
- control safety systems.

SS Rivne NPP power units have been designed, built and installed in accordance with the regulative documents that were in force at that time.

In 1971, the West Ukrainian NPP subsequently renamed in Rivne NPP has entered the design stage. The power plant is designed to cover electrical loads in the western part of the country.

SS Rivne NPP is the first nuclear power plant in Ukraine based on a VVER-440 water-water power reactor. The power plant construction was commenced in 1973. The first two units with

VVER-440/213 reactors were put into operation in 1980-1981, and the third power unit, 1000 MW VVER-1000/320 - in 1986.

The construction of the fourth Rivne NPP unit was commenced in 1984, with commissioning scheduled for 1991. However, due to the introduction of the moratorium on the construction of nuclear facilities on the territory of Ukraine by the Verkhovna Rada, the works were suspended at 85 % of the unit's readiness.

Construction was resumed in 1993. Following the withdrawal of the moratorium, Unit 4 was inspected, and a program for its modernization and a completion project dossier were prepared. Power Unit No. 4 at SS Rivne NPP was commissioned on 16 October 2004.

Operating lifetime periods for power units of SS Rivne NPP are given in Table 1.2. Information on SS Rivne NPP power units.

Table 1.2. Information on Rivne NPP power units.

Unit No.	Reactor unit type	Reactor unit series	Power unit connection date to the IPS	Commissioning date	End of design operation period	Operation extension date
RNPP-1	VVER-440	B-213	22.12.1980	22.09.1981	22.12.2010	22.12.2030
RNPP-2	VVER-440	B-213	22.12.1981	29.07.1982	22.12.2011	22.12.2031
RNPP-3	VVER-1000	B-320	21.12.1986	11.12.1987	11.12.2017	22.12.2035
RNPP-4	VVER-1000	B-320	10.10.2004	07.06.2005	07.06.2035	-

As of 2018, four power units are in operation at SS Rivne NPP (see Table 1.2):

- power unit I (VVER-440) with a capacity of 420 MW since 1980;
- power unit II (VVER-440) with a capacity of 415 MW since 1981;
- power unit III (VVER-1000) with a capacity of 1000 MW since 1986;
- power unit IV (VVER-1000) with a capacity of 1000 MW since 2004.

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008, 2009, 2010) and World Association of Nuclear Operators (WANO) (2001, 2004, 2005, 2012, 2014, 2015, 2016, 2018).

A sanitary protection zone (SPZ) is arranged around the nuclear facility. The SPZ is determined based on the limit annual intake of radioactive substances via the respiratory and digestive systems, limit external radiation doses for personnel and population, as well as permissible air and water concentrations of radioactive substances.

SPZ dimensions are determined taking into account radiation situation assessment in the area around the NPP during long-term operation.

The location of SS Rivne NPP and the boundaries of its observation zone and sanitary protection zone are shown in Fig.1.1.

SPZ of SS Rivne NPP is limited within the radius of 2.5 km around radiation-hazardous objects. The size of the observation zone is 30 km.

The dimensions of the SPZ and OZ were officially set in accordance with the SS Rivne NPP document, namely, "Decision on the size and boundaries of the Rivne NPP sanitary protection zone and the observation zone", No. 132-1-R-11-TsRB [8].

NPP safety systems ensuring protection of the population during accidents, including design basis accidents with the most severe consequences, are designed in a way that the values of equivalent individual doses calculated for the worst weather conditions on the SPZ border and beyond it do not exceed 3 mSv/year for thyroid gland in children due to inhalation intake and 1 mSv/year for the entire body in case of external exposure [8].

SS Rivne NPP power units include the following equipment:

- VVER-440 (B-213) reactor - units 1, 2 and VVER-1000 (B 320) - units 3, 4;
- K-220-44 turbine - units 1, 2 (2 pcs per unit) and K-1000-60/3000 - units 3, 4;
- TVV-220 turbogenerator - units 1, 2 (2 pcs per unit) and TVV-1000 - units 3, 4.

According to the design, SS Rivne NPP includes two VVER-440 power units and two VVER-1000 power units. Each power unit, in addition to normal systems, is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

Table 1.3 provides specifications of SS Rivne NPP power units.

Table 1.3. Specifications of SS Rivne NPP power units.

Parameter	Value	
	VVER-440	VVER-1000
Reactor capacity, MW	1375±27	3000
Pressure at 1 k (at active zone discharge) kgf/cm^2 (MPA)	125±1.2 (12.25±0.1)	160±3 (15.7±0.29)
Temperature of coolant at the reactor discharge, °C	300	320
Coolant heating in the reactor, °C	30.3	30.3
Average consumption of coolant for active zone cooling, t/h	42700400	84800^{+400}_{-480}
Steam production for all SG, t/h	2700	5880
Humidity of steam at SG discharge, %	0.25	0.2

Lifetime extension for the operating power units of nuclear power plants is determined by the “Energy Strategy of Ukraine for the period up to 2030” [9] and is a priority direction of SE NNEGC Energoatom activities.

Design lifetime of the operating nuclear power units in Ukraine is 30 years. In 2017, this threshold was crossed by SS Rivne NPP power unit No. 3 having VVER-1000 reactor. In 2012, in the framework of the preparation for the SS Rivne NPP power unit No. 3 lifetime extension, a one-of-a-kind repair of the upper unit sealing surfaces and the main reactor connector was carried out for the first time in Ukraine. Technical assessment of equipment, pipelines, buildings and structures was performed [10].

In 2016, to implement OTS measures at unit No. 3, an extended PEP, lasting for 114 days, has been scheduled and executed. In particular, work has been carried out on the implementation of the reactor unit diagnostics system, installation of hydrogen burn-up equipment for accidents and other measures.

Besides, a number of post-Fukushima measures has been implemented during PEP, which were aimed at makeup water supply using mobile pumping units, cooling pool, steam generators to ensure operation of process water consumers in case no water is present in spray pools, as well as a measure related to potential complete deenergizing of the NPP has beep planned and implemented by commissioning of a mobile diesel generator. After implementation of all the above-mentioned measures, it is planned to obtain a license for the safe operation of the Unit No. 3 reactor beyond its design life.

According to DSP 6.177-2005-09-02 [11] the category of the enterprise that uses radiation or nuclear technologies is determined by the degree of potential danger to the population in the design mode of operation and in the event of a radiation accident.

To determine the enterprise’s potential hazard, the possibility of personnel and population exposure resulting from a radiation accident at this enterprise is considered. Three categories of enterprises and facilities are defined.

production activity of SS Rivne NPP or in case of an accident on its territory, the radiation impact on the population is possible, therefore the enterprise belongs to category I according to Basic Sanitary Rules for Radiation Safety DSP 6.177-2005-09-02 [11].

Rivne NPP includes main, auxiliary and warehouse buildings and structures.

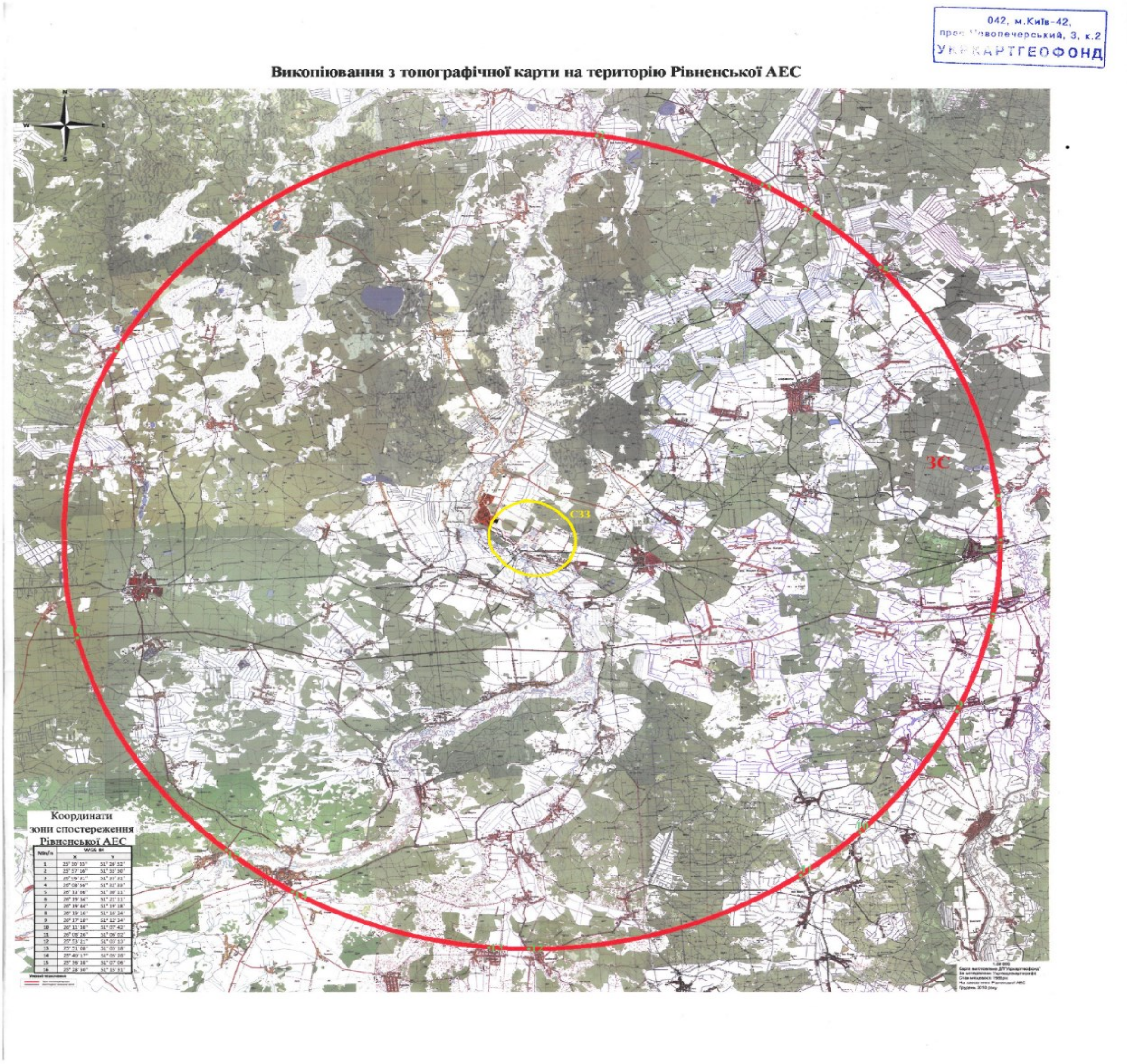

Fig. 1.1. SS Rivne NPP location area

The observation zone includes the area in which the radioactive releases and emissions from the radiation nuclear facility (NPP) are likely to occur with monitoring performed.

Radiation monitoring within the OZ is carried out as per Rivne NPP Radiation Control Regulations 132-1-R-TsRB [12], approved by Senior Vice-President, Chief Technology Officer of SE NNEGC Energoatom on 2 February 2016 and agreed by letter from State Nuclear Regulatory Inspectorate of Ukraine No. 15-28/7070 dated 25 October 2016 as approved by Head of Varash Interdistrict Department of Rivne Regional Laboratory Centre of State Sanitary and Epidemiologic Service of Ukraine HQ on 8 July 2016 and by Director General of SS Rivne NPP on 5 July 2016.

The major priority of the activity is safe generation of environmentally friendly thermal and electric energy.

SS Rivne NPP implements annual safety improvement plans and international projects.

Rivne NPP ensures preservation of jobs in other fields, which is vitally important for stability and revival of Ukraine's economy.

The process of economic operations, including all environmental impact factors and technical solutions, is intended to eliminate or reduce harmful releases, discharges, leaks and radiation in the environment.

SS Rivne NPP project is based on the modular configuration principle: each power unit, in addition to normal operating systems, is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

VVER-440 and VVER-1000 reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel.

Power units operate in a two-loop cycle: first (hot) loop is a water circuit with direct heat extraction from the reactor; second (cold) loop is a steam circuit with heat energy extracted from the first loop and converted into mechanical energy of turbine rotation, and then into electrical energy in a turbine generator.

The main building with 4 operating power units (two VVER-440 and two VVER-1000 units) includes a reactor room.

Main process equipment of reactor unit:

- reactor;
- steam generators;
- main circulation pumps;
- pressurizer;
- emergency core cooling tank;
- connecting pipelines arranged under the containment in boxes with solid walls of heavy concrete or reinforced concrete.

Key performance indicators of Rivne NPP as of 19 June 2018 are shown in Table 1.4.

Table 1.4. Key performance indicators of Rivne NPP.

Indicators	Power unit No. 1	Power unit No. 2	Power unit No. 3	Power unit No. 4	NPP
Electric energy generated per current day, mln kW·h	4.5	4.5	n/a	10.8	19.9
Electric energy generated per current month, mln kW·h	182.5	183.3	n/a	437.6	803.4
Electric energy generated per previous month, mln kW·h	309.5	308.6	n/a	736.9	1355
Electric energy generated year-to-date, mln kW·h	1346.8	1292.6	0	4061.9	6701.4
Capacity utilization factor (CUF) per current month, %	98	99.6	n/a	98.6	63.9
Capacity utilization factor (CUF) per previous month, %	99	99.9	n/a	99	64.2

Indicators	Power unit No. 1	Power unit No. 2	Power unit No. 3	Power unit No. 4	NPP
Capacity utilization factor (CUF) year-to-date, %	78.9	76.6	0	99.9	58.1

Electric energy generation by the Rivne NPP units started in 1981. Fig. 1.2. shows the amount of electric energy generated by Rivne NPP by years, in bln kW×h.

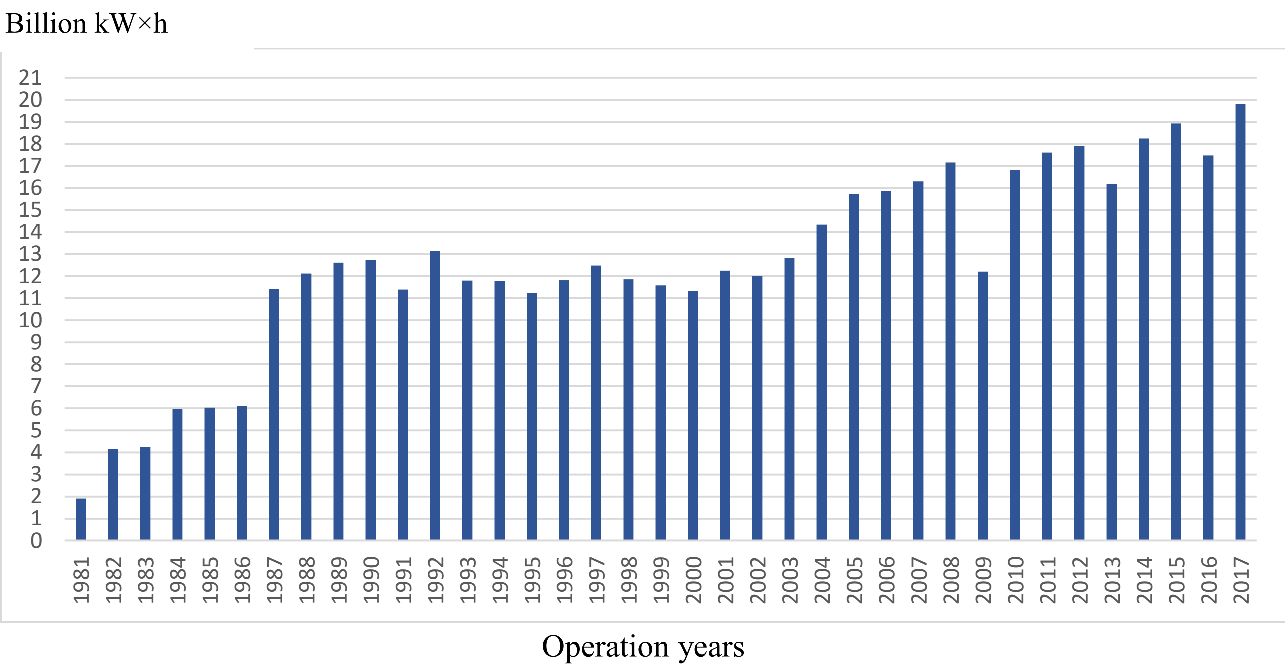

Fig. 1.2. Amount of electric energy generated by SS Rivne NPP by years.

Impacts of nuclear and thermal power plants may be compared to justify the above. Thermal power plants (TPP) have a considerably greater impact on the environment as compared to nuclear power plants (NPP). TPP stack emissions contain nitrogen and residual oxygen as well as carbon dioxide (CO_2), water vapour, sulphur dioxide (SO_2), nitrogen oxides and fly ash that were not trapped by electrostatic filters.

Solid waste from coal-fired TPP, e. g. ash and slag, is a critical issue of impact. Vast areas of land are allocated for solid waste storage.

When stored for a long time, ash and slag form leachables that penetrate into groundwater.

Emissions of carbon compounds have the greatest impact on the atmospheric air leading to a “greenhouse effect” that may result in global warming in future. In turn, global warming will result in events as follows:

- increase in the number of storms and hurricanes;
- flooding of lowlands (water level rise by 1 meter will flood the territory populated by 1 billion people);

- shifting of fertile areas and reduction in yields due to droughts and soil erosion in some regions and overwetting in others;
- extinction of certain animal and plant species;
- loss of freshwater resources in some regions, formation of deserts.

Substances formed during organic combustion - sulphur dioxide and nitrogen oxides - have an adverse environmental impact. When interacting with water drops from clouds and rain, they form acids followed by formation of acid salts that are often toxic. These compounds fall to the ground in the form of acid rains that affect flora, overacidify water reservoirs and soils. Design and actual values of NPP radioactive contamination demonstrate that additional impact is low as compared with natural background radiation and makes one-tenth of the permissible value.

Ventilation air released through vent stacks of the NPP is thoroughly decontaminated and is virtually free of substances that may change the air composition.

As soon as a RW treatment complex is commissioned, the state policy program in the field of radioactive waste (RW) handling will be implemented, with a focus on protecting the environment, life and health of the population against ionizing radiation, improving facility operating conditions and rejuvenating obsolete equipment.

Implementing a solid radioactive waste treatment complex (SRW TC) project will result in:
- reduced amount of RW in temporary storage at SS Rivne NPP site;
- beginning of SRW repositories emptying process;
-rational use of available SRW repositories;
-reduced personnel radiation exposure;
-obtaining SRW packings that meet the requirements of SRW acceptance for storage as per regulations currently in force in Ukraine.

2 SOCIAL ENVIRONMENT IMPACT

2.1 Brief description of the current social environment in the observation zone

The Rivne NPP is located in a mixed forest zone in western Volyn Polissia - in the northwestern part of the Rivne Region, 120 km away from the regional centre, in the Volodymyretskyi District, on the Styr River. This Ukrainian NPP is nearest to the neighbouring states [6].

SS Rivne NPP site choice was due to low fertility of sandy land and great distance from densely populated areas. The Rivne NPP and its satellite town Varash (former Kuznetsovsk) are located in the most stable seismic zone of Ukraine. The recurrence of magnitude 6 earthquakes according to the MSK-64 seismic scale is once in 5000 years [13].

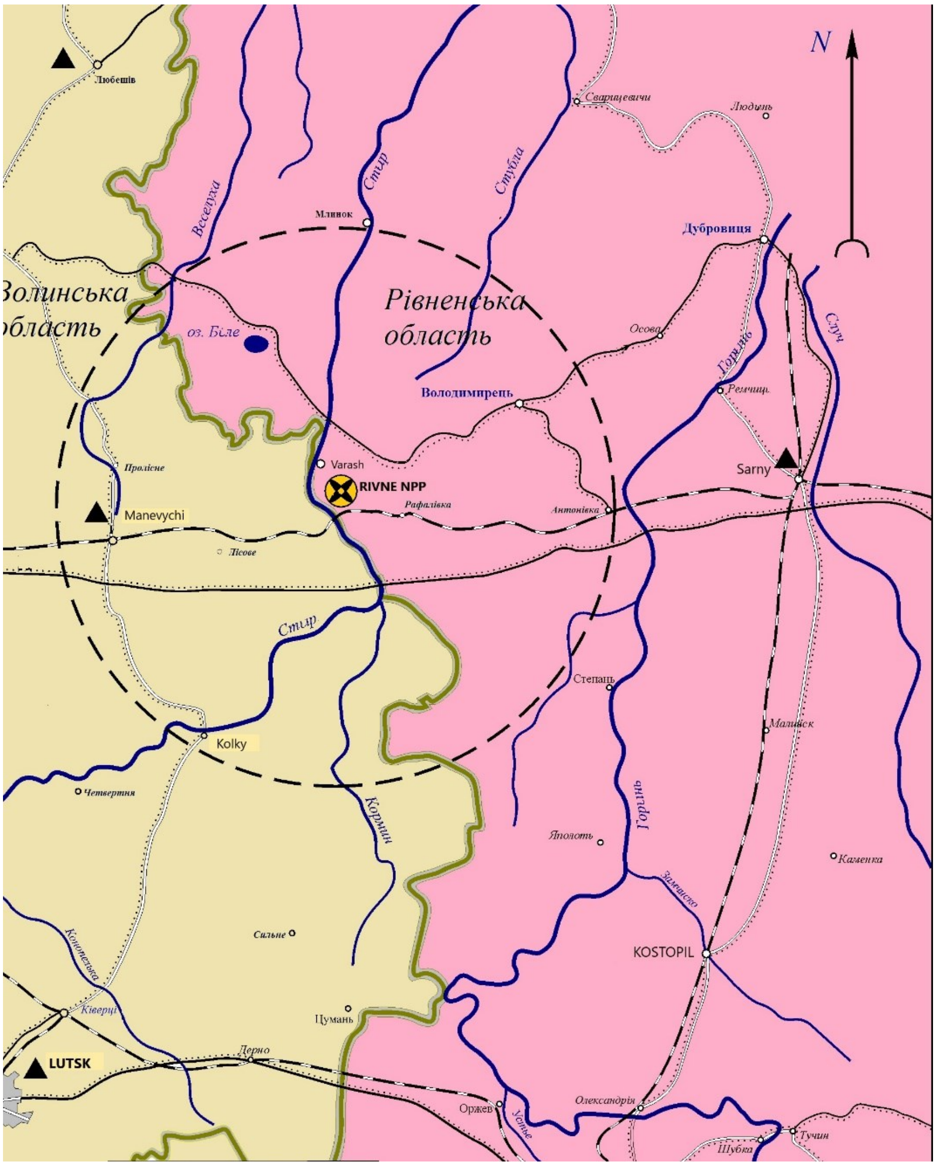

Fig. 2.1. SS Rivne NPP site and 30 km zone around it

The 30 km observation zone of SS Rivne NPP is within the boundaries of two regions: Rivne and Volyn. The size of population in 90 settlements over the territory of about 3,000 km^2 is about 130 thous. people. Fig. 2.1. shows the location of SS Rivne NPP and the 30 km zone around it that covers parts of Rivne and Volyn regions.

SS Rivne NPP is located in the moderate continental climate zone. West winds are predominant. Air quality is generally good due to limited industrial activities. The Styr River is the main source of surface water. Forests cover 50 % of SS Rivne NPP territory and are of a considerable economic and environmental value. Agricultural land use accounts for 27 %. 48 territories within the OZ of SS Rivne NPP are classified as nature reserve fund.

The OZ of SS Rivne NPP, which covers 2826 km^2, includes a total of 109 settlements with 143 thous. residents, with the population density of 58.82 people/km^2 in the Region of Rivne and 37.19 people/km^2 in the Region of Volyn.

See data on distribution of population by region as well as information related to sex and age of the population in Tables 2.1. and 2.2.

Table 2.1. Distribution of population by region with division into 5 km zones (0-30 km)

Zone, km	Number of settlements	Population size (thous. people)	Including:			Note
			Below working age (26 %)	Working age (56 %)	Above working age (18 %)	
I. Rivne Region						
0-5	4, incl. Varash	41.98	10.91	23.51	7.56	Input calculation data obtained at Rivne Regional Administration Letter No. 26/877 dated 14 September 2000
5-10	9	7.46	1.94	4.18	1.34	
10-15	12	8.02	2.09	4.49	1.44	
15-20	10	15.98	4.15	8.95	2.88	
20-25	8	5.03	1.31	2.82	0.90	
25-30	19	18.53	4.82	10.38	3.33	
II. Volyn Region						
0-5	2	1.66	0.55	0.71	0.40	Input calculation data obtained at Volyn Regional Administration Letter No. 539/2.4 dated 17 August 2000
5-10	6	1.91	0.63	0.82	0.46	
10-15	7	4.61	1.52	1.98	1.11	
15-20	8	4.55	1.50	1.96	1.09	
20-25	6	3.47	1.15	1.49	0.83	
25-30	15	20.13	6.64	8.66	4.83	

Table 2.2. Population structure by sex and age

Rivne Region									
Population categories (age, years)	Town of Varash			30-km zone without the Town of Varash			Total within the 30 km zone		
	Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
Total population	41.02	20.33	20.69	56.0	26.88	29.12	97.02	47.21	49.81
Below working age	11.93	6.11	5.82	12.99	6.77	6.22	24.92	12.88	12.04
Working age	27.16	13.64	13.52	27.78	15.21	12.57	54.94	28.85	26.09
Above working age	1.93	0.58	1.35	15.23	4.90	10.33	17.16	5.48	11.68
Volyn Region									
Population categories (age, years)	Town of Manevychi			30-km zone without the Town of Manevychi			Total within the 30 km zone		
	Both sexes	Male	Female	Both sexes	Male	Female	Both sexes	Male	Female
Total population	10.01	4.88	5.13	26.32	12.81	13.51	36.33	17.69	18.64
Below working age	3.30	1.61	1.69	8.69	4.23	4.46	11.99	5.84	6.15
Working age	4.31	2.10	2.21	11.31	5.51	5.80	15.62	7.61	8.01
Above working age	2.40	1.17	1.23	6.32	3.07	3.25	8.72	4.24	4.48

The data provided in Table 2.2 suggest that the major part of population within the 30 km zone resides on the territory of the Rivne Region - 97 thous. people (73 %), incl. population of working age - 54.93 thous. people; on the territory of the Volyn Region - 36.33 thous. people (23 %), incl. population of working age - 15.62 thous. people. 64.01 thous. people reside in towns or urban type settlements, 69.32 thous. people - in rural districts within the 30 km zone.

Only Varash has a city status; apart from Varash, there is the urban type settlement of Volodymyrets, the district centre located about 18 km away from the NPP, and the Urban Type Settlement of Rafalivka about 5 km away from the NPP in the Rivne Region.

In the Volyn Region, there is the urban type settlement of Manevychi - the district centre of the Manevytskyi District - located 26 km away from the NPP.

Table 2.3 provides comparison data for sizes of urban and rural population within the 30 km zone as of 2017.

Table 2.3. Urban and rural population within the 30 km zone.

Name of town, sett.	Population size, thous. people	Distance from SS Rivne NPP, km
Town of Varash	42.20	3
Sett. of Volodymyrets	8.699	18
Sett. of Rafalivka	3.200	5
Sett. of Manevychi	10.12	26

Satellite town of SS Rivne NPP, Varash, is 3 km away from the power plant and is the largest town in the observation zone. The town's population is about 42,000 people [14]. The density of population within this territory made 55 people/km^2 back in 1973, while currently it makes 3,684 people/km^2. Other relatively large nearby settlements include the urban type settlements of Manevychi (Volyn Region), Volodymyrets and Rafalivka (Rivne Region).

Demography as of 2017 is characterized by 46.7 % of urban population and 53.3 % of rural population. Development of electricity production capacities promoted urbanization process. The highest increase in population was observed in the NPP satellite town due to labour migration. Urban population growth in the region was accompanied with decrease in rural population (due to migration).

The estimated size of actual urban population as of 1 January 2017 made 42.2 thous. people. In 2016, the population decreased by 311 people, which made 7.4 people per 1,000 people of the actual population [14].

The size of population increased due to natural (264 people) and migration (47 people) growth.

Natural population growth level in 2016 made 6.3 people per 1,000 people of the actual population.

The birth rate made 11.9 live-born infants per 1,000 people of the actual population, and the death rate made 5.6 dead per 1,000 people of the actual population.

The urban type settlement of Volodymyrets with the population of about 9.0 thous. people (8.699 thous. people) [15] and population density of 1,447 people/km ^{2} is an investment-attractive region notable for its advantageous geographical location, well-developed transport and communications infrastructure, bank system, considerable industrial and construction potential, spare qualified workforce and executive staff, and reserves of primary natural resources. This is the place where two unique deposits of high-quality basalt suitable for mineral wool and stone-cast ware manufacture are located. There also are vast deposits of peat, white silica sand, clay, amber, zeolitic tuffs, and copper.

The size of population in the urban type settlement of Rafalivka (since 1959) as of 2017 made 3.278 thous. people, and population density made 264 people/km^2 [16]. Rafalivka has a railway station of the same name on the Kovel - Sarny line. The facilities that currently operate in Rafalivka include a sawmill, an asphalt plant and a furniture plant.

According to the data of the last all-Ukrainian population census (2011), the size of population in the urban type settlement of Manevychi made 11,190 people [17]; it increased by 17.3 % compared to the data of 1989 census (8,937 people) [18]. Manevychi is the biggest urban type settlement in Volyn [19]. As of 2017, the size of population here made 11,119 thous. people, while the population density reached 197.89 people/km^2.

As seen from Table 2.3, the Town of Varash, which owes its uprising and development to the construction of the NPP, is the only town within the 30 km observation zone, with the population size several-fold greater than that in the Volodymyrets and Manevychi district centres.

Varash appeared in 1973 as an NPP constructors' settlement with population of 14.79 thous. people (at that time). In 1984, Varash (former Kuznetsovsk) received a city status. Its population reached 23.8 thous. people as of 1 January 1985;

36.2 thous. people as of 1 January 1995;
41.2 thous. people as of 1 January 2000;
42.2 thous. people as of 1 January 2017.

Based on the data obtained within the framework of Kuznetsovsk Master Plan correction project (now Varash) (“Dipromisto”, 1996), a swell in population in 1973-1985 is mainly due to a positive migration balance, while in 1986-1991, due to the completion of the 3rd power unit and moratorium on construction of the 4th unit, positive migration balance reduced several-fold (to 365 people/year from 1987), and from 1992 until present it makes about 500 people/year.

The rate of natural population growth was also decreasing until 1991 (from 760 to 455 people/year), and starting from 1992, the natural growth rate has made about 400 people/year.

However, the population in Volodymyrets (district centre) grew from 8.26 thous. people in 1995 to 9 thous. people in 2000 (by 740 people in 5 years), and made 9.0 thous. people as of 2017. The population dynamics in Manevychi district centre is as follows: from 9.08 thous. people to 10 thous. people (increased by 992 people in 5 years); the population size makes 10.12 thous. people as of 2017.

Urban population dynamics in 1995-2017 is shown in Table 2.4.

Table 2.4. Urban population dynamics in the SPZ in 1995-2017.

Name of settlement	Population size (thous. people)		
	1995	2000	2017
Town of Varash	36.2	41.2	42.2
Sett. of Volodymyrets	8.26	9.0	8.69
Sett. of Manevychi	9.08	10.0	10.12

The OZ of SS Rivne NPP is characterized by low rates of industrial development and moderate rates of agricultural development. Low-tech industrial production is predominant in the region. Available enterprises mainly operate in food, wood processing and road-building industries, as well as in construction materials production. Basic agricultural crops include wheat, rye and oat. The total area of plantings is 18,500 hectares and tends to reduce due to economical reasons.

The specifics of social and economical living conditions of population within the OZ of SS Rivne NPP is defined by annual amount of subventions invested in the regional infrastructure.

Therefore, the most important factor of impact on the demographic situation within the 30 km zone is the Town of Varash that arose due to the construction and operation of SS Rivne NPP.

Construction of the nuclear power plant involved a significant number of young people of working age, who obtained highly qualified employment during construction and operation of the NPP.

Comparison of the age structure in Varash with mean indices for regions within the zone makes clear that the population of Varash shows a higher ratio of labour force and children (Table 2.5).

Table 2.5. Age structure of population in Varash and in the 30 km zone

Name of settlement (zone)	Population size	Including		
		Below working age	Working age	Above working age
Town of Varash	100	29	66.3	4.7
Rivne Region zone	100	23.2	49.6	27.2
Volyn Region zone	100	33	43	24

The potential population size in the Town of Varash was calculated within the framework of the Master Plan correction project ("Dipromisto", 1996). 25 years from 1996 until 2015 were taken as a design calculation period.

The project included a calculation of potential population size based on the workforce balance, which accounted for both town-forming and town-serving elements. The calculation took into account an entirely new approach for determining the town scope, in which a significant role is attributed to the degree of social infrastructure development. In this regard, the ratio of population engaged in service sector will increase (20 % of the total potential population of the town vs. current 14 %), and the ratio of population engaged in the town-forming sector will decrease (from actual 34 % to potential 29 %). The calculation data predicted that as by 1 January 2016 the population will make 45 thous. people, which is 2.8 thous. people more than the actual population in 2016 (42.2 thous. people).

2.2 Impact of SS Rivne NPP operations on population health in the observation zone

The ultimate goal and main task of all environmental protection measures are preserving and promoting people's health, which is the main criterion of the state of environment. In this regard, assessment of the environment may only be provided based on its actual and foretasted impact on population health.

Construction and operation of nuclear power facilities, including nuclear power plants, result in a change of radiation, environmental and health situation in the respective location areas, which may have an adverse impact on the health of population residing on these territories.

In 1976-1979, studies of radiation conditions of natural environment locations before NPP commissioning were conducted in the area of SS Rivne NPP construction, and so-called "zero background" was determined. The study results are used in assessing the radiation impact of SS Rivne NPP power units throughout their entire operation period [6].

According to the "zero background" data:

- the specific air activity of aerosols was within: ^{137}Cs - 1.11E-05÷5.92E-05 Bq/m^3; ^{90}Sr - 1.48E-05÷1.11E-04 Bq/m^3;
-the total beta-activity of atmospheric fallout was within: 7.4E+00÷3.29E+02 (Bq/m^3)/month;
- the content of ^{137}Cs in fir needles was within: 7.2E+00÷1.7E+01 Bq/kg; ^{90}Sr - within 2.96E+01÷1.05E+02 Bq/kg;
- the content of ^{137}Cs in plants was within: 2.55E+00÷9.55E+01 Bq/kg;
- soil surface contamination with ^{137}Cs before commissioning of SS Rivne NPP was within: 4.44E+02÷5.07E+03 Bq/m^2; with ^{90}Sr - within 1.85E+02÷2.92E+03 Bq/m^2;
- specific activity of ^{137}Cs in milk before commissioning of SS Rivne NPP was within: 6.3E-01÷6.6E+00 Bq/l;
- specific activity of ^{137}Cs in vegetables before commissioning of SS Rivne NPP was within: 1.5E-02÷2.0E+00 Bq/kg;
- specific activity of ^{137}Cs in grain crops before commissioning of SS Rivne NPP was within: 8.1E-01÷1.18E+00 Bq/kg.

Also, data provided by regional radiological services of the Ministry of Agrarian Policy were used to create maps of pre-accident contamination with ^{137}Cs and ^{90}Sr [20]. Radiation levels were monitored at study sites created in Ukraine in 1970s. Each affected region had, on an average, from one to five sites. Contamination maps were created using averaged data on ^{137}Cs and ^{90}Sr for 1981-1985 [21]. See overview maps of pre-accident contamination with ^{137}Cs and ^{90}Sr on a scale of 1:12,000,000 in Fig. 2.2. and 2.3.

It should be noted that before Chornobyl accident, the territory of Ukraine was relatively evenly contaminated with ^{137}Cs and ^{90}Sr of anthropogenic origin. After the accident, a wide range of types and compositions of released radioactive products, change of the effective release height, release duration and their non-monotonic nature, and a change of weather conditions during the peak release resulted in formation of complex patterns of radionuclide contamination areas, and the detailed study of their structure still remains a pressing task. Chornobyl contamination areas have uneven mottled structure, stretched along the streamlines. The following is conventionally distinguished within the structure: macrostructure that defines the main traces and spots; mesostructure that represents area variability within the macrostructural specifics; local structures (shore anomalies, roadsides, rainwater systems, etc.).

The macrostructure of the area is mainly defined by weather factors - air-mass transport direction and speed. The boundary atmosphere state, presence of precipitation, local landscape factors predetermine the mesoscale structure - a mottle of high and low contamination levels.

Three traces that form the macrostructure of the area are found within the territory of Ukraine: west, north-east and south. SS Rivne NPP site and the OZ belong to the west trace territories.

Fig. 2.2. Pre-accident ^{137}Cs contamination of the territory of Ukraine

Maps of Ukraine's territory contamination were developed using the observation data obtained within the framework of the program for specification of radiation conditions within the territory of Ukraine after the Chornobyl Accident, which was implemented in 1986-1995 by radiological divisions of various ministries and agencies (State Committee for Hydrometeorology, State Committee for Geology and Mining, Ministry of Agrarian Policy, Ministry of Health, National Academy of Medical Sciences, National Academy of Sciences of Ukraine, etc.). In addition, airborne gamma survey data of the most heavily contaminated areas of Ukrainian Polissia, including forestlands, were used. More comprehensive data sets were used than that used for the development of contamination maps [21-23].

Fig. 2.3. Pre-accident ^{90}Sr contamination of the territory of Ukraine

The situation is currently becoming more complicated due to the fact that the major part of the Rivne NPP adjacent territory appeared to be contaminated as a result of the Chornobyl Accident in 1986. Against the background of anthropogenic environmental contamination (resulting both from operations of Rivne NPP and various industrial and agricultural facilities), emergency release of Chornobyl radionuclides caused an extra population exposure.

Fig. 2.3 shows radiation contamination of a part of the territory of Ukraine with caesium-137 as of 10 May 1986 [21]. The Town of Varash in this map stands by its former name, Kuznetsovsk.

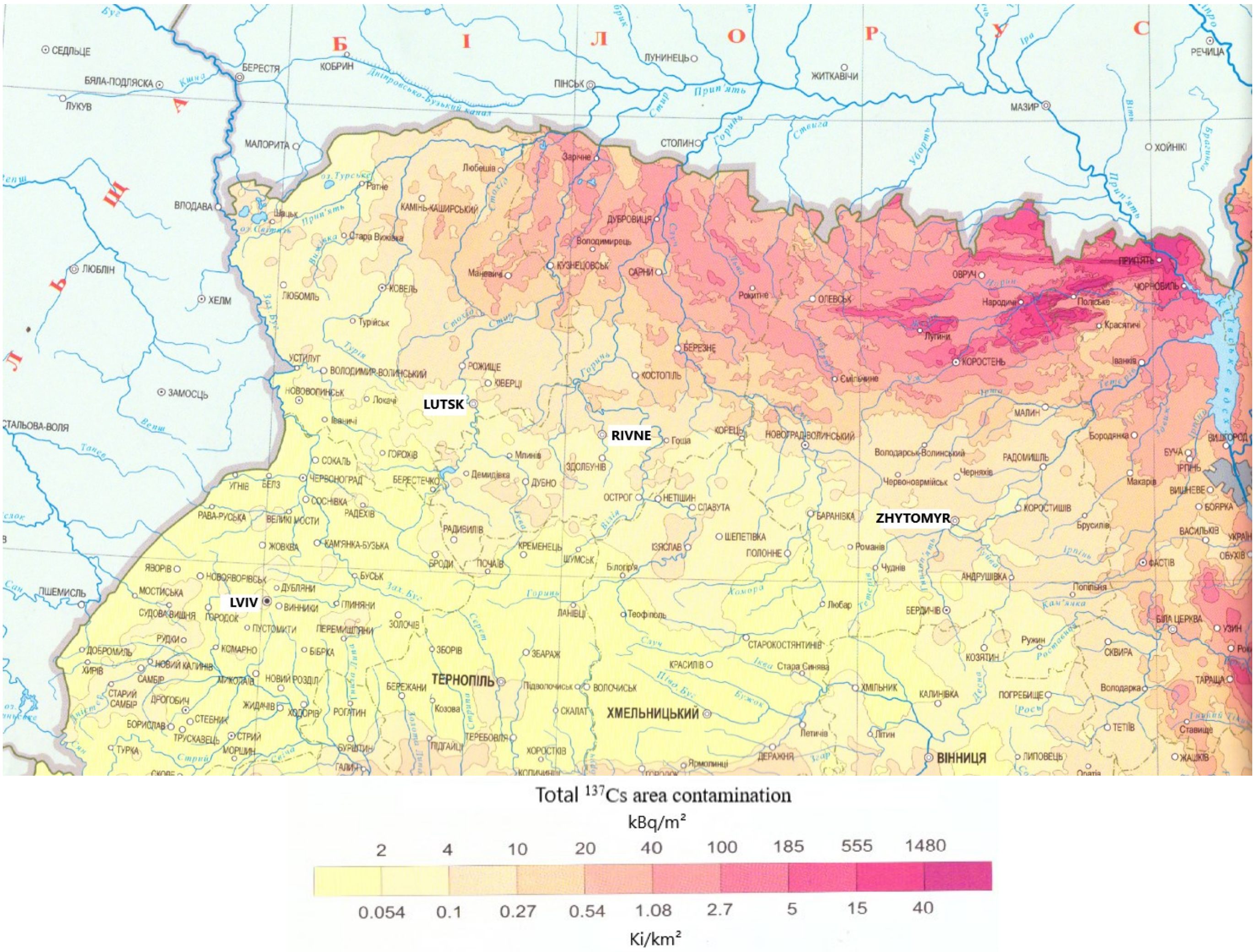

Fig. 2.4. ^{137}Cs contamination of a part of Ukraine’s territory.

Figure 2.4. shows radiation contamination of a part of Ukraine’s territory with ^{90}Sr. Strontium isotopes contamination is of a mixed nature: on ChNPP adjacent territories it is mainly due to a fuel component of emissions, while in regions that are 150-300 km away from the ChNPP in a south trace direction, the condensation component becomes predominant, so ^{90}Sr contamination has extended well beyond the exclusion zone [21].

The highest levels of ^{90}Sr contamination are observed along the west (fuel) trace and within the south trace, where fallouts had both fuel and condensation components.

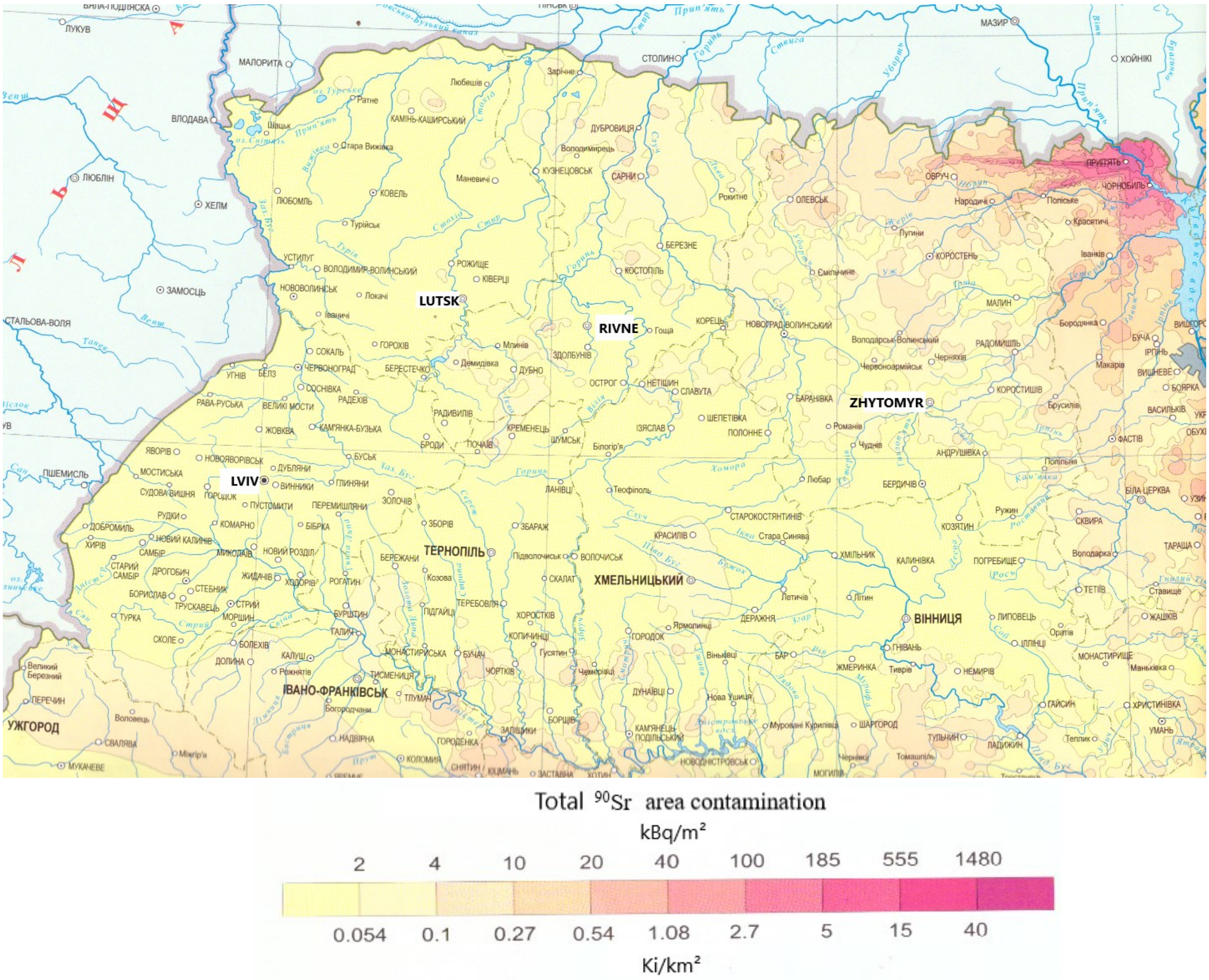

Fig. 2.5. ^{90}Sr contamination of a part of Ukraine’s territory.

This circumstance increases the risk of adverse anthropogenic impact on population health, since many chemical substances can change their action against the radiation background. Numerous researches by Ukrainian and foreign authors suggest increased disease incidence in population residing within the territory that suffered contamination of various degrees after the Chornobyl Accident.

Population health preservation and promotion tasks include determination (based on in-depth analysis) of preferred sanitary-epidemiological and prevention-care measures to prevent and eliminate the adverse environmental effects.

Epidemiological assessment of the adverse environmental impact of contamination includes the determination of the pathology risks. Risk assessment may be conducted on population and individual levels.

In the first case it should justify the adoption of healthcare managerial decisions.

In the second case, population should be informed of the hazard related to a particular factor, and then take conscious decisions on the need of any preventive actions.

This report is aimed at studying the impact of the environment situation in the Rivne NPP adjacent areas on the population health, and determining the potential adverse health changes due to the commissioning of a new power unit.

To achieve this purpose, the following tasks were established:

- study the dynamics of health in adult and child population residing within SS Rivne NPP adjacent territories;
- study the level and type of healthcare provided to the population residing within SS Rivne NPP adjacent territories;
- study the social and hygienic conditions of child population residing in the area, as well as the incidence rates for biomedical pathology risk factors in these children;
- study the physical growth and development, immunologic responsiveness and functional state of the body in children residing in these areas.

Population residing near SS Rivne NPP benefits from the environment being used by a very small number of industrial facilities, therefore it is marginally affected by industrial pollution. SS Rivne NPP is the major industrial facility in the region.

During normal operation of SS Rivne NPP, the radiation conditions and population doses in the region are defined by the existing natural background radiation. SS Rivne NPP radiation impact on the population and the environment does not exceed 0.05 % of the dose level produced by natural radiation sources, and does not change the natural radiation level in the area around the NPP.

Hazardous radiation levels exist only for personnel performing radiation hazardous works, however these risks are brought to a minimum if radiation safety rules are followed. No hazardous radiation risks are present for other works and beyond working hours during normal operation of SS Rivne NPP.

Observed contribution of SS Rivne NPP in air, water and soil pollution do not exceed the permissible levels and is insignificant compared with other pollution sources. The results of long-term radiation monitoring indicate the absence of a substantial radiation impact of the NPP on the environment and, consequently, on the population health in the OZ.

The major contribution in human body radiation exposure within the OZ during normal operation of the NPP is due to natural radionuclides and their decay products. The impact of artificial radionuclides from long-range fallout, Chornobyl radionuclides and, much less, radionuclides from SS Rivne NPP releases on the radiation amount is significantly lower. The hourly dose formed from natural radionuclides exceeds the dose from annual SS Rivne NPP releases.

As a result, it can be said that Rivne NPP has no adverse effect on the population health within the SS Rivne NPP OZ.

Estimated maximum population doses on the border of the SPZ, which are due to design basis accidents, are shown in Tables 2.6 and 2.7. The decisions on acceptability of certain release amounts were taken based on the level of unconditional justifiability for urgent countermeasures as per NRBU-97 [8].

In this case, the countermeasure with the lowest justifiability level - reduced stay outside for children - was chosen. The radiation levels make 10 mSv, 100 mGy and 300 mGy for the entire body, thyroid gland and skin, respectively.

Table 2.6. Maximum estimated population radiation doses during design basis accidents at power units No. 1 and No. 2 with VVER-440 reactors [6].

Design basis accident	Effective dose for the entire body, mSv	Dose for thyroid gland, mGy	Dose for skin, mGy
MDBA (double-ended rupture of the main coolant pipeline)	9.11	9.53	2.05×10^{-2}
Steam generator header cover lift-up	3.84	35.1	3.34×10^{-2}
Planned cool down line rupture (during PEP)	2.76×10^{-1}	2.20×10^{-1}	6.47×10^{-5}
Accidents caused by spent fuel pool leaks	2.87×10^{-4}	9.63×10^{-3}	1.93×10^{-7}
Accidents caused by fuel assembly drop in the spent fuel pool	2.19×10^{-1}	3.27	5.93×10^{-3}
Accidents caused by hydraulic lock drop in the spent fuel pool	4.39×10^{-1}	6.55	1.19×10^{-2}

Table 2.7. Maximum estimated population radiation doses during design basis accidents at power units No. 3 and No. 4 with VVER-1000 reactors [6].

Design basis accident	Effective dose for the entire body, mSv	Dose for thyroid gland, mGy	Dose for skin, mGy
MDBA (double-ended rupture of the main coolant pipeline)	6.51	1.43	0.0329
Coolant leakage from the first loop into the second loop (steam generator header cover lift-up)	5.63	85.9	0.361
Accidents caused by spent fuel pool leaks	0.26	0.74	0.01
Accidents caused by fuel assembly drop in the spent fuel pool	6.87	5.7	0.027
Accidents caused by hydraulic lock drop in the spent fuel pool	6.88	18.5	133

As can be seen from Tables 2.6 and 2.7, even during the MDBA maximum estimated radiation doses are well below the justifiability limit for population evacuation as per the current regulations (50 mSv for the entire body).

2.2.1 Study subjects and research methods

The study of population disease incidence included the following steps:

- analysis of primary disease incidence and prevalence of diseases of various classes and separate nosological entities or groups in adult population;
- analysis of primary disease incidence and prevalence of diseases of various classes and separate nosological entities or groups in child population;
- comparison of data on population disease incidence in selected settlements in the Rivne Region and relevant documents for the Rivne Region and Ukraine in general.

The source for the study of incidence dynamics in adult and child population was reporting forms (No. 1 and, for the recent years, No. 12) by healthcare facilities in the towns.

The study subject was the entire adult and child population residing in these towns.

Since the ultimate goal of the study was to determine the potential impact of operating power units of SS Rivne NPP on public health within the 30 km zone and predicting the future situation, the urban type settlement of Volodymyrets located within the 30 km zone around the NPP and the Volodymyretskyi District in general were selected for the study. The advantage of Volodymyrets, compared with the NPP satellite town of Varash, is the fact that the majority of Volodymyrets population is engaged in works at the NPP. This circumstance may have a significant impact on the disease incidence. Moreover, the satellite town differs from other settlements located within and beyond the 30 km zone in terms of the sanitary and hygienic welfare, pattern of housing development, and organization and specialization level of medical services, etc.

In view of the fact that Rivne NPP itself and the urban type settlement of Volodymyrets selected for the study are located within the territory that was contaminated by the Chornobyl Accident, two settlements located beyond the 30 km zone around SS Rivne NPP were selected as reference. The first reference settlement, Rokytne, is also located on the territory affected by accidental release from ChNPP, and the second, the Town of Kostopil, is beyond the assumed boundaries of the “west Chornobyl trail”. The three settlements are located in Rivne Region. The urban type settlement of Rokytne is 94 km away from Rivne NPP, the urban type settlement of Volodymyrets is within the OZ around SS Rivne NPP 28 km away from the plant, and the Town of Kostopil is 66 km away from the nuclear plant.

All documents received were processed using medical statistics methods. Contents of annual statistical digests of the MoH of Ukraine were used as an information source on public health in Ukraine and the Rivne Region in general.

An extract from the report form No. 20 TsRL (№ 20 ЦРЛ) was made for the purposes of analysis of the public healthcare level.

Groups of children of 7 and 8 years old were selected for detailed specification of child health development. This age group was selected for two reasons. First, physiological features of this age (immature immunodefences and morphofunctional instability of the body) determine hypersensibility to any external impacts. Second, the specifics of healthcare in primary school-aged children (annual extended medical examination involving physicians of different specializations) provides comprehensive information on the state of health in children of this age.

The study subject was the population of children that reside and study at general education schools in Volodymyrets, Rokytne and Kostopil. The data obtained during planned medical examinations, special studies of the functional state, and analysis of the physical growth and development in children were used as the main source of health state information at this stage.

Based on these data, a comprehensive assessment of health state of each child was made by assigning a child to one of the health groups as per the method developed by the Research Centre of Paediatric Healthcare [24]. These data were used to calculate averaged indicators that are widely used in paediatrics and paediatric hygiene: Mean Health Indicator (MHI) for children in the district, health fund (PHF) and health losses (HLP) in child population, with informative value proven in epidemiological studies of environmental hygiene [25].

Disease incidence documents were processed separately by disease classes as per the International Statistical Classification of Diseases, Injuries and Causes of Death (ICD), 10th revision [26], and specific nosological entities or groups of particular interest in terms of the environmental impact were identified. The materials received were processed using medical statistics methods, and prevalence of separate disease nosological entities, groups or classes, general disease incidence rates, as well as general and chronic pathology structures were calculated.

Immunological examinations in child population were made in two settlements in the Rivne Region: Volodymyrets that is located within the 30 km NPP zone (study area) and Rokytne, which is beyond this area (reference area).

The immune system in children was assessed using the two-stage immunoassay system recommended in [27, 28].

Stage 1 of the immunoassay, which is aimed at selection of children with immunodeficiency risk, was performed using a special questionnaire to obtain preliminary information on immune-mediated disease incidence and genetic predisposition thereto. The questionnaire also contains a child's personal data and information on social and hygienic living conditions.

Stage 2 included laboratory immunological tests in each settlement using R. V. Petrov primary immunological screening with micromodification [27].

The immune system in children was assessed using the following complex of indicators [29]:

- Peripheral blood (PB) WBC count and cellular composition;
- absolute and relative T-B lymphocyte count (by E- and EAC-rosette assay);
- PB A, M, G serum immunoglobulins (Ig) concentration (by J. Mancini's radial immunodiffusion technique);
- neutrophil phagocytic activity (NPA) assay.

The reliability and accuracy of the immunoassay results, sample representativeness, and adequacy of settlement data comparison were defined by strict compliance with a set of mandatory requirements.

For Stage 1 checks, groups of children of 7 to 10 years old were selected by continuous sampling. The choice of this group of population was conditioned by unimpaired function of the immune system and stability of immunological indicators at this age, absence of functional changes during hormonal mutations typical of pubertal age, higher neuropsychic stability compared to 6-year-olds and 11-12-year-olds in their prepubertal period, absence of unhealthy habits or occupational health hazards, as well as adequate persistence of low-intensity environmental impact on their bodies. Residence since birth and studying at a school in the settlement under survey were essential eligibility conditions.

Following the patient record analysis, two groups of children from each settlement were selected by random sampling for Stage II laboratory immunoassay: Group 1: children with no positive record of immune-mediated pathology, Group 2: children within immunodeficiency risk groups with no positive record of chronic pathology. Blood was sampled from children who had no physical complaints during the examination period.

Laboratory immunological tests were conducted in identical conditions at the same time of day and season, in autumn, to eliminate both seasonal/circadian and random variations.

Data were analysed using a specially developed computer software application (by Ph. D in Biology V. O. Voloshchenko) [30-33]. System functions of data analysis are implemented by standard mathematical statistics methods as well as special methods developed based on hygienic practices. Standard statistics methods within the software system database are adapted to the hygienic study specifics.

Data on all subjects were entered in the database of individual health indicators for each child. This database was used for statistic processing of the results. Processing was carried out using tools that were developed based on a special modified computer technology [30-33]. A questionnaire was created within this software environment, including all items of the questionnaire that was used during the epidemiological study, as well as immunograms.

Specially developed questionnaires were also used for sociological survey of the parents in order to determine the living conditions of the child subjects, i. e. presence of social and hygienic pathology risk factors. These data were supplemented and corrected by nurses, physicians and supervising teachers. Study factors were chosen based on the data on the incidence of these factors and their importance for children’s health, which were obtained from earlier studies conducted at the PHI [34, 35] and from the literature sources [36-38].

Therefore, the social factors include:

- adverse living conditions (assessment was based on the method developed at N. A. Semashko Scientific Research Institute for Social Hygiene and Healthcare Organization [39]);
- early enrolment in a preschool facility (before the age of 2);
- multiple children in the family (more than 3);
- presence of occupational health hazards in both parents at the time of birth.

Risk factors from this group suggest a positive social history (PSH).

The next group included risk factors related to the specifics of antenatal (pre-delivery) development:

- unfavourable mother’s age at birth (below 18 and above 30 for the first labour and above 35 for repeat labour);
- mother’s health problems before and during pregnancy;
- pathological pregnancy;
- multiple pregnancy;
- pathological labour;
- family record of hereditary diseases.

The group of risk factors related to the newborn’s state at the early postpartum stage included the following factors:

- immaturity;
- abnormal weight of the newborn;
- record of perinatal pathology.

Presence of one or more risk factors from the above two groups was a reason to place the child in a positive biological history (PBH) group.

The last group included risk factors that affect the child’s development and health during the first year of life:

- artificial or mixed feeding;
- diseases during neonatality (before 1 year of age);
- sensibilization reactions to food, medicinal or other substances;
- exudative diathesis, pneumonia, anaemia, frequent acute respiratory infections, rickets, etc.

The risk of child pathology was determined using the maximum likelihood method (likelihood ratio, LR), which is a “human” pattern recognition technique [40, 41].

2.2.2 Medical care in Volodymyrets sett., Rokytne sett. and the Town of Kostopil

There is a central district hospital (CDH) in Volodymyrets, which includes two rural district hospitals, one district hospital, three rural outpatient clinics, a state dental clinic, 44 medical and obstetric (MOS) and medical stations.

Hospital care in Volodymyrets and the surrounding district is provided at the CDH (335 beds) and at rural district hospitals. According to the 2001 census, 8,867 people resided in Volodymyrets [42]. The population made 9.05 thous. people in 2014, and 9.27 thous. people in 2017.

In Rokytne (population of 6.8 thous. people as of 1 January 2017 [43]), there is a CDH including three rural district hospitals, four outpatient clinics, a dental clinic, and 33 MOS and MS.

The Town of Kostopil (population of 33.0 thous. people as of 1999, which reduced and made 31.63 thous. people as of 1 January 2017 [44]) has a CDH including six rural outpatient clinics, a district hospital, one district polyclinic, one state dental clinic, and 44 MOS and MS.

The differences in the general level and profile of medical care in Volodymyrets, Rokytne and Kostopil are inessential [45]. Based on the statistics provided in the above document, the average number of medical appointments per one resident in Volodymyrets and Kostopil is quite similar. However, this number is significantly lower in Rokytne. Also, Volodymyrets is notable for the lowest rate of domiciliary visits (including for children below 14). This may be due to a lack of healthcare personnel, including primary care physicians and paediatricians.

The state of population health represents a complex of conditions. Its formation is influenced by a wide range of social and economic, natural and climatic, biomedical, anthropogenic and other factors.

Disease incidence is an especially essential indicator of population health, and its continuous monitoring provides for planning and optimization of the current and future practices of local authorities, including sanitary and epidemiological supervision bodies.

Population health analysis at this stage was based on a method described in guidelines "Study of population health indicators in relation to environmental pollution" (Kyiv, 1985) [46] and "Procedure of sanitary and epidemiological service activities for public health assessment in relation to environmental factors" (Moscow, 1989) [47].

The dynamics of disease prevalence in child and adult populations of Volodymyrets and reference settlements of Rokytne and Kostopil was analysed at this stage.

The observed surge of the general disease rate in children in Volodymyrets (in 1989-2017) is mainly due to the increase in the rate of infections, tumour growth, endocrine disorders, blood diseases, nervous system and sensory organ disorders, circulatory diseases, respiratory diseases, digestive, genitourinary and musculoskeletal system diseases, and congenital abnormalities. The most dramatic increase was observed in the rates of blood diseases (7.6-fold), genitourinary system diseases (5.9-fold), endocrine disorders (5-fold), musculoskeletal system diseases (4.8-fold), infections (4.6-fold), and nervous system disorders (4-fold).

The growth of the general disease rate in children in Rokytne is due to increased prevalence of the same nosological classes of diseases that induced the growth of general disease rates in Volodymyrets.

For example, the most dramatic surge, as in Volodymyrets, was observed in the rates of blood and blood-forming organ diseases (11.9-fold), endocrine disorders (2.1-fold), nervous system and sensory organ disorders (3.1-fold), and also circulatory diseases (4.7-fold), digestive system disorders and tumour growth (3.5-fold).

Over the survey period (1998-2017), a trend towards the growth of the general disease rate in child populations was also observed in Kostopil, another reference settlement located beyond the so-called "west Chornobyl trail" zone. However, the growth rates were well below the same in Volodymyrets and Rokytne.

While the general disease rate in Volodymyrets increased 3-fold over the study period, in Kostopil it only increased 1.8-fold over the same period. The data obtained suggest the possible contribution of factors related to the Chornobyl Accident in the child disease rates.

The comparison of data on child disease prevalence in Volodymyrets with the relevant data for Ukraine in general, Rivne Region and reference settlements (Table 2.8) has demonstrated that the general disease rate in the town under survey exceeded the respective indices in the reference settlements, Rivne Region and Ukraine in general. Besides, the rates of infections, respiratory diseases, genitourinary diseases, skin and subcutaneous tissue diseases, and musculoskeletal system diseases in Volodymyrets were above the respective indices.

At the same time, the reference settlement of Rokytne (located on the “west Chornobyl trail”) has shown significantly higher rates for the following disease classes: endocrine disorders, blood and blood-forming organ diseases, circulatory diseases, digestive system diseases, psychic disorders and congenital abnormalities.

The most favourable situation is observed in another reference town, Kostopil located beyond the 30 km zone around SS Rivne NPP, on the territory that wasn’t affected by the Chornobyl Accident.

Table 2.8. Comparative analysis of child disease rates in towns under survey in the Rivne Region with the general state and regional data (per 1,000 people).

Class name	Ukraine	Rivne Regions	Sett. of Volodymyrets	Sett. of Rokytne	Town of Kostopil
Infections and parasitic diseases	72.07	53.20	83.54	26.40	33.49
Tumour growth	4.30	2.28	6.11	5.62	2.68
Endocrine disorders	109.26	113.49	71.32	202.13	146.80
Blood and blood-forming organ diseases	43.99	80.75	100.79	178.31	44.87
Psychic disorders	31.43	19.49	19.40	70.11	16.34
Nervous system and sensory organ disorders	155.77	147.14	209.07	196.74	340.34
Circulatory diseases	22.07	53.20	52.54	121.24	70.72
Respiratory diseases	778.82	589.78	783.90	371.91	747.52
Digestive system diseases	111.86	113.84	99.57	199.10	90.81
Genitourinary system diseases	32.74	29.26	67.35	40.45	24.24
Skin and subcutaneous tissue diseases	77.72	64.35	106.29	37.30	51.03
Musculoskeletal system diseases	51.52	34.85	67.35	33.71	19.56
Congenital abnormalities	19.49	16.85	32.83	34.49	15.54
General disease rate	1581.42	1394.99	1881.95	1656.29	1686.85

Apart from the disease rate analysis in terms of separate disease classes, prevalence indicators for separate nosological entities have also been analysed.

A special focus was made on the surge of child anaemias: the incidence of this pathology has increased 7.5-fold over 10 years. A similar trend is observed in other Ukrainian cities and towns. The incidence rate of chronic amygdalopathy and adenoidopathy has increased 6.1-fold. The study had also identified an increase in the incidence rate of infantile cerebral paralysis (2.9-fold), congenital cardiac abnormalities (2.4-fold), acute rheumatism (2.3-fold), and renal infections (2.2-fold over the last 5 years).

At the same time, chronic otitis, diabetes mellitus, chronic pharyngitis and bronchitis, and rheumatoid arthritis incidence rates have reduced.

A similar situation is observed in the reference settlement of Rokytne, however the growth rates of the above nosological entities are much higher here. For instance, the incidence of child anaemias in this settlement has increased 19.5-fold over 10 years to 124.72 cases per 1,000 children.

The analysis of a long-term trend in the general disease rate dynamics in adult population of Volodymyrets, Rokytne and Kostopil has shown the following variations. For instance, while the general disease rate over the survey period has grown from 789.07 cases to 1,485.10 cases per 1,000 people in Volodymyrets and from 743.06 to 1,599.41 cases in Rokytne, in Kostopil the same indicator throughout the survey period remained practically unchanged.

The rates of blood and blood-forming organ diseases in Volodymyrets have grown 10.7-fold, nervous system and sensory organ disorders - 4.6-fold, congenital abnormalities - 2.9-fold, skin and digestive system diseases - 2.5-fold, respiratory and genitourinary system diseases - 1.9-fold, musculoskeletal system diseases - 1.7-fold, endocrine disorders - 1.4-fold. The rate of complications of pregnancy, labour and during postnatal period has increased 4-fold over 10 years.

At the same time, a decreasing tendency is observed for infections and parasitic diseases, and psychic disorders.

The similar situation is observed in the reference settlement of Rokytne ("west Chornobyl trail"). Here, the rates of blood diseases have also increased 5.2 - fold, circulatory diseases - 3-fold, respiratory diseases - 2.7-fold, nervous system and sensory organ disorders - 2.4-fold, congenital abnormalities - 2.2-fold, digestive system diseases - 1.8-fold, and genitourinary system diseases - 1.4-fold.

The comparison of data on adult disease prevalence in Volodymyrets with the relevant data for Ukraine in general, Rivne Region and reference settlements (Table 2.9) has demonstrated that the general disease rates for infections and parasitic diseases, tumour growth, nervous system and sensory organ disorders, genitourinary system diseases, skin and subcutaneous tissue diseases, and musculoskeletal system diseases are significantly higher in Volodymyrets. At the same time, the reference settlement of Rokytne (located on the "west Chornobyl trail") had the general disease rates and rates for blood and blood-forming organ diseases, psychic disorders, circulatory diseases, respiratory diseases and congenital abnormalities well above the corresponding rates in Volodymyrets, Rivne Region and Ukraine in general.

Table 2.9. Comparative analysis of adult disease rates in towns under survey in the Rivne Region with the general state and regional data (per 1,000 people).

Class name	Ukraine	Rivne Regions	Sett. of Volodymyrets	Sett. of Rokytne	Town of Kostopil
Infections and parasitic diseases	36.41	32.05	59.36	37.44	10.94
Tumour growth	35.27	26.28	44.20	28.67	6.60
Endocrine disorders	61.51	53.17	53.74	43.79	51.25
Blood and blood-forming organ diseases	7.18	7.17	5.15	8.87	2.86
Psychic disorders	49.56	44.33	84.48	93.20	17.58
Nervous system and sensory organ disorders	144.94	135.31	274.01	210.00	203.81
Blood-forming system diseases	383.86	298.46	190.65	360.10	379.94
Respiratory diseases	245.66	186.34	189.11	309.26	126.90
Digestive system diseases	131.34	130.32	126.78	126.26	113.82
Genitourinary system diseases	78.50	66.99	114.99	72.41	17.96
Skin and subcutaneous tissue diseases	42.14	37.29	66.24	39.66	31.73
Musculoskeletal system diseases	85.85	76.59	92.24	73.89	82.29
Congenital abnormalities	1.18	1.45	1.90	2.75	0.80
General disease rate	1373.30	1172.74	1485.10	1599.41	1112.83

The most favourable situation is observed in another reference town - Kostopil - located on the territory that wasn't affected by the Chornobyl Accident and beyond the 30 km zone around SS Rivne NPP.

Therefore, the analysis of disease rates in population residing within the 30 km zone around Rivne NPP and in reference settlements has revealed a set of features typical of the population residing in enhanced radioecological monitoring areas. No notable differences in population disease rates in Volodymyrets and Rokytne, which are located within the territories affected by the Chornobyl Accident, were observed. At the same time, significant differences of observed parameters from respective parameters in the reference town of Kostopil, which is located beyond the 30 km zone around SS Rivne NPP and is not covered by the "west Chornobyl trail", have been found.

The data suggest that no statistically-valid changes in the disease rates, which are related to residing within the 30 km zone around SS Rivne NPP, were observed.

Comparison of disease rates in the selected child populations in the three settlements (see Table 2.10) has demonstrated that general disease rates in children under survey in Volodymyrets (80.0 cases in 100 children) are practically similar to those in Kostopil (71.97 cases in 100 children) and are well below the general disease rate in Rokytne (215.38 cases in 100 children). It should be noted that the prevalence rates of almost all disease classes in Rokytne were well above the same rates in Volodymyrets and in the Town of Kostopil. At the same time, the prevalence of circulatory diseases in Volodymyrets is 3.2-fold as much, skin and subcutaneous tissue diseases, 5.9-fold as much, and musculoskeletal system diseases, 2.1-fold as much as that in Kostopil.

Table 2.10. Prevalence of diseases in surveyed primary school-aged children of three settlements in the Rivne Region (in 100 children).

Disease classes	Settlements		
	Sett. of Volodymyrets	Sett. of Rokytne	Town of Kostopil
Respiratory diseases	4.80	63.25*	9.85*
Digestive system diseases	4.80	21.37*	1.52
Circulatory diseases	9.60	12.82	3.03*
Endocrine disorders	28.00	46.15*	30.30
Blood and blood-forming organ diseases	1.60	5.13*	4.55*
Sensory organ disorders	4.00	17.95*	6.82
Skin and subcutaneous tissue diseases	9.60	27.35*	1.52*
Musculoskeletal system diseases	16.00	4.27*	7.58*
General disease rate	80.00	215.38*	71.97

* – statistically significant difference (p<0.05)

High prevalence of endocrine disorders mainly due to thyroid disorders is observed in all three settlements under survey. In-depth analysis of thyroid pathology has demonstrated that diffuse goitre is prevalent in children in Volodymyrets and Rokytne, while thyroid gland hyperplasia is prevalent in Kostopil. It should be noted, that diffuse goitre is a clinical pathology (Code E 04, Class IV "Endocrine, nutritional and metabolic diseases" of International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-X) (WHO, Geneva, 1998) [48].

Table 2.11. Prevalence of thyroid disorders in observed primary school-aged children of three settlements in the Rivne Region (in 100 children).

Nosological entity	Settlements		
	Sett. of Volodymyrets	Sett. of Rokytne	Town of Kostopil
Thyroid gland hyperplasia	2.40	0.80	25.00*
Diffuse goitre, deg. I-II	24.80	40.52*	2.27*
Other thyroid gland pathologies		5.17	
Total	27.20	46.55*	27.27*

* – statistically significant difference (p<0.05)

Apart from the pathology prevalence, we have analysed the parameters that are characteristic of the share of children under survey with a current or historic pathology (Table 2.12). Visual deficiencies (myopia, hypermetropia, astigmatism, heterophthalmia and cyclospasm) were found in 7.2 % of children in Volodymyrets, 16.36 % in Rokytne, 6.82 % in Kostopil, tonsil and adenoid hypertrophy - in 4.80 %, 6.90 % and 7.58 % of children, respectively. Volodymyrets is notable for a significantly high share of children with postural disorders (15.20 %).

In 20.0 % of examined children from Volodymyrets, allergic disorders were recorded, while the same value was significantly lower in the two reference settlements. Chronic diseases were recorded in 60.34 % of children in Rokytne, 35.20 % in Volodymyrets and only 12.12 % in Kostopil.

Table 2.12. Prevalence of diseases in surveyed primary school-aged children of three settlements in the Rivne Region (in 100 children).

Pathology name	Settlements		
	Sett. of Volodymyrets	Sett. of Rokytne	Town of Kostopil
Eye disorders	7.20	16.36*	6.82
Tonsil and adenoid hypertrophy	4.80	6.90	7.58*
Posture disorders	15.20	4.31*	3.79*
Allergic disorders	20.00	17.24*	9.85*
Chronic diseases	35.20	60.34*	12.12*
incl. chronic tonsillitis	2.40	34.19*	2.27

Therefore, in-depth study of children's health in the settlements selected has shown that each of the three settlements display certain specific features. However, the situation in Rokytne is the least favourable.

Functional state of the body is essential for health state characteristics at both individual and population levels. In this study, the functional state was described by functional state of respiratory organs (using vital capacity of lungs (VCL) as an example) and by comprehensive assessment of the circulatory system functions.

The results of division into groups by the degree of VCL deviation from mean values are shown in Table 2.13.

Table 2.13. Division of settlements in the Rivne Region based on the degree of VCL deviation from mean values (%, M±m)

Settlements	Index development level			
	low	below average	average	above average
Sett. of Volodymyrets	12.1±3.6	28.9±5.0	48.2±5.5	10.8±3.4
Sett. of Rokytne	20.2±4.3	28.1±4.8	48.3±5.3	3.4±1.9
Town of Kostopil	9.6±4.1	21.2±5.7	61.5±6.8	7.7±3.7

The obtained data demonstrate that the majority of the children examined in all settlements had average VCL indices (48.2 % in Volodymyrets; 48.3 % in Rokytne and 61.5 % in Kostopil), and a minor share of children had above average VCL indices.

Based on the assessment of documents regarding division of children into groups based in the functional state of their cardiovascular and respiratory systems, no essential differences or specific features were found in settlements under survey (see Tables 2.13-2.14).

Table 2.14. Division into groups based on the circulatory system functional state (%, M±m).

Settlements	Share of children with evident disorders of myocardial metabolism	Share of children with evident minor disorders of myocardial metabolism	Share of children with deviation from age-appropriate normal values
	Group A	Group B	Group C
Sett. of Volodymyrets	6.0±2.6	32.5±5.1	61.5±5.3
Sett. of Rokytne	7.9±2.9	34.8±5.1	57.3±5.2
Town of Kostopil	5.8±3.2	34.6±6.6	59.6±6.8

The average weight of newborn boys is 3.43 kg (m = 0.07; σ= 0.47) in Volodymyrets, 3.37 kg (m = 0.11; σ = 0.66) in Rokytne, and slightly higher, 3.52 kg (m = 0.12; σ = 0.64), in Kostopil. A similar tendency is observed in girls: 3.28 kg (m = 0.08; σ = 0.47), 3.42 kg (m = 0.06; σ = 0.45) and 3.45 kg (m = 0.07; σ = 0.31), respectively. The observed differences are of no importance since all values are within normal range.

Children were divided into health groups for comprehensive health assessment (see Table 2.15). It was found that about 1/3 of children (34.4 %) in Volodymyrets, about 80 % of children in Rokytne and only 12 % in Kostopil have chronic disorders, i. e. may be assigned to health groups III and IV.

Table 2.15. Division of children by health groups in three settlements (%).

Health groups	Settlements		
	Sett. of Volodymyrets	Sett. of Rokytne	Town of Kostopil
I	30.40	4.31	43.18
II	35.20	17.24	44.70
III	32.80	68.10	12.12
IV	1.60	10.34	

The average health index for children calculated using the data obtained is 2.06 in Volodymyrets, 2.85 in Rokytne and 1.69 in Kostopil (the index is considered better the closer it is to 1). The public health fund in these settlements is 0.79, 0.63 and 0.86; the losses are 0.21, 0.37 and 0.14, respectively. These values represent health reserve and roughly indicate that health may be improved in 21 children per 100 children in Volodymyrets, 37 in Rokytne and 14 in Kostopil by a set of preventive and rehabilitation activities.

The data on the comprehensive health assessment in children from the three settlements are in a complete accordance with the results of in-depth study of the disease rate and the functional state of the body, which suggest that children in Rokytne face the most significant adverse health changes. This report did not require identifying the cause of this fact. It deserves follow-up studies.

So, the analysis of health state in children from the Sett. of Volodymyrets, which is located within the 30 km area around SS Rivne NPP, followed by a comparison with similar values in the reference settlements (one located within the "west Chornobyl trail" zone and another within the territory that was not affected during the Chornobyl Accident), has revealed no downward trends in health indices in children from Volodymyrets, which might be due to the Rivne NPP operations.

Along with the common health indices (disease rate, death rate, life expectancy, etc.), in the recent decades hygiene studies have successfully utilized a biomarker approach to detect health disorders at early stages on the cellular, subcellular and molecular levels [49-52]. Immunobiological impact factors are most useful in environmental impact assessment [53].

Immune system is an integral body system that is most sensitive and responsive to the effects of endo- and exogenous hazards [54]. Current immunological methods with micromodifications offer the possibility to study the immune status of large groups of population, while the scientific approach involving new mathematical methods is used to calculate and predict the risk of immune-mediated pathology and take timely preventive measures for public health preservation.

The results of the recent studies demonstrate that chronic exposure to low radiation doses (below 2 sGy) causes adverse changes in the body, including endocrine, immune and nervous systems imbalance that leads to a disruption of compensatory and adaptive mechanisms. These changes show as various pathologies [55-57].

The study of medical impact of the Chornobyl Accident suggests that low radiation doses cause various immunological disorders in the population. Changes in the subpopulation T- and B-lymphocyte ratios, depressed function of the humoral component of immune system, and a wide range of autoimmune antibodies are the most common manifestations. These effects are stable and dose-dependent [57-61]. The study results suggest that chronic exposure to low doses over several decades promotes activation of tumour viruses (Epstein-Barr virus), which is due to immune suppression. The population shows disrupted immunoregulation processes, which shows as reduced anti-infective and anti-tumour resistance and development of pathological conditions: infective and autoimmune syndromes, oncological diseases [61].

In the context of chronic exposure to low radiation doses, based on the hypothesis put forward by some authors [61], changes at the individual and population levels occur in parallel, however population changes have a prolonged latency period, and deterioration of health is recorded at later stages as compared to the indicators that characterize the immune system state.

The immune status predetermines the health state and life expectancy to a large extent [62, 63]. In view of the specific environmental situation in the Rivne Region, where the major part of the territory, including the NPP area, was affected by radionuclides during the Chornobyl Accident [64], an immunological check of population to detect possible adverse dose-dependent health changes is relevant.

The results of epidemiological check (Stage I) to identify people at risk of immunodeficiency have shown that the ratio of children who suffered acute infections (general disease rate) was practically the same in Volodymyrets and in Rokytne (46.67 % and 49.72 %, respectively) (see Table 2.16).

The percent of children who had pertussis (14.53 + 2.63 %) and measles (20.11 + 3.0 %) in Rokytne was significantly higher, while the same indices in Volodymyrets made 1.11 + 0.78 % and 3.89 + 1.44 %, $p < 0.05$, respectively. More children in Volodymyrets had chickenpox (37.22 + 3.6, with 22.91 + 3.14 %, $p < 0.05$ in Rokytne). These differences may be considered as features of highly contagious infection incidence.

The risk factors of child immune resistance disruption include post-vaccination complications (after scheduled vaccination). Preventive vaccination in target population, based on the questionnaire survey results, was made timely in all respondents and had no complications in 98.33 %

of the respondents in Volodymyrets and in 96.09 % of the respondents in Rokytne (see Table 2.16). Complications were observed only in 1.67 % of children in Volodymyrets and in 2.79 % of children in Rokytne, and these values did not vary significantly (p> 0.05).

Possible reduction in immune resistance in children was indicated by record of inflammatory infections of various localization an common acute respiratory infections (ARI) (above 4-6/year). Inflammatory infections were observed in 61.11 % of children in Volodymyrets and in 60.34% of children in Rokytne, and ARIs - in 27.22 and 24.02 %, respectively. As can be seen, the differences are insignificant (p> 0.05) (Table 2.16). The total incidence of clinical signs of immune resistance disorders in child population made 63.33 % in Rokytne and 62.57 % in Volodymyrets.

Table 2.16 Incidence of risk factors of immune resistance disorder in child population residing in Volodymyrets, Rokytne in the Rivne Region (absolute value, %).

Name of settlement	Children examined	Acute infections	Vaccination complications	Clinical signs of immune resistance disorder		
				total	Inflammatory infections	Common ARIs
Sett. of Volodymyrets	180	84 46.6±3.7	3 1.67±0.95	114 63.3±3.6	110 61.1±3.6	49 27.2±3.32
Sett. of Rokytne	179	89 49.7±3.7	5 2.8±1.2	112 62.6±3.6	108 60.3±3.66	43 24.02±3.2

No significant differences were found in the rate of allergic disorders (Table 2.17) in settlements under survey (21.67 % and 24.58 % in Volodymyrets and Rokytne, respectively). Allergic reactions were mainly due to food stuffs, chemical and drug substances, and were observed in 16.67 % and 21.23 % of children, respectively.

Table 2.17 Incidence of certain immune-mediated pathology types in children residing in Volodymyrets and Rokytne of the Rivne Region (absolute value, %).

Name of settlement	Children examined	Allergic syndrome				Autoimmune syndrome	Lymphoproliferative syndrome	Genetic predisposition
		Total	Food, chemicals, drugs allergy, etc.	Bronchial asthma, asthmatic bronchitis, pollen fever, etc.	Eczema, neurodermatitis, exudative diathesis			
Sett. of Volodymyrets	180	39 21.7±3.1	30 16.7±2.8	5 2.78±1.22	5 2.78±1.22	7 3.89±1.44	3 1.67±0.95	14 7.78±2.0
Sett. of Rokytne	179	44 24.6±3.2	38 21.2±3.1	2 1.12±0.79	10 5.59±1.72	5 2.79±1.23	6 3.35±1.39	9 5.03±1.63

Allergic respiratory disorders were recorded in 2.78 % of school-aged children in Volodymyrets and in 1.12 % in Rokytne (Table 2.17). This value is more than 2 times higher in Volodymyrets, however it does not differ significantly from the same in the reference settlement ($p > 0.05$). Eczema, neurodermatitis, exudative diathesis were more common in Rokytne and made 5.59 % of the child population compared to 2.78 % in Volodymyrets, but the difference here was statistically insignificant as well ($p > 0.05$).

Autoimmune syndrome within the territories under survey was recorded in 2.79 % (Rokytne) to 3.89 % (Volodymyrets) of children (Table 2.17). Lymphoproliferative diseases were less common in the second settlement (1.67 % and 3.35 %, respectively). However, this difference was statistically insignificant ($p > 0.05$).

The population is known to include people with congenital predisposition for immune-mediated pathology. Various diseases are common in these persons in case of adverse conditions (especially environmental). We have analysed congenital predisposition for malignant tumours, autoimmune diseases, and recurrent chronic infections with adverse outcomes. The analysis revealed that the share of such children was slightly higher in Volodymyrets (7.78 %) compared to Rokytne (5.03 %) (Table 2.17). While no significant difference between the settlements was observed for the total value, more children with congenital predisposition for chronic infections were found in Volodymyrets than in Rokytne (5.56 %, + 1.71 and 0.56 % + 0.56, respectively, $p < 0.05$).

So, the results of stage I immunoassay indicate that immune-mediated pathology risk factors, which were observed in child population within and beyond the impact zone of SS Rivne NPP, occurred at a similar rate. Only congenital predisposition for recurrent chronic infections with adverse outcomes occurred in Volodymyrets at a significantly higher rate.

Based on stage I analysis results, immunodeficiency risk groups were formed within the examined populations. Children were randomly chosen for laboratory immunological tests during stage II examination. As mentioned above, immunograms were made both in children without record of immune-mediated pathologies (reference Group 1) and in children of the risk group (Group 2) in all settlements. The results are shown in Tables 2.18, 2.19, 2.20.

Comparison of values in immunograms obtained for children from the reference groups in settlements under survey established significant differences in the absolute neutrophil count (3.11×10^9/L in Volodymyrets compared with 4.16×10^9/L in Rokytne) (see Table 2.18).

At the same time, the total active phagocytic neutrocyte count in school-aged children, who reside within the impact area of SS Rivne NPP, was also significantly lower (2.86×10^9/L) compared to that in the reference settlement (3.89×10^9/L). However, against the background of suppressed nonspecific protection factors, activation of the T-lymphocyte immune system component is observed in children from the reference group in Volodymyrets compared with children from Rokytne, which is shown as increased E-rosetting lymphocyte count (45.6 % and 35.4 %, respectively, $p < 0.05$) (Table 2.19).

No significant differences were observed between the values that characterize the humoral component of immune system (B-lymphocyte count, A, M, G serum immunoglobulins count) (Table 2.20).

So, changes in separate immune system components in children without record of immune-mediated pathologies from the two settlements under survey may be attributed to body adaptive reactions.

Comparison of immune status parameters in children from immunodeficiency risk groups (Group 2) and Group 1, who reside within the impact area of SS Rivne NPP, established the increased activity of the humoral component of immune system, which is shown as increased B-lymphocyte count (EAC-rosetting cells: Group 2 - 19.66 %, Group 1 - 17.53 %, p <0.05) (Table 2.19).

At the same time, reduced A-immunoglobulins count is observed (1.31 g/L and 1.47 g/L, respectively, p <0.05), which, however, is within the normal range as used in the literature (Table 2.20). Reduced peripheral blood neutrophil count is observed in school-aged children of Group 2, who reside outside of the impact zone of SS Rivne NPP (48.88 %, 51.47 % in Group 1, p <0.05) (Table 2.18).

Table 2.18 Values of nonspecific resistance in children residing in settlements under survey in the Rivne Region (M±m).

Settlements; target group	Children examined	WBC	Neutrophils		Phagocyte count	
	Children	$\times 10^9$/L	%	$\times 10^9$/L	%	$\times 10^9$/L
Volodymyrets, Group 1	11	6.12±0.23	51.0±0.64	3.1±0.1**	92.1±1.2	2.8±0.1**
Volodymyrets, Group 2	34	6.70±0.26**	52.1±0.68**	3.5±0.2	90.9±0.7	3.2±0.2
Rokytne, Group 1	9	7.91±3.08	51.5±1.2	4.2±0.4	93.5±1.4	3.9±0.4
Rokytne, Group 2	39	7.72±0.42	48.8±0.6*	3.7±0.2	92.8±1.1	3.5±0.2
As shown in literature in the CIS	-	6.87-6.91	57.2-57.4	3.94-3.95	78.9-84.9	-

Note:
1.* Significant differences compared with Group 1 values for children in the settlement under survey (p<0.05).
2. ** Significant differences in groups of the same name compared with values in the reference settlement of Rokytne (p<0.05).

Table 2.19. Values of immune status in children residing in settlements under survey in the Rivne Region (M±m).

Settlements; target group	Children examined	Lymphocytes		E-rosetting cells		EAC-rosetting cells	
		%	$\times 10^9$/L	%	$\times 10^9$/L	%	$\times 10^9$/L
Volodymyrets, Group 1	11	43.9±0.6	2.7±0.1*	45.6±2.9**	1.2±0.1	17.5±1.0	0.5±0.03**
Volodymyrets, Group 2	34	42.1±0.8**	2.8±0.1**	44.4±1.4	1.2±0.1	19.6±1.0*	0.5±0.03
Rokytne, Group 1	9	42.6±1.3	3.3±0.2	35.4±2.7	1.1±0.1	17.8±1.0	0.56±0.04
Rokytne, Group 2	39	45.1±0.6	3.5±0.2	30.7±9.2	1.1±0.1	17.3±0.8	0.6±0.05

Settlements; target group	Children examined	Lymphocytes		E-rosetting cells		EAC-rosetting cells	
		%	$\times10^9$/L	%	$\times10^9$/L	%	$\times10^9$/L
As shown in literature in the CIS		38.6-42.0	2.3-2.5	48.5-70.0	1.0-2.5	19.8-22.0	0.5-0.78

Note:
1. * Significant differences compared with Group 1 values for children in the settlement under survey ($p<0.05$).
2. ** Significant differences in groups of the same name compared with values in the reference settlement of Rokytne ($p<0.05$).

Table 2.20. Primary serum immunoglobulins content in children residing in settlements under survey in the Rivne Region (M±m).

Settlements; target group	Children examined	Immunoglobulins content (g/L)		
		Ig A	Ig M	Ig G
Volodymyrets, Group 1	11	1.480±0.030	1.080±0.020	9.370±0.030
Volodymyrets, Group 2	34	1.550±0.030**	1.050±0.010	9.540±0.170
Rokytne, Group 1	9	1.470±0.050	1.100±0.030	9.210±0.210
Rokytne, Group 2	39	1.31 0±0.030*	1.060±0.030	9.240±0.160
As shown in literature in the CIS	-	0.93-1.83	0.74-1.58	8.70-12.7

Note:
1. * Significant differences compared with Group 1 values for children in the settlement under survey ($p<0.05$).
2. ** Significant differences in groups of the same name compared with values in the reference settlement of Rokytne ($p<0.05$).

Comparison of mean immunological values in children within both groups in settlements under survey (tables 2.18 and 2.19) has shown a set of differences. For example, a significant difference in the total WBC count was observed. It was below 6.70×10^9/L in children in Volodymyrets (7.72×10^9/L in Rokytne, $p<0.05$). By contrast, the relative neutrophil count was significantly higher in children from Volodymyrets (52.06 % compared with 48.88 % in Rokytne, $p<0.05$).

Both relative and absolute lymphocyte counts were also significantly lower (42.11 % and 2.72×10^9/L compared with 45.06 % and 3.52×10^9/L).

It should also be mentioned that the listed indicators in children from Volodymyrets were closer to “normal” values as used in research literature in the CIS than the same in children residing in Rokytne.

Moreover, during the determination of serum immunoglobulin concentrations IgA levels in children from Group 2 residing in Volodymyrets were significantly higher (1.55 g/L compared with 1.31 g/L for the reference settlement) (Table 2.20).

The prevalence of immunodeficiency states was established based on the data obtained from immunograms. Children with deviations of 1.5 to 2.0 σ from the mean values in Group 1 were included in the immunodeficiency risk group, while children with deviations of 2.0 σ and above by several immunological indicators - to the immunodeficiency group.

The obtained data is shown in Table 2.21.

Table 2.21. Immunodeficiency (ID) rate in children residing within the territories under survey of the Rivne Region (absolute value, %±m).

Settlement			
Sett. of Volodymyrets		Sett. of Rokytne	
Children examined	Children with ID	Children examined	Children with ID
50	4 8.0±3.84	48	4 8.33±3.99

The results indicate no significant differences in the immunodeficiency rates in children residing in Volodymyrets and Rokytne: the rates were 8.0 % and 8.33 %, respectively, $p > 0.05$.

Individual immunograms show deviations in children with immunodeficiency from the settlement under survey, mainly within the nonspecific resistance system: each of four school-aged children had deviations in quantitative indicators of the Differential WBC Count due to a change in the neutrophil count, and in one child changes in a total WBC and lymphocyte counts were observed. In addition, all children showed increased neutrophil phagocytic activity. Also, two children had deviations in the B-lymphocyte immune system component, which suggests deeper disorders.

Four children with ID were found in Rokytne. Deviations within the nonspecific resistance system were observed in all four of them. Three children had deviations in the lymphocyte count, and one child had deviations in the neutrophil count and neutrophil phagocytic activity. Immunodeficiency in three children was notable for deviations in the humoral component of immune system, which was shown as increased EAC-rosetting cells count. In addition, two children had T-cell immunodeficiency.

Individual immunograms indicate that while ID incidence rates in children from the settlements under survey are similar, children from Rokytne, who were included in the immunodeficiency group, demonstrated deeper immune disorders compared with residents of the NPP impact zone.

So, immunological checks in child population residing within and beyond SS Rivne NPP impact zone have shown that the territories under survey are similar in their immune-mediated pathology rates. However, higher levels of congenital predisposition for recurrent chronic infections with adverse outcomes in Volodymyrets should be noted, and prevention and spread control should be enhanced.

Child population checks within the areas under survey have shown a set of deviations of the immune indicators from the normal values as used in the literature, both in school-aged children without record of immune-mediated pathologies and in immunodeficiency risk groups. Deviations in children without record of immune-mediated pathologies should be treated as regional specific features of immune status formation under adverse environmental conditions. Immune status disorders in children within immunodeficiency risk groups from different areas are diverse.

For instance, while stimulation of certain immune system components in Volodymyrets is observed, the same components are suppressed in Rokytne.

Immunodeficiency states occur with a similar rate both within and beyond SS Rivne NPP impact zone. However, adverse immune system changes in population residing within the Rivne Region territories, which were affected during the Chornobyl Accident, gives reasons to decide on the need for immunological monitoring (within the framework of state health enhancement programs) within the NPP impact zone and in the region in general. Immunological monitoring is necessary for prenosological diagnostics of immune disorders and for timely preventive health protection measures.

2.2.3 Study of social and hygienic conditions and incidence rates for biomedical pathology risk factors in children

At this stage, studies were conducted in two settlements (study settlement of Volodymyrets and reference settlement of Rokytne), which are located within the territory affected during the Chornobyl Accident. This approach has brought to a minimum the possible impact of this factor on children’s health development.

Population health in general and children’s health in particular is affected by various factors. Among them, social factors are of high importance. A large number of studies in this field suggest that living, learning and parenting environment conditions and other factors are crucial for changing a child’s health. As a result, these factors are fully compliant with the risk factor concept and are hereinafter referred to as medical and social health risk factors. Of the variety of factors, those that are crucial for children’s health development were studied (see Table 2.22).

Table 2.22. Rate of medical and social health risk factors in children under survey in two settlements in the Rivne Region (%; P±m)

Risk factors	Settlements		
t	Volodymyrets	Rokytne	
Presence of medical and social risk factors	37.4±5.3	49.4±5.3	1.60
incl. - presence of occupational health hazards in parents	2.4±1.7	2.2±1.6	0.09
- multiple children in the family (more than 3)	8.4±3.1	10.1±3.2	0.38
- enrolment in a preschool facility before the age of 2	2.4±1.7	3.4±1.9	0.39
- enrolment in a preschool facility at 2 or 3	41.0±5.4	20.2±4.3	3.01
- adverse living conditions	32.5±5.1	36.0±5.1	0.49

Since the major part of the day is spent indoors, living and learning environment at general education schools is of utmost importance. The schools under survey (these were selected jointly with physicians from the local SES) were constructed according to a typical project. The buildings are located well away from the sources of air pollution or urban noise, etc. Sanitary requirements for buildings management are met in both schools; teaching mode, catering and physical education of children are the same. So, the choice of schools has brought to a minimum the possible impact of these factors.

Sociological survey of the parents did not reveal any significant differences in the living conditions of children under survey. Almost 1/3 of children in both settlements had adverse living conditions (in 32.5 % of children in Volodymyrets and in 36.0 % of children in Rokytne).

The major social factors also include the age of engagement with organized groups. It is common knowledge that the younger the child the more labile its body is and the more open it is toward the adverse external impact. Psychological component, stressful situations that often accompany the transfer from home parenting to upbringing at preschool facilities (PSF), shall also be taken into account.

All of the above predetermines the treatment of early enrolment with the PSF as a pathology risk factor. A major share of children in both settlements get enrolled with the PSF after the age of 3. However, statistically more children in Volodymyrets (t = 3.01) visit PSF starting from the age of 2 to 3 (40.96 % of children in Volodymyrets and 20.22 % in Rokytne).

No significant difference in the incidence of families with multiple children has been found: 8.43 % of children from such families in Volodymyrets and 10.11 % in Rokytne.

Moreover, no difference was observed in the proportion of children whose parents face occupational health hazards. Only two percent of parents in both settlements acknowledged this factor.

Medical and social health risk factors were found in a total of 37.35 % of children under survey in Volodymyrets and 49.44% in Rokytne (the difference is of no statistic significance).

Therefore, no essential differences in the incidence rates of separate and combined medical and social health risk factors were observed in two settlements under survey, the only exception being the age of enrolment with the PSF.

Biomedical pathology risk factors were observed in 65.1 % of children in Volodymyrets and 67.4% in Rokytne (Table 2.23). This group of risk factors commonly included: mother's health problems before and during pregnancy, artificial or mixed feeding of newborns.

The feeding situation in Rokytne is more favourable: 33.7 % of children here were on artificial feeding, compared with 38.6 % of newborns in Volodymyrets.

The share of children on mixed feeding was considerably higher here: 30.3 % compared with 24.1 %. However, the differences observed are not statistically significant.

A statistically significant difference in the perinatal pathology rate was observed in children from the settlements under survey. For instance, while 14.5 % of children in Volodymyrets had this pathology, in Rokytne it was observed only in 5.6 % of children.

These differences may be due to a proper organization of obstetric care, but they must be taken into account as a pathology factor in older children groups.

This table also contains data on the incidence of another group of children's health risk factors: diseases and pathologies that occurred at infancy (under one year of age).

The data suggest there is no statistically significant difference in these factors in both settlements under survey.

Table 2.23. Incidence rates of biomedical and other risk factors in target child populations (%; P±m).

Risk factors	Settlements		
	Volodymyrets	Rokytne	t
Presence of biomedical risk factors	65.1±5.2	67.4±5.0	0.32
incl. - unfavourable mother's age at birth	12.1±3.6	12.4±3.5	0.06
- mother's health problems	44.6±5.5	40.5±5.2	0.54
- maturity of the foetus	4.8±2.4	4.5±2.2	0.09
- perinatal pathology	14.5±3.9	5.6±2.4	1.96
- artificial feeding	38.6±5.3	33.7±5.0	0.67
- mixed feeding	24.1±4.7	30.3±4.9	0.91
- - diseases at infancy	68.7±5.1	71.9±4.8	0.46
- pathologies at infancy	22.9±4.6	32.6±5.0	1.43

So, minor differences have been observed in the living conditions, rates of biomedical and other pathology risk factors in children in the two settlements under survey.

2.2.4 Determination of the pathology risk degree in population

In many countries, decisions related to environmental impact are based on the population health risks of the impact factors.

The analysis of adverse impact of a single factor or multiple factors includes two essential stages: quantitative risk assessment and taking risk management decisions [65].

Risk assessment normally means a set of operations to analyse and identify the impact mechanism of events in order to prevent or eliminate their occurrence [66]. As regards the study of environmental impact on the population health, the anthropogenic pollution factor assessment involves identification of their impact on health development, analysis and qualitative assessment of the harmful effect. Risk analysis results in a determination of a population share exposed to the impact, in which adverse health effects are expected.

Impact assessment involves exploring the existing situation with direct factor intensity measurement and prediction, as well as analysing the current health level of the population exposed to such factors.

The final risk assessment procedure involves drawing up a characteristics, including determination of the extent of separate accounted factors and a set of unaccounted factors on formation of the population health. The resulting qualitative assessment of environmental impact on the population health allows proceeding to the next important step - risk management by analysing the costs-efficiency ratio.

The risk index calculation method includes special studies that are based on qualitative determination of exposed and unexposed population (in case of environmental impact assessment), or a population share exposed or not exposed to a certain risk factor.

As mentioned above, the risk degree was calculated using the likelihood ratio (LR).

The check of population health in settlements under survey showed no significant changes in the health state in child and adult populations related to their residing within the 30 km zone around SS Rivne NPP. At the same time, significant differences of observed parameters from similar parameters in the reference town of Kostopil, which is located beyond the 30 km zone around SS Rivne NPP and is not covered by the “west Chornobyl trail”, have been found.

According to the calculations, the risk of disease in children residing in the “west Chornobyl trail” (including in Volodymyrets) is 1.17-fold as much as that in Kostopil. In addition, the risk of oncological diseases is 3.16-fold, blood and blood-forming organ diseases - 3.11-fold, congenital abnormalities - 2.86-fold, diffuse goitre - more than 20-fold.

Minor statistically insignificant differences in the disease rate in child populations under survey in Volodymyrets and in the reference settlement within the “west Chornobyl trail”, Rokytne, may be due to other health-forming factors. Calculations indicate that the risk of disease in children of Volodymyrets is slightly higher (1.21-fold) than that in Rokytne. Since no substantial differences in the environment in both settlements were observed, risks related to other health-forming impacts were analysed to find the cause of this difference.

It was found that early enrolment of children with preschool facilities in Volodymyrets enhances the likelihood of pathologies in children 2-fold; complete shift to artificial feeding - 1.15-fold; mother’s health problems before and during pregnancy - 1.1-fold; perinatal pathology - 2.59-fold. The likelihood of increased disease rate in children from Volodymyrets with parents facing occupational health hazards is 1.1-fold as much as the same parameter in Rokytne. Therefore, minor differences in the child disease rate in the two settlements under survey may be due to a set of biomedical and social risk factors.

2.3 Assessment of the total population radiation dose in the area near Rivne NPP

The top-level national regulation on radiation safety issues is DHN 6.6.1-6.5.001-98 Radiation Safety Standards of Ukraine (NRBU-97) [8]. NRBU-97 specifies two groups of exposed persons: personnel (categories A and B) and all population (category C):

- Category A includes personnel that is directly involved in operations with ionizing radiation sources (IRS) on a continuous or temporary basis.
- Category B includes personnel that doesn’t work directly with IRS, but may be exposed to additional radiation due to the location of work stations in premises or at sites of facilities utilizing nuclear radiation technologies.
- Category C includes all population.

Document [8] established limits by the following criteria:

- internal and external exposure of personnel and population;
- maximum permissible radioactive releases in the environment.

Numeric values of external radiation doses per calendar year by organs or tissue groups, as well as total external and internal radiation doses in accordance with [NRBU-97] requirements are given in Table 2.24.

Table 2.24. Limit radiation doses (mSv/year) (LD).

Organ or tissue	Exposed category		
	A	B	C
LDE (limit effective dose)	20[1]	2	1
Limit external dose equivalents:			
- LD_{lens} (for crystalline lens)	150	15	15
- LD_{skin} (for skin)	500	50	50
- LD_{extrem} (for hands and feet)	500	50	-
[1] On average for any successive 5 years, but not more than 50 mSv per year			

Individual annual effective doses and external dose equivalents for personnel of Categories A and B and population (Category C) shall not exceed LD values for respective category (see Table 2.24).

The list of radionuclides, permissible air release values and limit annual discharge of radioactive substances are specified in the documents currently in force at SS Rivne NPP:

- Permissible gas-aerosol release of radioactive substances from Rivne NPP (group 1 radiation and hygienic regulation) 132-2011-ДВ-ЦРБ approved by letter No. 7.03-58/56 of the MoH of Ukraine dated 23 February 2012;
- Reference levels of gas-aerosol release and liquid discharge from SS Rivne NPP (group 1 radiation and hygienic regulation) 132-2016-КР-ЦРБ approved by letter No. 7.03-58/171-16/29017 of the MoH of Ukraine dated 9 November 2016.

Regulation and control of population exposure (Category C) are based on the calculations of annual effective and equivalent radiation doses for critical population groups. Limit dose rates for population are specified for relevant nuclear radiation facilities. Permissible discharge (PD) and permissible release (PR) values are specified based on the limit dose rates for each facility. Limit dose rates for NPP release and discharge values are given in Table 2.25.

Table 2.25. Limit dose rates used to determine PD and PR values.

Nuclear radiation facility	Release: DL_E rate due to all dose formation pathways		Discharge: DL_E rate due to a critical water use type		Total DL_E rate due to air and water dose pathways	
	%	μSv	%	μSv	%	μSv
NPP, NCP	4	40	1	10	8	80

Limit values of radionuclide intake through the respiratory system (PI^{inhal}) and digestive system (PI^{ingest}), as well as limit radionuclide concentrations in the air (PC^{inhal}) and drinking water (PC^{ingest}) are specified for the population (Category C). Numeric values of permissible levels in case of impact of a single radiation type, single radionuclide and single radiation pathway under relevant reference radiation conditions are given in Table 2.26.

Table 2.26. Permissible levels of radionuclide intake through the respiratory and digestive systems, air and water concentrations of radionuclides for Category C.

Radionuclide	PI^{inhal}, Bq/year	PI^{ingest}, Bq/year	PI^{inhal}, Bq/m^3	PI^{ingest}, Bq/m^3
^{54}Mn	4×10^4	2×10^5	20	8×10^5
^{58}Co	3×10^4	3×10^4	10	6×10^5
^{60}Co	3×10^3	1×10^5	1	8×10^4
^{90}Sr	6×10^2	4×10^3	0.2	1×10^4
^{110}Ag	5×10^3	4×10^4	2	2×10^5
^{131}I	8×10^3	6×10^3	4	2×10^4
^{134}Cs	3×10^3	4×10^4	1	7×10^4
^{137}Cs	2×10^3	5×10^4	0.8	1×10^5
^{3}H	2×10^5	8×10^6	100	3×10^7

Within the period under survey (2004-2017), permissible release and discharge at SS Rivne NPP were regulated in accordance with documents that specify limits for release and discharge (PR_i and PD_i) of the key dose forming radionuclides during normal operation. Permissible release and discharge rates at SS Rivne NPP were reviewed twice over the period under consideration.

Limit release values (PR_i) for key dose forming radionuclides during normal operation are currently established at SS Rivne NPP and agreed upon with the MoH of Ukraine (23 February 2012) (see Table 2.26).

Permissible release/discharge values meet the requirements for NPP operation from the viewpoint of radiation safety of the population within the local natural ecological system. PR_i and PD_i values are not affected by the number of power units in operation. Permissible release/discharge values are not allowed to be exceeded during normal operation of the NPP.

In accordance with the document "Permissible water discharge of radioactive substances from SS Rivne NPP" (group 1 radiation and hygienic regulation) 132-2011-КУ-ЦРБ, limit discharge PD_i values (limit permissible amount of radioactive substances, which may be discharged into the environment with water from SS Rivne NPP) for the key dose forming radionuclides during normal operation are currently established and agreed upon with the MoH of Ukraine (23 February 2012) (see Table 2.12). Permissible discharge values meet the requirements for NPP operation from the viewpoint of radiation safety of the population within the local natural ecological system. PD_i values are not affected by the number of power units in operation.

Permissible discharge values are not allowed to be exceeded during normal operation of the NPP.

According to the requirements of [8], reference levels of gas-aerosol release and liquid discharge of radioactive substances were established for SS Rivne NPP.

See Table 2.27 and Table 2.28 for the reference levels of gas-aerosol release and liquid discharge from SS Rivne NPP, as approved by Deputy Minister of Health of Ukraine on 13 May 2013.

Table 2.27. The value of coefficients ($ПВ_i$) [89].

No	Radionuclide (group of radionuclides)	GBq/day
1	Long-lived radionuclides (LLR)	0,37

No	Radionuclide (group of radionuclides)	GBq/day
2	Inert radioactive gases (IRG)	67000
3	Radionuclides of Iodine	5,5
4	^{51}Cr	620
5	^{54}Mn	3,0
6	^{59}Fe	9,9
7	^{58}Co	9,4
8	^{60}Co	0,17
9	^{89}Sr	23
10	^{90}Sr	0,48
11	^{95}Zr	13
12	^{95}Nb	25
13	^{110m}Ag	0,49
14	^{134}Cs	0,40
15	^{137}Cs	0,35
16	^{3}H	930

Table 2.28 The value of coefficients (ПС$_i$) [90].

No	Radionuclide	GBq/year
1	^{3}H	2400000
2	^{51}Cr	53000
3	^{54}Mn	490
4	^{59}Fe	290
5	^{58}Co	450
6	^{60}Co	52
7	^{65}Zn	270
8	^{89}Sr	6700
9	^{90}Sr	130
10	^{95}Zr	200
11	^{95}Nb	2600
12	^{106}Ru	840
13	^{110m}Ag	2900
14	^{131}I	1200
15	^{134}Cs	57
16	^{137}Cs	83
17	^{144}Ce	310

The permissible emission / discharge reflects the requirements for NPP operation in terms of radiation safety of the population in the conditions of the local natural ecological system. The values of ПВ$_i$ and ПС$_i$ do not depend on the number of power units in operation. Exceeding the permissible emission / discharge during normal operation of the NPP is not allowed.

In accordance with the "Permitted water discharges of radioactive substances of the Rivne NPP" (Radiation and Hygiene Regulations of the first group) 132-2011-DS-TSB", currently established and agreed with the Ministry of Health of Ukraine (23.02.2012) limits of discharges ПС$_i$ (the maximum permissible amount of radioactive substances, the receipt of which in the environment is acceptable with the water discharges of the Rivne NPP) of the main dose-forming radionuclides under normal operation. The allowable discharge reflects the requirements for NPP operation in terms of radiation safety of the population in the conditions of the local natural ecological system.

The values of control levels of gas-aerosol discharges and water discharges of the Rivne NPP 132-2016-KR-TSBB, agreed on 09.11.2016 by the Deputy Minister of the Ministry of Health of Ukraine, Letter No. 7.03-58 / 1701-16 / 29017, given in Table 2.29 and table 2.30.

Table 2.29. Gas and aerosol emission control levels for radionuclide groups and for individual radionuclides

Group of radionuclides	**Control level, MBq/day**
Суміш довгоживучих радіонуклідів (ДЖН)	9,0
Інертні радіоактивні гази (ІРГ)	$8{,}7 \times 10^5$
Радіонукліди йоду	140
Group of radionuclides	**Control level, MBq/month**
^{3}H	$5{,}2 \times 10^5$
^{60}Co	35
^{134}Cs	48
^{137}Cs	42

Table 2.30. Control levels of liquid discharges of radioactive substances

Radionuclides	**Control level, MBq/year**
^{3}H	$5{,}6 \times 10^6$
^{60}Co	18
^{90}Sr	64
^{134}Cs	20
^{137}Cs	240
^{144}Ce	110

Chornobyl Accident had a dramatic impact on the radiological environment in the Rivne Region, especially in its north parts that were covered by the “west radioactive trace” [21].

Research was conducted in Volodymyrets sett., the Town of Kostopil and Rokytne sett. (Rivne Region) and in Manevychi sett. (Volyn Region). These residential places were selected since they are located at different distances and in different directions away from the NPP, and are within/beyond the territories affected during the Chornobyl Accident (“west Chornobyl trail”).

Assessment of design basis releases and discharges from SS Rivne NPP, similar to assessment the NPP impact on the radiation conditions of natural environment locations, was conducted within the framework of EIA reports for RNPP-4. See the assessment results in [67].

Numeric values of design basis air radionuclide releases during normal operation of SS Rivne NPP power units No. 1-4 are given in Table 2.31 (total release from power units No. 1-4). Table 2.29 also contains calculated values of release for power units No. 3, 4.

Table 2.31. Design release from SS Rivne NPP during normal operation, Bq/day.

Radionuclides	Release from power units No. 3, 4	Total release from power units No. 1-4
Long-lived radionuclides (LLR)	1.11×10^{6}	7.81×10^{6}
Inert radioactive gases (IRG)	8.66×10^{12}	1.34×10^{13}
Iodine	1.42×10^{7}	1.17×10^{8}
Chrome-51	2.34×10^{4}	2.38×10^{6}
Manganese-54	3.40×10^{3}	1.54×10^{4}
Ferrum-59	3.56×10^{2}	3.32×10^{4}
Cobalt-58	2.30×10^{3}	6.23×10^{4}
Cobalt-60	5.30×10^{3}	2.78×10^{4}
Strontium-89	2.66×10^{3}	2.85×10^{4}
Strontium-90	6.68	5.70×10^{1}
Zirconium-95	4.46×10^{2}	8.23×10^{5}
Niobium-95	1.07×10^{2}	1.48×10^{4}
Caesium-134	1.53×10^{5}	1.87×10^{6}
Caesium-137	2.48×10^{5}	8.20×10^{6}
Tritium	1.42×10^{10}	3.23×10^{10}

Design release values suggest that the population dose during normal operation of SS Rivne NPP power units No. 1-4 does not exceed the limit population dose rate of 40 µSv/year [8].

2.3.1 Assessment of annual doses for critical population groups

The results of assessment of annual doses for critical population groups at SS Rivne NPP based on the actual data of routine releases and discharges demonstrate that the limit population dose rates due to release/discharge from SS Rivne NPP are not exceeded.

A software suite for radiation dose monitoring in critical population groups within the OZ around SS Rivne NPP during routine releases and discharges (RNPP_Doses) has been utilized at the NPP since 2006. The software was developed in order to fulfil the requirements of para. 5.5.1 of NRBU-97.

RNPP_Doses calculates effective doses formed throughout the calendar year during routine gas-aerosol release and water discharge from Rivne NPP for critical population groups residing within the OZ around SS Rivne NPP.

Radiation dose calculation methods within the software suite are specified in the document "Monitoring of doses for critical population groups within the observation zone around Rivne NPP (during routine release and discharge). Guidelines" [68] and approved by the MoH of Ukraine.

Output data for effective dose calculations in 2007 by the software suite were represented by five file types prepared by Meteostat application of the Atom suite:

- Files with aggregate daily meteorological data including statistics on frequency of atmospheric stability classes (acc. to Pasquill) by 16 wind directions and 10 wind speed ranges.
- Files with aggregate daily meteorological data including statistics on relative precipitation rate.
- Files with aggregate daily values of IRG and radioiodine gas-aerosol release.

- Files with aggregate monthly values of gas-aerosol release for the following radionuclides: ^{3}H, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{95}Nb, ^{95}Zr, ^{110m}Ag, ^{134}Cs, ^{137}Cs.
- Files with aggregate monthly values of water discharge for the following radionuclides: ^{3}H, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{110m}Ag, ^{131}I, ^{134}Cs, ^{137}Cs, ^{144}Ce.

Daily files on IRG and radioiodine releases were based on the data of Radmon suite. Meteorological data, aerosol release and discharge data files were formed based on the data of Atom suite.

See Table 2.32 for 2007-2016 for estimated total effective doses for critical population groups due to releases and discharges of SS Rivne NPP and % of the limit dose rate (Table 5.2 in NRBU-97) based on the data of [69].

Table 2.32. Estimated total effective doses for critical population groups due to releases and discharges of SS Rivne NPP.

Year	Effective dose, μSv	% of the limit dose rate
2007	0.59	0.73
2008	0.42	0.52
2009	0.45	0.57
2010	0.26	0.32
2011	0.35	0.44
2012	0.37	0.46
2013	0.34	0.42
2014	0.31	0.39
2015	0.31	0.39
2016	0.27	0.34

2.3.2 Research methods

The following research methods were used to fulfil the study tasks.

External radiation doses (mSv) were calculated based on 17 hours/day of outdoor and 7 hours/day of indoor stay of a person (yearly average), screening factor of 0.8 for the open terrain and 0.7 for indoor locations, in accordance with the tabulated data in Appendix 10 to NRBU-97 [8]. Incorporated caesium-137 was determined directly, by measuring the isotope content with a mobile personal radiation monitor (PRM), with the minimum detectable activity for caesium-137 of 50 nCi (1850 Bq) in adults. Caesium-137 body activity and resulting dose are calculated in accordance with the guidelines “Assessment of internal radiocaesium doses for Ukrainian population using personal radiation monitors” [70].

2.3.3 Radiation from natural sources

The main radiation sources for population residing in Ukraine are natural radionuclides, which are present in soil and in underlying rocks. The studies have shown that the average weighted total effective dose for the population in Ukraine is approximately 3.5 mSv/year. Radon-222 (^{222}Rn) makes the main contribution to the above dose in the building air - 2.4 mSv/year [86].

The main radon source in the building air is its emanation from underlying rocks (soils). Radioactive gas ^{222}Rn is formed due to a decay of natural ^{238}U uranium radionuclides that are present in underlying rocks.

Apart from radon-222, the following radiation sources were taken into account in effective dose calculation [86]:

1) natural radionuclides:
   – in construction materials with the effective dose of 0.23 mSv/year;
   – in artesian drinking water with the effective dose of 0.12 mSv/year;
   – in food (^{238} U, ^{232}Th and ^{40}K) with the effective dose of 0.18 mSv/year;
2) natural γ-background radiation with the effective dose of 0.15 mSv/year;
3) cosmic radiation with the effective dose of 0.3 mSv/year.

Also, artificial radionuclides ^{90}Sr and ^{137}Cs from global fallout and Chornobyl accident release have their share in the total effective dose of population radiation.

2.3.4 External radiation doses

In 2018, analysis of exposure dose rate (EDR) in settlements under survey was performed, using documents by State Enterprise Rivne Regional Laboratory Centre of the MoH of Ukraine and results of own studies at SS Rivne NPP [71]. The data is shown in Table 2.33.

Table 2.33. EDR measurement results within the OZ of SS Rivne NPP, μR/h.

Settlement	1976	1987	2000	2017
Town of Varash	8-9	20-25	12-14	11-13
Sett. of Volodymyrets	7-8	20-25	12-18	11-17
Town of Kostopil	7-8	16-20	9-10	9-11
Sett. of Rokytne	6-8	40-45	20-24	19-24
Sett. of Manevychi (Volyn Region)	8-9	30-35	18-20	18-19

2.3.5 Internal radiation doses

Internal population radiation doses within the observation area around SS Rivne NPP were calculated using methods based on a direct measurement of ^{137} Cs (radiocaesium) in human body using mobile personal radiation monitors (PRM).

At the same time, an attempt was made to assess the internal radiation dose of ^{137} Cs in population in the area under survey by content in milk. This was justified by the fact that agricultural industry in the area of Rivne NPP is notable for its focus on dairy production. Dairy products make 60-70 % of the population diet in the region. From these considerations, a calculation principle as per Digest 5 “Dosimetric Certification of Settlements in Ukraine...” [72] may be adopted, where it is stated that 1 nCi/L (37 Bq/L) of radiocaesium in milk results in an annual dose of 30 mrem (0.3 mSv).

In general, the basic local food products used by population within the OZ around SS Rivne NPP - milk, vegetables and grain crops - are subject to monitoring. Samples were taken during ripening.

Food samples were tested by γ-spectrometry to detect potential radionuclides originating from plant releases, especially ^{131}I.

Since 1981, isotope specific activity monitoring of agricultural products was conducted by analysis and comparison with the "zero background" measurements and detection of isotopes with MDA using spectrometric equipment. In 2004-2016, ^{134}Cs, ^{137}Cs, ^{131}I, ^{60}Co isotope activities in all samples tested were below the MDA. MDA values (within 0.23-0.61 Bq/L) were well below the permissible levels of radionuclide content in food products.

Since the ratio of mean ^{134}Cs, ^{137}Cs isotope activities in grain crops does not match the same in Rivne NPP releases, and ^{137}Cs isotope activity does not drop as the distance from Rivne NPP increases, a conclusion can be made that ^{137}Cs isotope activity originates from the Chornobyl Accident. High ^{137}Cs content in food as compared to the "zero background" is due to the high factor of conversion within the "soil - solution - plant" chain for the area around SS Rivne NPP. The above conclusions are justified by data obtained during regular radiological checks at SS Rivne NPP.

Milk samples are taken at dairy plants and commercial dairy farms. The sampled volume is 3 litres. After sampling, γ-spectrometry is performed without radiochemical sample treatment.

Table 2.34 shows data on specific activities in milk in 2004-2016. Average activity values are given for each year.

Table 2.34. Specific radionuclide activity in milk in 2004-2016.

Year	^{7}Be, Bq/L	^{40}K, Bq/L	^{60}Co, Bq/L	^{131}I, Bq/L	^{134}Cs, Bq/L	^{137}Cs, Bq/L
2004	<2.7E+00	5.71E+01	<3.2E-01	<3.7E-01	<2.9E-01	7.67E+00
2005	<4.3E+00	5.28E+01	<5.3E-01	<6.1E-01	<5.2E-01	5.40E+00
2006	<2.3E+00	4.88E+01	<2.7E-01	<3.3E-01	<2.3E-01	5.74E+00
2007	<1.7E+00	4.90E+01	<1.3E-01	<2.5E-01	<1.5E-01	1.99E+01
2008	<2.0E+00	4.69E+01	<1.8E-01	<2.9E-01	<1.8E-01	4.02E+00
2009	<6.1E+00	6.37E+01	<5.1E-01	<8.7E-01	<5.7E-01	9.16E+00
2010	<2.6E+00	5.31E+01	<2.4E-01	<3.6E-01	<2.4E-01	1.06E+01
2011	<1.6E+00	4.62E+01	<1.4E-01	<2.0E-01	<1.7E-01	7.07E+00
2012	<2.7E+00	4.87E+01	<2.3E-01	<3.2E-01	<2.6E-01	1.33E+01
2013	<2.7E+00	4.56E+01	<1.7E-01	<3.4E-01	<2.2E-01	1.73E+01
2014	<1.3E+00	5.04E+01	<2.1E-01	<6.8E-02	<1.9E-01	9.10E+00
2015	<1.6E+00	4.78E+01	<8.9E-02	<1.9E-01	<1.3E-01	2.38E+01
2016	<1.1E+00	4.94E+01	<9.0E-02	<1.6E-01	<1.1E-01	3.80E+01

Note. Increased MDA values in 2005 are due to a repair of spectrometric equipment - high sensitivity detector of high-purity germanium, and resulting measurements using less sensitive DGDK detectors.

Average contamination of dairy milk within the area around SS Rivne NPP with ^{134}Cs and ^{137}Cs isotopes is illustrated in Fig. 2.5.

Caesium-134 is found in data on specific activity in milk after the Chornobyl Accident. Since ^{134}Cs half-life is 2.06 years, its detection in food, including milk, is irrelevant due to its low content.

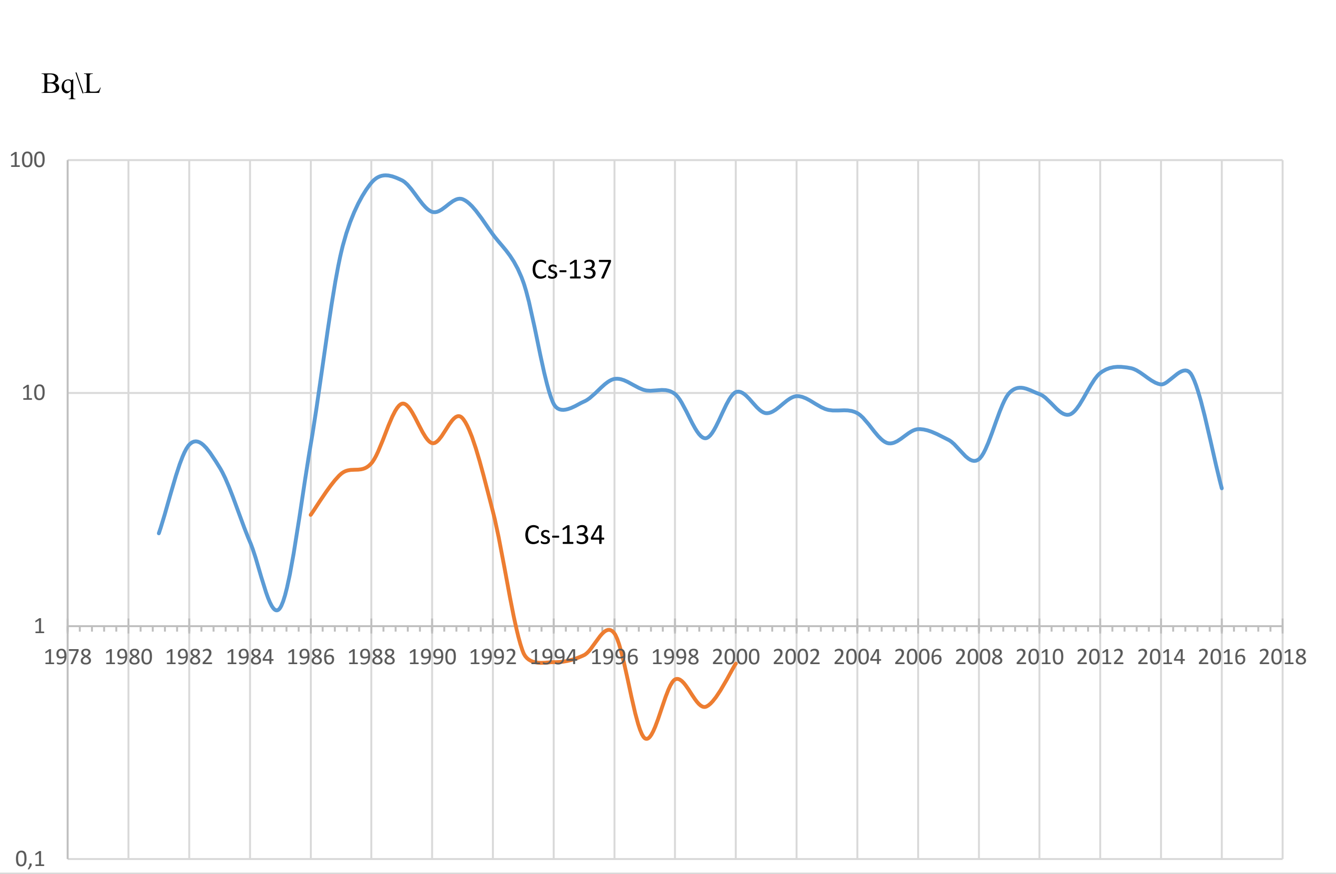

Fig. 2.6. Average contamination of milk within the area around SS Rivne NPP

Table 2.35 contains data on ^{137}Cs content in milk by settlements within the 30 km zone.

Table 2.35. ^{137}Cs content in milk in 1976-2018.

Area	Years												
	1976	1978	1985	1987	1988	1989	1990	1991	1992	1993	1994	2000	2017
North of the Rivne Region	2.99	3.0	2.0	444.7	1683.0	815.7	523.2	500.0	576.5	261.0	237.0	200.0	189.0
Village of Krasyn, Manevychi District, Volyn Region	-	3.2	2.5	1397.3	1200.0	620.0	405.1	300.5	200.1	220.0	222.7	220.0	218.3
Town of Kostopil	-	-	-	-	-	-	-	-	-	10.5	9.8	8.0	7.8

Data in Table 2.35 regarding ^{137}Cs milk concentrations suggest that since 1987, a dramatic surge in concentrations compared with the pre-accident period has been observed. The entire observation zone around Rivne NPP is a part of the enhanced radioecological monitoring area (IV), with ^{137}Cs soil contamination density of 1-5 Ci/km^2 (1kBq/m^2÷5 kBq/m^2). Acidic soils in this region provide for a high isotope transfer rate to grass and therefore to milk.

Compared with 1987, a substantial decrease (5.5-fold) of ^{137}Cs content in milk was observed in 1993, while compared with the Rivne NPP precommissioning period (1976-1978) ^{137}Cs milk concentrations increased 66-fold. At present, caesium-137 concentration is 2 times as much as the DR-97 values [73]. The comparison of ^{137}Cs milk concentration data since 1985, when two power units of SS Rivne NPP were in operation, demonstrates a reduction, rather than growth, of isotope milk concentration values until 2000. This also proves that SS Rivne NPP does no have any impact on ^{137}Cs isotope concentrations.

During calculation of internal radiation doses due to ^{137}Cs in milk, the calculation principle provided in digest “Dosimetric Certification of Settlement in Ukraine...” [72] was taken into account, and data from the study “Global ^{137}Cs fallout and humans” [74], which states that population in the Polissia region consumes 1 L of milk (all dairy products are converted to milk equivalent) and milk makes 60-70 % of the overall local diet, was used.

In view of the above, the population dose of internal radiation due to ^{137}Cs isotopes is 110 mrem (1.1 mSv).

Comparison of this value with a similar value obtained during the precommissioning period (1976-1978) suggests that the dose increased 55-fold. As seen from the above, ^{137}Cs milk concentrations correlate with internal radiation doses.

It should also be noted that milk data were taken for the private sector, while ^{137}Cs concentrations in milk from state facilities were 5-10 times less, and therefore the internal radiation dose reduced down to 20÷11 mrem (0.2÷0.11 mSv). It would be interesting to compare these data with the similar data obtained in Kostopil. As mentioned above, Kostopil was chosen as a reference settlement and its area was not particularly affected by releases during the Chornobyl Accident. The average caesium concentration in milk was 0.216 nCi/L (8.0 Bq/L) as of 2000, and the dose made 6 mrem (0.06 mSv), respectively. If the difference in ^{137}Cs concentrations in milk from state and private farms is taken into account, these dose may reduce down to 2-3 mrem (0.02-0.03 mSv).

At the same time, direct measurement of the internal radiation dose due to ^{137}Cs isotopes was performed by measuring the incorporated radionuclide content in the human body.

2.3.6 Total population radiation exposure in the observation zone around SS Rivne NPP

The total Category A and B personnel and Category C (all population) radiation dose is calculated as a sum of external and internal radiation doses from incorporated radionuclides [11].

Table 2.36 contains averaged data for doses in population residing within the observation zone around SS Rivne NPP.

Table 2.36. External and internal radiation doses in Category C population residing within the OZ around SS Rivne NPP.

Area under survey	External radiation dose, mSv	Internal radiation dose, mSv	Total annual dose, mSv
OZ of SS Rivne NPP. Districts: Volodymyrets, Rokytne, Manevychi	0.67±0.1	0.21±0.05 0.02±0.01 (87 people) (PRM)	0.88±0.01
Town of Kostopil	0.4±0.1	0.02±0.01 (36 people) (PRM)	0.42±0.05
NRBU-97. Category C - all population, limit radiation dose per year LD_E	-	-	1.0

Analysis of Table 2.36 suggests that the population radiation dose within the observation zone around SS Rivne NPP and in the reference settlement is below the established limit radiation dose per year as per NRBU-97 [8].

At the same time, the external radiation dose forms the main portion of the total dose in the population. External radiation doses in north regions are 76 %, and in the reference settlement - 95 % of the total annual dose. This is due to the fact that milk produced locally contains much lower ^{137}Cs concentrations.

Prior to commissioning of SS Rivne NPP power units (zero background), the total dose of external and internal radiation in the construction area (due to dairy products consumption) was 30÷40 mrem (0.3÷0.4 mSv). So, the above statements suggest that the population radiation dose within the observation zone around SS Rivne NPP has grown 2-fold, while the same in the reference settlement (the Town of Kostopil) has remained at the permissible level.

Based on the data collected by off-site surveillance, the total dose of external and internal radiation (by inhalation or orally) due to the impact of SS Rivne NPP alone makes 3.4×10^{-7} mrem (3.4×10^{-9} mSv). This value was calculated for release from two power units: VVER-440 and VVER-1000. This dose is 2.6×10^{7} times lower than the current dose within the OZ of 88 mrem (0.88 mSv), so it is really difficult to differentiate this value.

2.4 Positive and negative impact of SS Rivne NPP site on the social environment

To describe the existing social environment within the 30 km zone and assume ways for its further development, first of all, account should be taken of the impact on the social conditions in the are of Varash, which dominates by population (42,200 people live in the town, which is more than 31.0 % of the total population of the territory), by the level of engineering infrastructure and public services development.

Given the remoteness of Varash from the existing district centres, as well as the current labour, cultural and recreational functional connections, according to the Preliminary Regional Plan of the Rivne Region (Dipromisto, 1979), Varash is considered to be the centre of the district settlement system. It also serves as the centre of the local interfarm settlement system. Based on these conditions, when adjusting the Master Plan of Varash (formerly known as Kuznetsovsk) (Dipromisto, 1996), the need to develop the public service sector not only in the town, but also in the adjacent settlements was taken into account. Therefore, within the 30 km zone around the NPP, now and in the future, Varash provides a higher level of social conditions both to its citizens and to the residents within its umland (about 70 thous. people).

The current situation in social protection, including the demographic situation, is as follows.

The estimated size of actual urban population as of 1 January 2017 made 42.2 thous. people. In 2016, the population decreased by 311 people, which made 7.4 people per 1,000 people of the actual population.

The size of population increased due to natural (264 people) and migration (47 people) growth.

Natural population growth level in 2016 made 6.3 people per 1,000 people of the actual population.

The birth rate made 11.9 live-born infants per 1,000 people of the actual population, and the death rate made 5.6 dead per 1,000 people of the actual population.

In January 2017, subsidies for reimbursement of housing and utility expenses were granted to 251 households (all that applied for housing subsidies).

The total amount of subsidies granted in January 2017 made UAH 88.7 thous., while the average size of the subsidy per household in January 2017 amounted to UAH 353.

In January 2017, the population paid UAH 7 mln for housing and utilities, including repayment of debts of previous periods. The charges to the population for housing and utilities made UAH 6.8 mln, and the level of payment for services rendered was 102.4 %.

At the end of 2017, the situation in the field of employment and unemployment was as follows. The number of registered unemployed persons who were registered with the town's State Employment Service amounted to 651 persons at the end of January 2017. Within the total number of unemployed persons, 55.1 % are women, 54.1 % are young people under the age of 35, and 18.9 % are people living in rural areas.

The number of vacancies declared by employers to the State Employment Service was 31 at the end of January 2017. At the same time, the number of registered unemployed persons applying for one vacancy was 21 people.

The average unemployment benefit in January 2017 amounted to UAH 1,785, which is equivalent to 55.8 % of the statutory minimum wages (UAH 3,200).

The average monthly nominal (gross) wages for a full-time employee in 2016 amounted to UAH 9,747 (hereinafter the data is provided on legal entities and separate subdivisions of legal entities with the number of employees of 10 and more), which is 6.1 times the statutory minimum wages (UAH 1,600 in December 2016).

Compared to 2015, wages increased by 26.4 %, or by UAH 2,038.

The size of wages in the town in 2016 exceeded the average regional level (UAH 4,364) 2.2-fold, or by UAH 5,383.

The situation in the area of justice and crime is as follows. According to the Prosecutor's Office, 35 criminal offences were registered in the town in January 2017, which is 25.5 % less than in January 2016.

Of the total number of criminal acts documented by law enforcement authorities, 12 were serious and extremely serious (9.1 % more than in January 2016). During this period, 8 persons who committed crimes were identified.

Capital investments and construction in Varash are promising. In January-December 2016, UAH 67.8 mln of capital investments were made in economic development of the town by economic entities from all financing sources, which is 1.7 % of the total amount in the region.

Spent capital investments per person made UAH 1.6 thousand. In January 2017, the town enterprises carried out construction works for the amount of UAH 53.7 mln, which is 67.2 % of the total amount in the region.

In 2016, 6.6 thousand square meters of the total housing area was put into operation in the town, which is 3 times more compared to 2015. Contracting companies built 93.2 % of the total housing, while individuals built 6.8 %. The share of the town in the total amount of commissioned housing in the region was 2 %.

Social welfare of people residing in the 30 km zone is primarily determined by the number of jobs and the employment rate of the population.

To date, Varash industrial enterprises employ more than 8,300 people, including 7,932 employees at SS Rivne NPP, which is a team of professionals. Of these, 5,351 are men and 2,581 are women. Including: 6,522 industrial workers and 1,410 non-industrial employees. 4,062 persons have higher education degree.

The urban services sphere, which includes healthcare, education, trade, catering, and housing and communal services employs 5.0 thousand people. Other categories (small enterprises, recreation establishments, subsidiary agricultural enterprises) employ another 2,400 people.

The plant provides significant financial support to its pensioners:

- one-time cash retirement benefit is paid (the amount depends on the length of service);
- monthly supplement is granted to non-working pensioners (the size depends on the length of service and job position);
- monetary compensation is granted to NPP workers and pensioners for consumed electricity and heat.

The following are the main objects of the social sphere in Varash, which serve both urban and rural population; dependence of their operation and development on the NPP is shown below.

The town’s housing stock made 598,719 m^2 of the total area based on statistical data as of 1 January 2000. The average housing per capita is 14.5 m^2 of the total area. The itemized list of objects that are part of the start-up facility of power unit No. 4 includes 4 residential buildings and a hostel for small families with a café. The available housing stock was built at the expense of NPP contributions, and further expansion is also at the expense of the station.

Currently, there are 12 kindergartens in the town. The above-mentioned itemized list provides for construction of another kindergarten for 305 children.

There are 4 general education schools and vocational schools in the town, and another general education school for 1,296 students will be built according to the itemized list.

The town’s medical care will be improved following the completion of the children’s clinic for 480 visits (the existing operating clinic is designed for 600 visits). It should be noted that the adjacent settlements are served by first-aid stations.

A health care centre for personnel and pensioners of the plant, “White Lake” recreation centre, and “Varash” hotel are on the plant’s balance sheet.

The city has a sports and recreation centre, an equestrian school, a swimming pool, a stadium, a gym, a shooting range, and a children’s sports school. These facilities are on the plant’s balance sheet. Classes in sports clubs are also paid by the plant; they can be visited by residents of nearby settlements.

The community centre, the library and the park also on the balance sheet of the plant. These facilities serve both residents of Varash and the people from the nearby settlements.

The trade network, catering and consumer enterprises currently serve the town and villages within the umland. In the future, the network of these enterprises is expected to expand taking into account provision of services to residents of the surrounding settlements.

The plant’s shipping department includes a bus park for service trips and a truck fleet serving the town’s enterprises and institutions.

Varash has a Class 3 bus station, which performs suburban and long-distance trips. Within the 30 km zone, Varash bus station joins all settlements, so that residents from surrounding villages first arrive to the town, and than go to facilities located in other settlements. In the future, the construction of a new road from Varash to the Kyiv-Kovel highway is planned, which will connect the city with the network of Ukrainian highways of general use in the most efficient way.

The “White Lake” cultural and recreational complex, built by the plant, is currently in operation; plant’s employees and their families have rest on subsidized vouchers. The Master Plan of Varash includes the development of zones for short-term and long-term recreation. According to sanitary standards, such zones should be located at least 10 km away from the NPP. According to the project, sports and fishing-and-hunting recreation facilities and lands are recommended to be established on the basis of pine forests of the Sarny and Strashiv forestries and the Sluch River, and Karasynske and Somyn lakes. Health camps for children should be accommodated in the pine forest of Voronkovske Forestry, near the Voronky Lake. The development of recreation areas is impossible without the financial participation of the NPP.

Over the last 10 years (2007-2017), surveillance in all the three settlements under survey has revealed an increase in the overall disease incidence in child population. However, disease growth rates were much higher in Volodymyrets and Rokytne than in Kostopil, which is located outside the so-called “west Chornobyl trail” zone.

While the general disease rate in children over the survey period has increased almost 3-fold in Volodymyrets and 2.5-fold in Rokytne, in Kostopil in only increased 1.8-fold. The growth of the general disease rate in children in Volodymyrets and Rokytne is due to increased prevalence of the same nosological classes of diseases. The most dramatic surge was observed in the rates of blood and blood-forming organ diseases (7.6-fold in Volodymyrets and 11.9-fold in Rokytne), endocrine disorders (5-fold in Volodymyrets and 2.1-fold in Rokytne), nervous system and hearing organ disorders (4-fold in Volodymyrets and 3.1-fold in Rokytne), circulatory diseases (2.4-fold in Volodymyrets and 4.7-fold in Rokytne), and tumour growth (1.2-fold in Volodymyrets and 3.5-fold in Rokytne).

The analysis of a long-term trend in the general disease rate dynamics in adult population of Volodymyrets and Rokytne in 1989-1999 has shown growth, while in Kostopil the same indicator throughout the survey period was practically unchanged. For instance, while the general disease rate over the survey period has grown 1.9-fold in Volodymyrets, in Rokytne it only increased 2.2-fold. At the same time, the prevalence of the main pathology classes in 1999 in Volodymyrets and Kostopil was lower than in Rokytne.

The analysis of disease rates (based on statistics data) in population residing within the 30 km zone around Rivne NPP and in reference settlements has revealed a set of features typical of the population residing in enhanced radioecological monitoring areas. No significant differences in disease rates of population in Volodymyrets and Rokytne, which are located within the territory affected during the Chornobyl Accident, were observed. At the same time, significant differences of observed parameters from similar parameters in the reference town of Kostopil, which is located beyond the 30 km zone around SS Rivne NPP and is not covered by the “west Chornobyl trail”, have been found. The obtained data suggest the predominant adverse impact of the radiation factor associated with the Chornobyl Accident on the formation of the disease rate in child and adult population of Volodymyrets and Rokytne. No statistically significant changes in the disease rates due to residing within the 30 km zone around SS Rivne NPP were observed.

In-depth analysis of disease rates in child population has demonstrated that general disease rates in children under survey in Volodymyrets (80.0 cases in 100 children) are practically similar to those in Kostopil (71.97 cases in 100 children) and are well below the general disease rate in Rokytne (215.38 cases in 100 children). It was found that about 30 % of children in Volodymyrets, about 80 % of children in Rokytne and only 12 % of children in Kostopil have chronic disorders, i. e. may be assigned to health groups III and IV.

High prevalence of endocrine disorders mainly due to thyroid disorders is observed in all three settlements under survey. It was found that diffuse goitre is prevalent in children in Volodymyrets and Rokytne, while thyroid gland hyperplasia is prevalent in Kostopil.

So, in roughly equivalent conditions of thyroid gland pathologies occurrence in children of 3 settlements under survey, the degree of severity and the depth of lesions vary greatly in Volodymyrets and Rokytne, on the one hand, and in Kostopil, on the other. The obtained data suggest that the spatial distribution specifics for this pathology can be considered as a consequence of the adverse effects of the Chornobyl Accident.

For the purposes of discussion, health may be improved in 21 children per 100 children in Volodymyrets, 37 in Rokytne and 14 in Kostopil by a set of preventive and rehabilitation activities.

Studies of the rate of immune-mediated pathologies and respective congenital predisposition suggest the absence of significant differences in the corresponding indicators in child population in Volodymyrets and Rokytne.

The analysis of health state in children from the Sett. of Volodymyrets, which is located within the 30 km area around SS Rivne NPP, followed by a comparison with similar values in the reference settlements (one located within the “west Chornobyl trail” zone and another within the territory that was not affected during the Chornobyl Accident), has revealed no downward trends in health indices in children from Volodymyrets, which might be due to SS Rivne NPP operations. Based on the study of the total population radiation exposure within the observation zone around SS Rivne NPP, the following conclusions were made:

- Exposure dose rate (EDR) for γ-radiation in the observation zone of SS Rivne NPP in 2000 was within 66.96×10^{-10} to 111.6×10^{-10} C/kg·h (12-20 μR/h), within 50.22×10^{-10} to 55.810^{-10} C/kg·h (9-10 μR/h) in the reference settlement of Kostopil and within 111.6×10^{-10} to 133.92×10^{-10} C/kg·h (20-24 μR/h) in Rokytne.
- The increase in EDR was due to emissions from the Chornobyl NPP (west trail). The observation area is mainly located in the fourth zone of contamination, where the density of contamination with ^{137}Cs is 1 to 5 Ci/km^2 (1 kBq/m^2 to 5 kBq/km^2).
- The external radiation dose in the observation zone is within the range of 50-90 mrem (0.5-0.9 mSv).
- The internal population radiation dose calculated based on ^{137}Cs intake with milk was 110 mrem (1.1 mSv) (max.) and 20-11 mrem (0.2-0.11 mSv) (min.) in districts under survey (Volodymyretskyi, Rokytnianskyi, Manevytskyi), and 6 mrem (0.06 mSv) (max.) and 2-3 mber (0.02-0.03 mSv) (min.) in the reference settlement.

- Internal radiation doses calculated using personal radiation monitors (PRM) are 21 mrem (0.21 mSv) for districts under survey and 2 mrem (0.02 mSv) for the reference settlement.

- The main share in the total population radiation doze is contributed by external radiation: 75 % in districts under survey and 95 % in the reference settlement.

- The population radiation doze in the observation zone of SS Rivne NPP is mainly due to the global fallout and release from the Chornobyl Accident (the "west trail").

- The population radiation doze in the reference settlement of Kostopil matches the radiation dose in effect before NPP commissioning (zero background) and is mainly due to the global fallout.

- The total population radiation doze within the 30 km observation zone only due to releases from the power units currently in operation (VVER-440 and VVER-1000) is 3.4×10^{-7} mrem (3.4×10^{-9} mSv), which is 2.6×10^{7} times less than the current actual radiation dose.

Based on the above, operation of SS Rivne NPP has no adverse impact on health in population residing within the 30 km zone, so no increase in the pathology rate in population is expected (provided that the plant operates in an accident-free mode).

2.4.1 Mitigation of social and economic risk for population within the observation zone around the NPP

SS Rivne NPP is not only an environmentally friendly site for the production of thermal and electric energy, it also has an annual social guarantee in the form of a state subvention, which adds to the nuclear facility observation zone settlements budgets.

In accordance with the current legislation of Ukraine, the population permanently residing in the 30 km observation zone around NPP has the right to receive social and economic compensation for risks to their activities, which includes in particular: establishment and maintenance of a special-purpose social infrastructure in good condition, privileges for consumed electric energy payments at tariffs set in accordance with the Law of Ukraine "On Electricity" [87].

According to the Resolution of the Cabinet of Ministers of Ukraine, the distribution of state subventions between local settlement budgets within the observed areas of nuclear power plants is as follows:

- 30 % - for regional budgets;
- 55 % - for district and regional subordination city budgets;
- 15 % - for budgets of cities neighbouring with nuclear facilities.

These funds are used exclusively in the ways and in the manner established by the Cabinet of Ministers.

Subventions are directed, first of all, to:

- construction, reconstruction, capital and current repair of facilities of special social infrastructure and protective structures of civil defence;

- purchase of respiratory protective equipment and stable iodine pills;

- population training on the use of protective equipment and civil defence facilities.

Control over the proper use of funds by local authorities and local self-government bodies is carried out in accordance with the current legislation.

Taking into account the subvention amounts for socio-economic compensation of the population's risks in the observation zone, Rivne NPP is the main budget-creating enterprise in the region contributing to its sustainable economic development.

In 2017, the government directed more than UAH 32 mln of state subsidies to finance social and economic risk compensation measures for the population living in the OZ of SS Rivne NPP.

Distribution of subventions to local budgets in 2017 was as follows:

- Rivne Region (regional share) - UAH 7 million 18.3 thousand;
- Volyn Region (regional share) - UAH 2 million 757.9 thousand;
- Manevytskyi District (Volyn Region) - UAH 7 million 227.6 thousand;
- Volodymyretskyi District (Rivne Region) - UAH 9 million 895.9 thousand;
- Sarny District (Rivne Region) - UAH 646 thousand;
- Kostopilskyi District (Rivne Region) - UAH 153.6 thousand;
- Town of Varash (Rivne Region) - UAH 4 million 888.1 thousand.

2.5 Public information in the Town of Varash and settlements within the OZ around the SS Rivne NPP

In 2017, 248 public information notices regarding the current state of the SS Rivne NPP were sent. According to the results of events at SS Rivne NPP - meetings, conferences and inspections - press releases are distributed to the media and the press service of NNEGC Energoatom. 480 press releases were distributed in 2017.

Since 2006, an official external website of SS Rivne NPP has been running; information is collected and updated by employees of the Information and Public Relations Department of SS Rivne NPP. The website is updated with the daily news.

Twice a week the press of Rivne, Volyn and Lviv regions is monitored to track the public demand for the information.

About 1,199 articles were published in the regional media in 2014, 160 articles in 2014, 1,905 articles in 2016, and 1,688 articles in 2017, which indicates that the public is interested in events at SS Rivne NPP. The articles mainly dwell on the reliability of the power units, radiation safety, modernization and reconstruction measures to increase safety of the units, social partnership, cooperation with local authorities, and development of infrastructure in the adjacent territories of SS Rivne NPP.

In order to demonstrate the high level of safety and reliability of domestic nuclear power plants, press tours at Rivne NPP for regional mass media was conducted twice in 2014 and 2015. The tours were attended by representatives of regional and local TV companies, news agencies, print and electronic mass media, public organizations of Volyn and Rivne regions. A press tour for representatives of central mass media was organized together with the Ukrainian Nuclear Forum Association in 2014 within the frame of EU Sustainable Energy Week. Its topic was “Nuclear power engineering and its impact on climate change”. In 2015, the 4th Summer School of SE NNEGC Energoatom and a tour to the production site for participants of the Spring Nuclear School were held.

In 2014, the information centre held workshops for H&S teachers from district and regional schools, and a meeting with lecturers and students of Lesya Ukrainka Eastern European National University and Ternopil Ivan Puluj National Technical University. A photo competition and a photo exhibition were held, dedicated the 10th anniversary of commissioning of power unit No. 4 of SS Rivne NPP.

Torus are held for the population and visitors of the town:

421 tours for 2,719 people were organized in 2014, and tours for 5,368 visitors in 2015, including 184 tours for 2,499 school-aged children. 588 tours for 5,722 people were organized in 2016, including 283 tours for 3,009 school-aged children. 730 tours for 7,428 people were organized in 2017, including 304 tours for 3,801 school-aged children.

The Information Centre is ranked high among the cultural and recreational establishments of the town and the region in general. It is included in the list of sites to be visited during tours to the West of Ukraine.

Since the major employee pool of our enterprise is represented by young people from the town and adjacent territories, Rivne NPP makes a focus on vocational guidance. For example, the following events were held in 2014:

The department held meetings with representatives of the local authorities and the public of the observation zone. In 2014, tours for people's deputies of the Lutsk City Council and teachers from Lutsk were initiated.

The tradition of competitions among school students extended to the observation area around SS Rivne NPP. The results of the work demonstrate great interest of young people residing in the adjoining territories in topics related to nuclear energy.

Publicity materials are distributed among personnel of SS Rivne NPP, town, district and regional organizations and institutions, and educational establishments.

In 2017, competitions for students from settlements within the observation zone were held: student report competition, “brain ring” quiz “Atomic energy and the world”, and a drawing contest “Peaceful atom unites Ukraine”. Also, a creativity competition named “NPP: building our future together!” for the best colour sketch façade design for the joint auxiliary building (JFB) of SS Rivne NPP was held in 2017.

Employees of the enterprise are informed via station media - radio broadcasts and a newspaper, as well as by electronic means - via an electronic board, a plasma panel at C/P-1, and informational stands at C/P-1, C/P-2, and VLK.

Enerhiia newspaper is published weekly in printed form with an average circulation of 2000 copies and in electronic form on SS Rivne NPP website. Work is in progress to improve the information content of the newspaper. Hourly radio programs are broadcast twice a week (on Tuesday and Friday). Television and radio editors office, in addition to own programs broadcast on the internal channel, create “Pulse of RNPP” programs, which are broadcast on regional television in the cities of Rivne and Lutsk. In 2014, 16 and 78 programs were created and broadcast on the above channels, respectively. In 2015, 16 and 24 programs were created and broadcast on the above channels, respectively. In 2016, 21 and 24 programs were created and broadcast on the above channels, respectively. In 2017, 24 programs were broadcast.

Editorial TV pieces were regularly transmitted to the press service of SE NNEGC Energoatom to be broadcast on national channels. Attention is constantly paid to the issues of safe operation of SS Rivne NPP, preparation and carrying out of planned preventive repairs, financial and economic condition of the plant, coverage of international inspections, namely the IAEA and WANO missions.

Particular attention is focused on the formation of the need to adhere to the safety culture principles in the employees. Issues regarding occupational safety, labour discipline, healthcare, leisure of NPP workers, and social protection were raised. Much attention was paid to the use of funds directed at risk compensation to the population residing in the observation zone around the plant.

In 2014, an advertising campaign to improve the image of the nuclear power industry continued by placement of advertising information on billboards in Rivne, Sarny and Volodymyrets.

Information on the electronic information board (C/P-1) is updated on a daily basis.

The plasma panel displays presentations dedicated to state and professional holidays, covers conferences, peer visits, announcements by the trade union committee, year's results, photo materials on the history of SS Rivne NPP, and cultural events.

I&PR employees participate in events held at SS Rivne NPP or supported by SS Rivne NPP, for the purposes of their media coverage.

In order to present the company, the department employees took part in the exhibition "Energy Forum of Ukraine's fuel and energy sector: present and future".

I&PR specialists as part of the information support team took part in the plant accident prevention training. During the year, the personnel prepared and printed booklets for the Emergency Planning and Response Department, a photo album for the 10th anniversary of commissioning of power unit No. 4, the renewal of the Alley of Labour Glory and the Board of Honour, creative staff of the RTR editor's office created video films dedicated to the anniversary dates of shops and units. I&PR provided full support to SS Rivne NPP in organizing and conducting the "Wear vyshyvanka" campaign dedicated to the Constitution Day and covered this in the media.

In 2017, the employees provided the renovation of the Alley of Labour Glory and the Board of Honour, creative staff of the RTR editor's office created video films dedicated to the anniversary dates of shops and units. I&PR together with the Public Facilities Department (PFD) organized and conducted the patriotic flashmob "Unity Chain" on the eve of the Unity Day of Ukraine and vyshyvanka ethno-runway dedicated to the Constitution Day of Ukraine.

Subscriptions to periodicals for 2015-2018 for workshops and units of the station were conducted within the limits of available funding.

I&PR specialists as part of the information support team take part in the plant accident prevention training in order to improve work with the population and the media in the event of a radiation accident or another emergency.

As part of the ARSMS system implementation, a subsystem for remote monitoring of radiation and technological parameters of SS Rivne NPP was developed and is currently in operation.

Within the boundaries of the SPZ and the OZ of SS Rivne NPP, radiation control is carried out within the framework of the Radiation Control Regulation 132-1-Р-ЦРБ agreed with the Chief State Sanitary Inspector of the facility and the State Nuclear Regulatory Inspectorate of Ukraine. According to the Regulation, about 2,500 environmental samples are taken and measured during the calendar year.

Apart from the laboratory control of the radiation impact of SS Rivne NPP on environment and population, continuous monitoring has been carried out since April 2007 using the automated radiation state monitoring system (ARSMS). 13 ARSMS control stations are installed within the SPZ and the OZ.

Fig. 2.7. Arrangement of settlements within the OZ around the SS Rivne NPP.

In the course of monitoring, control of radioactive releases into the atmosphere, atmospheric air, precipitation, vegetation, needles, soil, agricultural products, dose rates, liquid discharges, water, bottom sediments, fish and algae of the river Styr is carried out. In general, radiation monitoring covers 43 of the 110 settlements within the OZ of SS Rivne NPP.

The Radiation Safety Standards of Ukraine [8] set the dose limits for personnel who directly work with ionizing radiation sources and for the entire population. Dose limit is the main radiation and hygienic standard, which purpose is to limit the personnel and population exposure to all industrial sources of ionizing radiation in practical activities. The population dose limit for radiation from industrial sources is 1 mSv/year, which is several times less than doses of radiation of natural origin. Out of this limit, the NPP has a quota of 8 % for the operation of all power units, regardless of their number.

Regulation and control of population exposure are based on the calculations of annual effective and equivalent radiation doses for critical population groups. A critical group is a portion of the population that, based on its sex and age, social and occupational conditions, place of residence and other features, receives or can receive the highest levels of radiation from a given source.

The limitation of population exposure is carried out by regulating and monitoring the activity of objects of the environment (water, air, etc.), gas-aerosol releases and liquid discharges during the NPP operation. Permissible levels of gas-aerosol releases and liquid discharges have been determined, for which the total annual effective dose in a critical population group representative due to all radionuclides, which are present in releases and discharges, does not exceed the limit dose rate. The established levels are regularly reviewed and agreed with the MoH of Ukraine.

In order to limit the personnel and population exposure below the above dose limits, based on the actual achieved level of radiation well-being, reference release and discharge levels are set at the NPP [11]. The reference levels are based on the analysis of actual releases and discharges over the past 5 years.

In order to react promptly to changes in the activity of releases and discharges, the operating organization, SE NNEGC Energoatom, has set additional indicators: administrative and technological levels. Release levels are set for each power unit during power operation and repairs.

In the process of operation, continuous monitoring is performed for exceedance of administrative and technological, reference and permissible release and discharge levels at SS Rivne NPP, and the activity of anthropogenic radionuclides is compared to the "zero background" value.

Since 2000, the external radiation control laboratory is certified to operate in the field of the environment radiation control. The last regular certification took place in 2015. The validity and adequacy of hardware and methodological support, staffing and personnel classification, workplace setup and compliance with the sanitary requirements were checked. The laboratory is equipped with up-to-date instruments and tools from the world's leading manufacturers. The laboratory is subject to regular inspections with the participation of representatives of the State Committee for Technical Regulation and Consumer Policy of Ukraine. Supervision is carried out through the Sanitary and Epidemiological Service, Nuclear Regulatory Inspectorate of Ukraine, and the State Ecology Department in the region.

Apart from the laboratory control of the radiation impact of Rivne NPP on environment and population, continuous monitoring has been carried out since April 2007 using the ARSMS system. The ARSMS includes:

- 16 control stations at the industrial site of SS Rivne NPP:
    - ✓ 6 stations for gas-aerosol emissions control to measure the dose rate in ventilation stacks, concentration of IRG, iodine, aerosols; perform sampling to determine tritium concentration in the emissions;
    - ✓ 2 stations at the industrial site to measure the dose rate, iodine and aerosol concentration in the air;
    - ✓ 7 stations located on the roofs of primary buildings of the industrial site to measure the dose rate.
- 13 stations within the SPZ and OZ to measure:
    - ✓ dose rate;
    - ✓ iodine and aerosol air concentrations in case of a radiation accident;
    - ✓ sampling of aerosols in atmospheric air, atmospheric fallout for laboratory control;

- ✓ based on the ISS system, ^{137}Cs, ^{60}Co activities, discharged water volume are measured, and water is sampled to determine the concentration of tritium.

The system is in operation since April 2007. The quarterly information on the radiation situation around the NPP is submitted to the State Nuclear Regulatory Inspectorate of Ukraine and to NNEGC Energoatom. Measurements are in accordance with all current requirements, including the requirements of the World Meteorological Organization.

All parameters can be tracked on-line on the website of the RNPP.

For example, mobile laboratories built on the basis of GAZ-3308 trucks are equipped with GPS-navigators to determine their location accurate to 10 meters. They transmit information on-line via satellite communication channels and networks of mobile communications providers.

It is important that RODOS Realtime Online Decision Support System has been introduced at all NPPs within the framework of the Ukraine-EC cooperation program. Experts analyse the radiation situation at the NPP and in the environment, meteorological conditions in the surface air and at altitudes of up to 3 km, even weather forecast information. The introduction of RODOS integrates our country into a global system and allows prompt tracking and responding to possible nuclear events in Ukraine and globally.

ARSMS is in operation 24 hours a day, and performs 22 types of control. Even the fact below suggests high sensitivity and precision of the equipment used.

From 23 March to 10 May 2011, specialists from the radiation safety department of Rivne NPP recorded the presence of microscopic values of radioactive caesium, iodine, tellurium in the air after the nuclear fuel accident at the Fukushima Daiichi NPP. At the same time, the radionuclide concentrations were at levels that were thousandfold below the permissible air values, and therefore posed no threat to the health of the population.

Equipment used to control the population radiation impact measures concentrations that are millionfold below the permissible values for the air content of radioactive elements regulated by the Ministry of Health of Ukraine.

In June 2015, the seismic surveillance system was introduced, and was put into operation at SS Rivne NPP last year. Seismic monitoring within the NPP observation zone is a requirement of the IAEA: it provides data to study the sources of local earthquakes. Seismometers that are located at a depth of 30-90 meters in special wells at the territory of ARSMS control stations, automatically record and localize all significant earth movements. (Even nuclear weapon tests in the DPRK are recorded at Rivne NPP).

Real-time information is transmitted to the Main Control Centre of the State Space Agency of Ukraine and is used to register global seismic events.

Thermoluminescent dosimeters have been installed in settlements within the observation zone of SS Rivne NPP to measure the annual dose of external radiation. Twice a year, dose rates and β-radiation density are measured in these 90 settlements.

As part of the ARSMS system implementation, a subsystem for remote monitoring of radiation and technological parameters of SS Rivne NPP was developed and is currently in operation. Videoframe details are shown in Fig. 2.8.

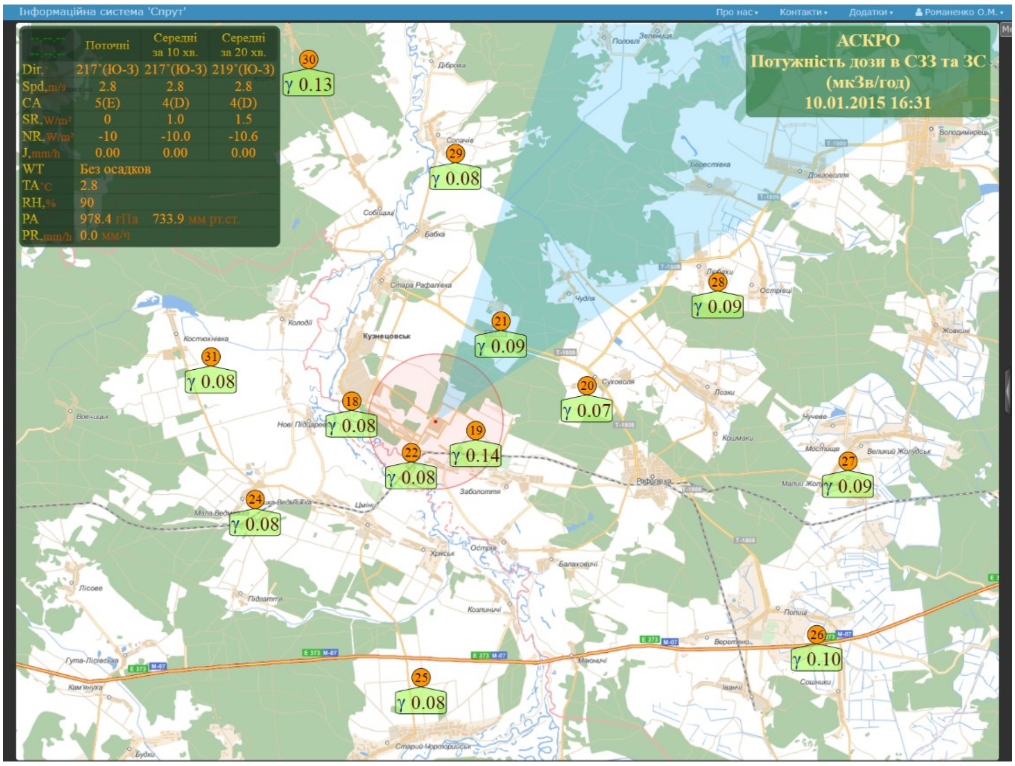

Fig. 2.8. Videoframe detail from the subsystem for remote monitoring of radiation and technological parameters at SS Rivne NPP.

Real-time information is transmitted to Rivne Regional Administration and Rivne Regional Emergency Services and Environment Department. In addition, real-time information on the radiation and meteorological situation is available at SS Rivne NPP website (http://www.rnpp.rv.ua).

3 ANTHROPOGENIC ENVIRONMENT IMPACT

3.1 Brief description of the current state within the observation zone

The major part of the 30 km zone around SS Rivne NPP is occupied by territories of two districts: Manevytskyi (Volyn Region) and Volodymyretskyi (Rivne Region). Agriculture in the regions specializes in grain crop production and meat and dairy cattle breeding. Agricultural lands in both districts are located mainly on soddy-podzolic soils.

Manevytskyi District is situated in the northern part of the Polissia lowland, which is particularly marshy. 25,000 hectares of marshy areas in the district have been drained, which currently represents about one third of the agricultural lands. 17 communal households of different ownership forms in Manevytskyi District are within the observation zone, and, due to the change of the land ownership, there is an ongoing restructuring of communal households. The area of arable lands tends to reduce due to the acute shortage of resources. The agricultural soils are poor; several-fold increase in their yields is possible trough fertilizing, but the households lack funds for the necessary agrotechnical measures.

There are 53,000 hectares of agricultural land in the district, of which 31,500 hectares are for arable land, while the crop area, for the above reason, made only 18,500 hectares in 1999. The number of meat and dairy cattle at communal households has reduced more than four times, and a decrease in the average milk yield per cow is observed. The reason for these negative trends is the lack of feeds and feed additives, as well as the use of low productivity cattle breeds.

In the Volodymyretskyi District, 23 communal households are within the observation area around SS Rivne NPP, with 51,500 hectares of agricultural land, of which about 30,000 hectares are of arable land and about 18,000 hectares - of crop area. The livestock population was 27,700 heads in 1995 and 5,700 heads in 1999, and the average milk yield per cow has also decreased.

Analysis of the existing situation in the agricultural production in the 30 km zone around SS Rivne NPP suggests that there is a need for significant investments to improve soil fertility, feed supplies and breeding activities in livestock production. Therefore, the situation in the agricultural sector depends on the general state of the national economy.

Industry on the territory under consideration is represented by food industry enterprises (bakery plants, dairy plants), construction material enterprises, quarries and a peat plant, motor transport enterprises, and a road construction management office.

Industry within the 30 km zone around SS Rivne NPP is represented by food industry enterprises (bakery plants, dairy plants), construction material enterprises, quarries and a peat plant, motor transport enterprises, and a road construction management office [6]. A section of the Kyiv-Kovel railway line passes 150 m south of the industrial site of the NPP. The nearest railway station Rafalivka is 5 km east of the NPP. Kyiv-Kovel state motor road passes about 20 km south of the industrial site of the NPP. There are also several gas stations, Rafalivskyi Karier PubJSC (a quarry) for the extraction of sand, gravel, clay and kaolin, Polytskyi basalt quarry, etc. within the OZ around SS Rivne NPP. In total, there are 28 industrial facilities within the OZ around SS Rivne NPP: 13 in the Volyn Region and 15 in the Rivne Region.

Public institutions are concentrated in the Town of Varash. Housing fund within the 30 km zone (except for Varash) is represented by one-story buildings with a significant degree of wear. Residential construction is not provided with district water supply, sewage and heat supply networks, even in district centres (Manevychi and Volodymyrets). Public institutions located within the zone (except for Varash) also have no utility support.

The emissions of air pollutants from the stationary sources are carried out on the basis of the permits issued by regional representatives of the Ministry of Environmental Protection of Ukraine No. 5620881201-1 and permits issued by the Department of Ecology and Natural Resources of the Rivne Oblast State Administration: № 5610700000-8 dated 23.09.2013 (validity period – 5 years), 5610700000-11 dated 27.12.13 (validity period - 5 years), 5610700000-12, 5610700000-13 dated 24.10.2014 (validity period is not limited), 5610700000-14 dated 24.10.2014 (validity period - 10 years) and permit number 5610700000-16 dated 24.10.2014 (validity period is not limited)To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for air emissions from stationary sources has been developed, approved by the Department of Ecology and Natural Resources of the Rivne Regional State Administration.

14 sources of air emissions are equipped with gas treatment units (GTU). Certificates were provided for each GTU. Gas treatment equipment is operated in accordance with the Regulations on Technical Operation of Gas Treatment Units. Persons responsible for the technical operation of GTUs were appointed by order of the Director General of SS Rivne NPP. In accordance with the design documents and working conditions, operating manuals for each GTU were developed and approved. Daily time records are kept for each GTU.

Annual reports are submitted to the Main Statistics Department and the Department of Ecology and Natural Resources of the Rivne Regional State Administration according to the form 2-TP (air). Reports are developed using a calculation method based on the data on the use of raw materials, fuel, materials, and equipment operating time. During the year, stationary sources of SS Rivne NPP release 33 to 37 t of pollutants into the air, including:

- non-methane volatile organic compounds - 18-25 t;
- nitrogen compounds - 5-9 t;
- substances in the form of suspended solid particles (microparticles and fibres) - 1.4-2.7 t;
- sulphur compounds - 1.4-2.7 t, etc.

Air pollutant emissions from the NPP are 2-3 thousand times less than that from a coal-fired TPP with a similar installed capacity.

Sampling and monitoring of the radionuclides content in the surface air are carried out in accordance with the radiation control regulations in force at Rivne NPP once every 10 days at 16 control stations. The volumetric activity of anthropogenic radionuclides in atmospheric air over 37 years of observations did not exceed the standard values as per NRBU-97. The volumetric activity for ^{90}Sr and ^{137}Cs is within the “zero background”.

Operation of SS Rivne NPP has no adverse impact on the existing agricultural, industrial and civil buildings.

Public institutions located within the zone (except for Varash) have no utility support.

The total area of residential buildings and the main civilian facilities in Varash and in the Volodymyrets and Manevychi district centres are presented in Table 3.1.

Table 3.1. Main civilian facilities in settlements within the 30 km zone around the SS Rivne NPP.

Name of settlement	Total housing area, m^2	Hospitals	Community centres, clubs	Schools	Kindergartens
Town of Varash	598,719	1*	3	7	12
Sett. of Volodymyrets	126,669	1**	6	6	3
Sett. of Manevychi	129,540	2	2	2	-

*- the specialized primary healthcare unit No. 3 has a transfusion department, Kuznetsovsk Town District Laboratory Research Department of SE Rivne Regional Laboratory Centre of the State Sanitary and Epidemiological Service of Ukraine, Kuznetsovsk Interdistrict Disability Evaluation Board.A network of pharmacies, dental offices, ultrasound and massage rooms is being developed in the town. A health care centre operated at Rivne NPP and insurance medicine is being actively developed.

In Varash, an English language school, language club, public library, libraries for children and youth, dance theatre school, modern choreography school, photo and video school, 12 kindergartens, 7 schools (including one gymnasium), as well as “Signal” driving school in Rafalivka and massage courses were established and operate. Sports facilities include “Energetic” swimming pool, CYSS of the Department of Education and CYSS at Rivne NPP, as well as vocational training centres VTC No. 1 and VTC No. 10.

** Volodymyrets CDH runs a transfusion department, Volodymyretskyi District Department of Kuznetsovsk Town District Department of Laboratory Research of SE Rivne Regional Laboratory Centre of the State Sanitary and Epidemiological Service of Ukraine.

A network of pharmacies, veterinary pharmacies and medical centres is being actively developed in Volodymyrets and the region in general. The town has an optical store, a paediatrician’s office, dental offices, “Rodolad” private family medical centre, health insurance companies, etc. District department of Professional Disinfection Communal Enterprise operates in Volodymyrets.

Within the 30 km zone around SS Rivne NPP in the Volodymyretskyi District, medical facilities operate in Rafalivka, the villages of Kidra, Ozero, Velyki Tseptsevychi, and there are MOS in the villages of Sobishchytsi, Krasnosillia, Lypne, and Kanonychi.

In Volodymyrets, the following educational facilities operate: inter-town vocational training centre; Volodymyrets District College, and an experimental education institution of the all-Ukrainian level.

In Manevychi, only 2 medical facilities operate: Manevychi Central District Hospital and Manevychi District Primary Healthcare Centre. The settlement has the Manevychi Children’s and Youth Sports School, a general education school levels I through III and a gymnasium. There also is a District Community Centre and a Department of Culture at Manevychi District State Administration.

3.2 Historical and cultural landmarks

The inventory of historical and cultural landmarks is based on the register of state-protected landmarks, i. e. they have a certain status, represent a resource for recreational activities and tourism and are of high scientific value.

Only landmarks of 3 categories that are located within the 30 km observation zone around Rivne NPP are included in the list of historical and cultural landmarks [75]: archaeological landmarks, architectural landmarks and memorial monuments.

Archaeological landmarks are mainly represented by barrows and ancient settlements of 1 thous. years B. C to 11-13th ct. A. C. [76]. These are mainly Kyivan Rus and early Slavic monuments.

The barrows are well represented visually and are considered as both tourist resources and cultural landscape elements.

Architectural landmarks are not numerous, and are represented by buildings of worship of 17-18th ct. (Dominican Church and St. Nicholas Church) [77].

Memorial monuments [78] are mainly represented by Civil War and WW2 mass graves or monuments to fallen fellow villagers. These are mainly concentrated in Manevychi and in the Village of Kolky in Manyvytskyi District of the Volyn Region, and in Volodymyrets and Rafalivka in the Volodymyretskyi District of the Rivne Region.

Archaeological landmarks [79]:

Volyn Region, Manyvytskyi District:

1. Sett. of Volodymyrets - 12-14th ct. B. C. barrow hill (4 km south-west).
2. Village of Starosillia - 9-13th ct. barrow.
3. Village of Staryi Chartoryisk - 11-12th ct. ancient settlement.

Rivne Region, Volodymyretskyi District:

1. Sett. of Volodymyrets - 12-14th ct. B. C. barrow hill (4 km south-west).
2. Village of Babka - 9-10th ct. ancient settlement (1.5 km south-east).
3. Village of Horodets - 11-12th ct. ancient settlement (railway bridge over the river Horyn).
4. Village of Zelenytsia - 1st ct. B. C. - 1st ct. A. C. barrow (Podkozel common).

The total of 7 archaeological landmarks are located within the 30 km zone. Most of them are concentrated southwest from SS Rivne NPP (Table 3.2). Sectors: north (N), north-east (NE), east (E), south-east (SE), south (S), south-west (SW), west (W), north-west (NW).

Table 3.2. Distribution of archaeological landmarks within the 30 km zone around SS Rivne NPP by sectors in the OZ.

Zone, km	Sector							
	S	NE	E	SE	S	SW	W	NW
0-10	1	-	-	-	-	-	-	-
10-20	-	2	-	-	1	-	-	-
20-30	-	-	-	-	-	1	1	-

Architectural landmarks:

Volyn Region, Manyvytskyi District:

1. Village of Staryi Chartoryisk - Dominican Church (1639).

Rivne Region, Volodymyretskyi District:

1. Village of Stara Rafalivka - Mykolaivska Church (18th ct.).

The total of 2 architectural landmarks are located within the 30 km zone around SS Rivne NPP: one in the south (10-20 km zone) and one in the north (0-10 km) sectors.

Historical and cultural landmarks [80]:

Historical and cultural landmarks are mainly represented by monuments to fallen fellow villagers, Fascism and Nazism victims, and beds of honour in the following settlements:

Volyn Region, Manevytskyi District:

1. Sett. of Manevychi
2. Village of Budky
3. Village of Velyka Vedmezhka
4. Village of Velyka Osnytsia
5. Village of Velyka Yablunka
6. Village of Kolky
7. Village of Komarovo
8. Village of Kostiukhnovka
9. Village of Krasnovolia
10. Village of Kukly
11. Village of Mala Osnytsia
12. Village of Prylisne
13. Village of Starosillia
14. Village of Staryi Chartoryisk
15. Village of Tsmyny

Rivne Region, Volodymyretskyi District:

1. Sett. of Volodymyrets
2. Sett. of Rafalivka
3. Village of Antonivka
4. Village of Balakhovychi
5. Village of Bilska Volia
6. Village of Velyki Telkovychi
7. Village of Velykyi Zholudsk
8. Village of Voronky
9. Village of Horodets
10. Village of Dovhovolia
11. Village of Zhovkiny
12. Village of Zabolottia
13. Village of Krasnosillia
14. Village of Lozky
15. Village of Liubakhy
16. Village of Mulchyntsi
17. Village of Novaky
18. Village of Ozero
19. Village of Ozertsi
20. Village of Ostrovtsi
21. Village of Polytsi
22. Village of Romeiky
23. Village of Rudka
24. Village of Svaryny

25. Village of Sopachiv
26. Village of Stara Rafalivka
27. Village of Sukhovolia

There are total 49 monuments, which are evenly distributed within zones and sectors (Table 3.3). Sectors: north (N), north-east (NE), east (E), south-east (SE), south (S), south-west (SW), west (W), north-west (NW).

Table 3.3. Distribution of memorial monuments within the 30 km zone around SS Rivne NPP by sectors in the OZ.

Zone, km	Sector							
	S	NE	E	SE	S	SW	W	NW
0-10	2	-	5	2	-	2	-	-
10-20	2	6	2	1	3	2	1	-
20-30	2	4	4	-	1	6	3	1

The territory within the 30 km observation zone of SS Rivne NPP is characterized by a relatively weak density of historical and cultural landmarks (the density factor is 0.34). The territorial structure is represented by centres of three categories.

First category (A) centres that include monuments of all types - only one in Staryi Chartoryisk, second category (B) centres that include monuments of two types in any combination - three: Volodymyrets and Starosillia of Manevytskyi District have both memorial monuments and archaeological landmarks, and Stara Rafalivka in the Volodymyretskyi District - memorial and architectural monuments. Other settlements (39) are centres of the third category (C) with the monuments any other type. The overwhelming majority is represented by memorial monuments: the villages of Babka and Zelenytsia of Volodymyretskyi District and the Village of Horodok of Manevytskyi District have archaeological landmarks (Table 3.4).

Table 3.4. Combination of landmarks and categories of centres within the 30 km zone around SS Rivne NPP.

Combination of landmarks	Categories of centres
1 - memorial monuments	A - first
2 - archaeological landmarks	B - second
3 - architectural landmarks	C - third

<u>Volyn Region, Manevytskyi District:</u>

1. Sett. of Manevychi - 1/C (combination of landmarks/centre category)
2. Village of Budky - 1/C
3. Village of Velyka Vedmezhka - 1/C
4. Village of Velyka Osnytsia - 1/C
5. Village of Velyka Yablunka - 1/C
6. Village of Horodok - 2/C
7. Village of Kolky - 1/C

8. Village of Krasnovolia - 1/C
9. Village of Komarovo - 1/C
10. Village of Kukly - 1/C
11. Village of Kostiukhovka - 1/C
12. Village of Mala Osnytsia - 1/C
13. Village of Prylisne - 1/C
14. Village of Staryi Chartoryisk - 1,2,3/A
15. Village of Starosillia - 1,2/B
16. Village of Tsmyny - 1/C

Rivne Region, Volodymyretskyi District:

1. Sett. of Volodymyrets - 1,2/B
2. Sett. of Rafalivka - 1/C
3. Village of Antonivka - 1/C
4. Village of Bilska Volia - 1/C
5. Village of Vel. Telkovychi - 1/C
6. Village of Babka - 2/C
7. Village of Velykyi Zholudsk - 1/C
8. Village of Balakhovychi - 1/C
9. Village of Voronky - 1/C
10. Village of Horodets - 1,2/B
11. Village of Dovhovolia - 1/C
12. Village of Zhovkyny - 1/C
13. Village of Zelenytsia - 2/C
14. Village of Zabolottia - 1/C
15. Village of Krasnosillia - 1/C
16. Village of Lozky - 1/C
17. Village of Liubakhy - 1/C
18. Village of Mulchytsi - 1/C
19. Village of Novaky - 1/C
20. Village of Ozertsi - 1/C
21. Village of Ozero - 1/C
22. Village of Ostrivtsi - 1/C
23. Village of Polytsi - 1/C
24. Village of Rudka - 1/C
25. Village of Romeiky - 1/C
26. Village of Sopachiv - 1/C
27. Village of Stara Rafalivka - 1,3/B
28. Village of Sukhovolia - 1/C
29. Village of Svaryny - 1/C

Of the total number of landmarks within the 30 km zone, 13 landmarks (22.5 %) are located within the 10 km zone, 21 (36.2 %) within the 10-20 km zone, and 23 (41.3 %) within the 20-30 km zone. Landmarks are distributed more evenly within the sectors, although they are mainly located in 6 sectors of 8 (93 %), except for the south-east and north-west sectors. More than half of the landmarks (53 % or 31 landmarks) are concentrated in the north, north-east and east sectors;

22 landmarks (40 % of the total number in the 30 km zone around SS Rivne NPP) are concentrated in the south, south-west and west sectors.

Let's proceed with the analysis and assessment of the potential damage to the objects of the historical and cultural fund due to an accident at the NPP.

The following scenarios are roughly defined:

1. The contamination level does not affect the integrity and function of the objects.
2. The contamination level leads to a complete withdrawal of the 30 km zone from economic use. In this case, archaeological landmarks can be damaged or destroyed during decontamination works, completely excluded from tourist and recreational activities; their use for scientific purposes can be extremely limited and will require additional expenses for safety measures, allowances for hazardous works, etc. Architectural landmarks can suffer damages similar to archaeological landmarks, but in addition, without proper supervision can be affected by accidental fires, acts of vandalism and natural destruction. Access to memorial monuments will be restricted.
3. Intermediate scenario - contamination is differentiated based on the particular accident type. The probability of contamination of the territory depends on the distance from the contamination epicentre and distribution of the radioactive transfer. The specific contamination levels in this case are probabilistic and can have an unlimited number of scenarios. Based on the above, the level of damage to landmarks within the impact zone of the NPP may not be subject to a specific monetary evaluation, but is distributed based on the relative loss according to the probabilistic principle.

The methodology involves a relative assessment of landmarks based on their categories and uncertain contamination of their locations within the zone. Relative expert evaluation by landmark categories reflects their value by exponential distribution:

- memorial monuments - 1 point;
- archaeological landmarks - 3 points;
- architectural landmarks - 9 points.

The total score was based on the segments of concentric zones (0-10, 10-20, 20-30 km) within 8 sectors:

- north (N), north-east (NE), east (E), south-east (SE), south (S), south-west (SW), west (W), north-west (NW) (Table 3.5).

Table 3.5. Expert evaluation of historical and cultural landmark value within the 30 km zone around SS Rivne NPP by sectors within the OZ.

Zone, km	Sector							
	S	NE	E	SE	S	SW	W	NW
0-10	14	-	5	2	-	2	-	-
10-20	2	12	2	1	15	2	1	-
20-30	2	4	4	-	1	9	7	1

The distribution of contamination within the zone depends on the distance from the source of contamination and submits to the dispersion law (inversely proportional to the square of the distance), which is confirmed by the empirical data on the analysis of contamination from the Chornobyl NPP. The probability of contamination should be consistent with the frequency of wind directions by sectors.

Data from weather stations at Manevychi and Sarny for 1966-1997 were used for analysis.

Weather station of Manevychi is located in the western part of the 30 km zone around SS Rivne NPP, and weather station of Sarny is nearest to the 30 km zone: SS Rivne NPP site is located to the east from it, so that the Manevychi station, SS Rivne NPP site and the Sarny station are arranged along the same line. Therefore, the data on the frequency of winds from the Manevychi and Sarny weather stations for SS Rivne NPP were interpreted by interpolation taking into account their distance from SS Rivne NPP site (Table 3.6).

Sectors: north (N), north-east (NE), east (E), south-east (SE), south (S), south-west (SW), west (W), north-west (NW).

Table 3.6. Frequency of wind directions (% year) and data interpolation.

Weather station	Direction (rhumb)							
	N	NE	E	SE	S	SW	W	NW
Manevychi	9.6	5.9	10.4	14.7	12.0	12.3	20.4	14.6
Sarny	10.3	6.7	8.8	13.8	15.3	13.0	19.4	12.7
SS Rivne NPP (interpolation)	9.8	6.2	9.9	14.4	13.1	12.5	20.1	14.0

The percentage distribution of the frequency of wind directions per year by rhumb shows that the north, north-east and east wind directions provide a downward bias from the average level (from 20 to 50 %). Accordingly, the south, south-west and west sectors of the 30 km zone are the safest ones in terms of the radioactive transfer. Among other sectors, where the frequency of winds exceeds the average value, the most dangerous are east (20.1 %), north-west (14.4 %) and south-east (14.0 %) sectors.

The probabilistic contamination density factors for sectors in concentric zones were calculated according to the formula and are given in Table 3.7:

$$\mathbf{B_{vz} = P / R^2,}$$

Where:

B_{vz} is the probabilistic contamination density factor;

P is wind frequency by sector, % per year;

R is the remoteness to the source of contamination, km/10 km.

Table 3.7. Probabilistic contamination density factors within the 30 km zone around SS Rivne NPP by sectors of the zone (expressed in magnitude)

Zone, km	Sector							
	S	NE	E	SE	S	SW	W	NW
0-10	52.4	50.0	80.4	56.0	39.2	24.8	39.6	57.6
10-20	5.8	5.6	8.9	6.2	4.4	2.8	4.4	6.4
20-30	2.1	2.0	3.2	2.2	1.6	1.0	1.6	2.3

Probabilistic losses were assessed by introducing an appropriate contamination factor in the assessment of landmarks by zones and sectors (Table 3.8).

Table 3.8. Expert evaluation of probabilistic losses (expressed in magnitude).

Zone, km	Sector								
	S	NE	E	SE	S	SW	W	NW	Total
0-10	733.6	0	402	112	0	49.6	0	0	1297.2
10-20	11.6	67.2	17.8	6.2	66	5.6	4.4	0	178.8
20-30	4.2	8	12.8	0	1.6	9	11.2	2.3	49.1
Total	749.4	75.2	432.6	118.2	67.6	64.2	15.6	2.3	1525.1

Historical and cultural landmarks in the north, east and south-east sectors are within the zone of possible losses (probabilistic loss - 1300.2 points, which is 85.3 % of the total probabilistic damage). One of the "dangerous" sectors, the north-west sector, had the lowest density of landmarks, and therefore probabilistic damage indicators here are minimal. Also, a relatively small loss is possible in the west sector.

The maximum probabilistic loss in the north sector of the 10 km zone is due to a complex of valuable landmarks in the villages of Stara Rafalivka (18^{th} century St. Nicholas Ch=0(9-10^{th} century acient settlement) in the Volodymyretskyi District.

The results of the analysis of probabilistic contamination in the zone and probabilistic loss suggest the asymmetry between the distribution of landmarks by zones and sectors and the field of probabilistic contamination: isolines of the probabilistic contamination field go along the north-west - east, south-east axis, while the greatest density of landmarks of all types observed along the south-west - east, north-east axis.

The evaluation with respect to SS Rivne NPP has only the scientific and methodological significance as a demonstration of the possibilities of the method used to calculate the possible damage to the objects of the historical and cultural fund, since even in the beyond design basis accident scenario as described in the EIA, the contamination of the territory will not exceed the limits of Scenario 1 of this methodology (zero loss).

3.3 Impact on man-made objects

During normal operation, the impact of SS Rivne NPP on the anthropogenic environment is limited by the following factors:

- activities and infrastructure that may develop in adjacent territories of the NPP are restricted for security reasons: such restrictions include, in particular, potentially hazardous activities, recreational activities, flying objects, transportation of hazardous substances;
- the presence of the NPP promotes local economy, small and medium-sized businesses, providing direct or indirect services related to operations of the NPP;
- SS Rivne NPP satellite town profits from certain infrastructure investments by the NPP.

Harmful air releases and water discharges, thermal releases and discharges, as well as water consumption by the NPP do not significantly affect the anthropogenic environment.

In the case of design basis accidents at SS Rivne NPP, including the MDBA, their negative impact on the man-made objects will not exceed the permissible limits and will not require any special measures.

In the case of an analysed beyond design basis accident, temporary restrictions on the use of food produced within a restricted area along the accidental radioactive trail may be necessary.

So, during normal operation, SS Rivne NPP does not produce an adverse impact on the anthropogenic environment.

3.4 Impact of man-made objects on SS Rivne NPP operations

According to the Code of Civil Protection of Ukraine [81], anthropogenic security characterizes the state of protection of population and territories against anthropogenic emergencies.

The reliability of the operation of NPP buildings and structures depends on the stability of geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability - once in 100 years): magnitude 5, maximum estimated earthquake (probability - once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

The construction site of SS Rivne NPP was selected in 1965 by the government commission as the most favourable site in the Rivne Region of the Ukrainian SSR based on the entire set of all factors, in particular geotechnical. The site was selected in compliance with all regulatory requirements then in force, and agreed upon with the ministries and departments concerned. Over 1800 wells were drilled during the design process. No caverns were found during the survey of the territory.

However, in April 1982, a crater with a diameter of 3 m and a depth of 2.5 m was formed in the excavation for workshop in the special building of unit No. 3, which was under construction. The results of additional geotechnical surveys demonstrated that karst-suffosion processes in the geological section of SS Rivne NPP site in chalk rocks (depth of occurrence of 25 ÷ 40 m) are possible. In connection with the individual manifestations of this process that occurred at SS Rivne NPP site, the commission formed by the Council of Ministers of the USSR in 1983 and the Ministry of Energy of the USSR determined the appropriate measures to ensure reliable and safe operation of operating power units No. 1 and No. 2, unit No. 3 (which was under construction), and unit No. 4 (which was on the design stage).

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;

- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Essential structures of power unit No. 4 were built on piles, which are based on basalts and, consequently, completely cut through the layer that is exposed to karst processes, which ensures the reliability of their operation. Soil cementation was carried out under the rest of buildings and structures of power unit No. 4.

On 20 April 2002, a meeting of an independent expert group chaired by V. M. Shestopalov, Member of the National Academy of Sciences of Ukraine, was held at SS Rivne NPP to discuss the geotechnical state of the industrial site and base soils of structures at Rivne NPP. The following was established by the expert group:

- the structures were operated in a stable mode, levels of soil subsidence and core samples from the buildings over the entire period of operation were well below the design values;
- the efficiency of the anti-karst measures under buildings of power units No. 1-3 (in particular, cement grouting of the chalk layer) is confirmed with time;
- continuous attention at SS Rivne NPP was paid to the geological and anthropogenic state of the environment and to the reliability of operation of the buildings;
- the possibility of building power unit No. 4 on piles based on basalts, which will cut through the chalk layer, raises no doubts.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of geological environment and is the key factor for ensuring safe operation of SS Rivne NPP.

In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:

- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;
- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuously cooperates with leading scientific organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Annual reports are drawn up based on the works performed.

Within the frame of extension of operational lifetime of power units No. 1 and No. 2, SE Kyiv Institute of Engineering Surveys and Research “ENERGOPROEKT” performed a set of geotechnical surveys and geophysical soil studies in 2008. According to the results of the studies, Scientific and Technical Report on Geotechnical Survey (a comprehensive analysis of the soil conditions at the bases of buildings and structures) 14-349/07-08, 10-439.1 was issued with a positive conclusion on further safe operation of buildings and structures [82].

Within the frame of extension of operational lifetime of power unit No. 3, SE Kyiv Institute of Engineering Surveys and Research "ENERGOPROEKT" developed Scientific and Technical Report on Complex Geotechnical and Geophysical Survey 14-126-08, 10-726-1 [83] in 2014. The results of the studies suggested that the engineering and geological situation within the structures of power units No. 1-3 are in line with the operational lifetime extension, namely:

- karst monitoring did not record any active karst processes;
- the observation data on subsidence of buildings did not exceed the permissible values;
- according to hydrogeological monitoring data, the hydrogeological situation is characterized as stable and controlled by all indicators;
- soil condition ensures reliable operation of structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013- 2016.

According to the results of the surveys, specialists of Prydniprovska State Academy of Civil Engineering and Architecture issued positive opinion on further extension of operation of power unit buildings and structures. Decisions on further operation of power unit buildings and structures were agreed with the SNRIU.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

3.5 Justification of anthropogenic environment preservation activities

The assessments have shown that the major share of gas-aerosol release within the dose during operation of power units of SS Rivne NPP will be by inert gases through irradiation from the cloud. The maximum annual average concentrations of these radionuclides in the air were obtained in the east direction at a distance of about 1.5 km from the plant. They made: 1.351×10^{-11} Ci/m^3 (0.5 Bq/m$^{3)}$ for ^{133}Xe; 2.703×10^{-13} Ci/m^3 (0.01 Bq/m^3) for ^{85}Kr; 5.406×10^{-14} Ci/m^3 (0.002 Bq/m^3) for ^{41}Ar.

Non-exceedance of the effective dose of 100 mrem/year (1 mSv/year) for population (Category B) is possible when maximum air concentrations of these radionuclides are as follows: 26.489×10^{-8} Ci/m^3 (9.8 kBq/m^3) for ^{133}Xe; 54.06×10^{-8} Ci/m^3 (20 kBq/m^3) for ^{85}Kr; 0.973×10^{-8} Ci/m^3 (0.36 kBq/m^3) for ^{41}Ar, which is 10^3-10^6 times higher than the maximum design concentrations of radioactive noble gases (RNG) during normal operation of the power units.

Preservation of the anthropogenic environment is provided by a number of special measures. They include:

- layout and design measures;
- safety systems are provided in accordance with the staged protection principle;
- system for possible discharge and release monitoring;
- organization of operation in accordance with the regulations and instructions that prohibit work in case of violation of safe operation limits;
- emergency planning system.

The radiation impact of the NPP on the environment, including anthropogenic environment, is assessed by radiation monitoring of both sources of possible radiation contamination (discharges and releases by the NPP) and the radiation situation affected, for which purpose systems for observation of underground and surface water, soil condition and geological processes were also developed and are in operation.

A public alert system is in place within the 30 km zone.

CONCLUSIONS

The reliability and efficiency of power generation by nuclear power plants are recognized worldwide. Considering the instability of world markets and rising prices for gas, oil and coal, the importance of nuclear power to fulfil the needs of the manufacturing sector and the population by providing relatively cheap electricity is ever increasing.

Each year, the power plant supplies about 19 billion kilowatt hours of electricity to the country's integrated power system and adds almost UAH 25 million to local budgets for social and economic compensation to the population of the observation zone.

Rivne NPP is the nearest NPP to the neighbouring countries located approximately 60 km from the border with the Republic of Belarus and 130 km from the Republic of Poland.

In 1973, the density of population in this territory was 55 persons/km^2, while today's population in Varash is 3,684 persons/km^2.

Each year, SS Rivne NPP generates about 13 % of the total electricity amount produced in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Town of Varash and Village of Zabolottia.

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008, 2009, 2010) and World Association of Nuclear Operators (WANO) (2001, 2004, 2005, 2012, 2014, 2015, 2016, 2018).SPZ dimensions are determined taking into account radiation situation assessment in the area around the NPP during long-term operation.

SPZ of SS Rivne NPP is limited within the radius of 2.5 km around radiation-hazardous objects. The size of the observation zone is 30 km.

NPP safety systems ensuring protection of the population during accidents, including design basis accidents with the most severe consequences, are designed in a way that the values of equivalent individual doses calculated for the worst weather conditions on the SPZ border and beyond it do not exceed 3 mSv/year for thyroid gland in children due to inhalation intake and 1 mSv/year for the entire body due to external exposure [6].

Radiation control within the OZ is carried out as per Rivne NPP Radiation Control Regulations 132-1-Р-ЦРБ [7] approved by Senior Vice-President, Chief Technology Officer of SE NNEGC Energoatom on 2 February 2016 and agreed by letter from State Nuclear Regulatory Inspectorate of Ukraine No. 15-28/7070 dated 25 October 2016 as approved by Head of Varash Interdistrict Department of Rivne Regional Laboratory Centre of State Sanitary and Epidemiologic Service of Ukraine HQ on 8 July 2016 and Director General of SS Rivne NPP on 5 July 2016.

The major priority of the activity is safe generation of environmentally friendly thermal and electric energy.

SS Rivne NPP implements annual safety improvement plans and international projects.

Rivne NPP ensures preservation of jobs in other fields, which is vitally important for stability and revival of Ukraine's economy.

Design and actual values of NPP radioactive contamination demonstrate that additional impact is low as compared with natural background radiation and makes one-tenth of the permissible value.

Ventilation air released through vent stacks of the NPP is thoroughly decontaminated and is virtually free of substances that may change the air composition.

Normal operation of SS Rivne NPP produces no adverse impact on the population health, and will produce no such impact in future.

Even during the accident maximum estimated radiation doses are well below the justifiability limit for population evacuation as per current regulations (50 mSv for the entire body).

Following the implementation of the program for improving the safety of power units at the NPP, the safety level has improved, which also means reduced risk of accidents that could potentially affect the health of personnel and population.

In addition, reduction of the risk of accidents should reduce the level of stress related to working or residing near the NPP, which will positively affect the psychological state of the employees and the population in the surrounding areas. For this influence to be effective, the population of the area around the NPP must be aware of the safe operation of SS Rivne NPP.

Therefore, the results obtained during the environmental impact assessment of SS Rivne NPP site are expected to have a positive but insignificant impact on employment in SS Rivne NPP area.

The activities of SS Rivne NPP are acceptable, and the impact on the social and anthropogenic environment is environmentally acceptable.

LIST OF REFERENCES

1. «Атомна енергетика»/Українська радянська енциклопедія: у 12 т./гол. ред. М. П. Бажан ; редкол.: О. К. Антонов та ін. — 2-ге вид. — К. : Головна редакція УРЕ, 1974–1985.
2. «Атомна енергетика» / Енциклопедія сучасної України : у 30 т./ред. кол. І. М. Дзюба [та ін.] ; НАН України, НТШ, Координаційне бюро енциклопедії сучасної України НАН України. — К., 2003.–2016.
3. Закон України «Про використання ядерної енергії та радіаційну безпеку».
4. Постанова Кабінету Міністрів України від 17.10.1996 р. № 1268 «Про створення Національної атомної енергогенеруючої компанії «Енергоатом».
5. ДБН В.1.1-12:2014. Будівництво у сейсмічних районах України.
6. Нетехнічне резюме. Матеріали з обґрунтування безпеки продовження терміну експлуатації енергоблоку № 3 ВП «Рівненська АЕС» у понадпроектний термін, 2018 р.- 57 с.
7. «Рішення про розміри та межі санітарно – захисної зони та зони спостереження Рівненської АЕС», № 132-1-Р-11-ЦРБ.
8. ДНГ 6.6.1.-6.5.061-98 «Норми радіаційної безпеки України (НРБУ-97)», МОЗ України, м. Київ, 1998.
9. Енергетична стратегія України на період до 2030 року.
10. Режим доступу: https://www.rnpp.rv.ua/assets/DocSite/czentr/Raes_1_23.pdf.
11. ДСП 6.177-2005-09-02. Основні санітарні правила забезпечення радіаційної безпеки України (ОСПУ-2005).
12. «Регламент радіаційного контролю Рівненської АЕС» 132-1-Р-ЦРБ, 2016 р.
13. Шкала MSK-64
14. Головне управління статистки у Рівненській області, ресурс доступу:https://www.kuznetsovsk-rada.gov.ua/ofitsijna-informatsiya/1161-sotsialno-ekonomichne-stanovishche-m-varash-u-sichni-2017-roku
15. код доступу: http://mistaua.com/
16. Рафаловка / Большая советская энциклопедия. Главн. ред. А. М. Прохоров, 3-е изд. Тома 1-30. — М.: «Советская энциклопедия», 1969–1978. (рос.).
17. коддоступу:http://2001.ukrcensus.gov.ua/regions/select_reg1/?box=1.1W&data=1&botton=cens_db&k_t=07&rn=07236
18. код доступу: http://demoscope.ru/weekly/ssp/sng89_reg2.php
19. коддоступу:https://uk.wikipedia.org/wiki/%D0%9A%D1%80%D0%B0%D0%B2%D1%87%D1%83%D0%BA_%D0%9F%D0%B5%D1%82%D1%80%D0%BE_%D0%90%D0%B2%D0%BA%D1%81%D0%B5%D0%BD%D1%82%D1%96%D0%B9%D0%BE%D0%B2%D0%B8%D1%87
20. Довідник з агрохімічного та агроекологічного стану ґрунтів України. –К., 1994 р.
21. Атлас. Україна. Радіоактивне забруднення/ Міністерство надзвичайних ситуацій України та ТОВ «Інтелектуальні системи ГЕО», 2011 -52 с.
22. Атлас загрязнения Европы цезием после Чернобыльской аварии. –Люксембург: Люксембургское бюро официальных изданий Комиссии Европейских Сообществ, 1998. -175 с.
23. Атлас радиоактивного загрязнения Европейской части России, Белоруссии и Украины. – М.:Федеральная служба геодезии и картографии России, 1998. -143 с.
24. Методические рекомендации по комплексной оценке состояния здоровья детей и подростков при массовых врачебных осмотрах:/ Ин-т гигиены детей и подростков МЗ СССР.-М.,1982.-17с.

25. Бердник О.В. Використання комплексного показника «група здоров'я дітей» при оцінці впливу навколишнього середовища //Медичні перспективи.-1997.-Т.2,N 2.-с.88-91.
26. Міжнародна статистична класифікація хвороб та споріднених проблем (МКХ-10); 10-й перегляд. -Всесвітня організація охорони здоров'я, Женева, 1998.-Т.1.1-685с.;Т.1.2-710с.
27. Комплексная оценка иммунного статуса при гигиенических массовых обследованиях здоровья населения: методические рекомендации. НИИОКГ им. А.Н.Сысина АМН СССР, и-нт иммунологии МЗ СССР, Самаркандский мед. институт, МВТУ. - М., 1988. – 74 с.
28. Земсков А.М., Земсков В.М., Золоедов В.И. Доступные методы оценки и коррекции иммунных нарушений у больных // Клиническая лабораторная диагностика. - 1997. - № 3. - с. 3-4.
29. Оценка влияния факторов окружающей среды на иммунологическую реактивность организма: методические рекомендации / Министерство здравоохранения УССР. - Киев, 1988. - 24 с.
30. Волощенко В.О. Методологія реалізації засобів обробки та аналізу результатів гігієнічних досліджень у адаптивному програмному середовищі, розробленому за комп’ютерною технолоґією // Український журнал медичної техніки і технології. - 1998. - № 4. - с.76-82.
31. Волощенко В.О. Непроцедурний принцип розробки програмних систем зберігання, обробки і аналізу результатів еколого-гігієнічних досліджень у рамках адаптивного програмного середовища // Гигиена населенных мест: Сб. науч. статей.- 1999. - Вып. 35. - с.562-571.
32. Волощенко В.О. Реалізація у адаптивному програмному середовищі проектів результатів вимірювань в області гігієни і екології // Гигиена населенных мест: Сб. науч. статей. - 1999. - Вып. 35. - с.530-540.
33. Волощенко В.О. Адаптивні можливості, системні функції та запити програмного середовища, призначеного для реалізації систем обробки та аналізу результатів еколого-гігієнічних досліджень // Довкілля та здоров'я. - 1999, №3(10). - с.28-32.
34. Бердник О.В., Серых Л.В., Зайковская В.Ю. Факторы окружающей среды как факторы риска развития патологии у детей // Довкілля та здоров'я.-1998.-N 3(6).-с.20-23.
35. Бердник О.В. Ризик формування захворюваності дітей, пов'язаний з впливом антропогенних чинників навколишнього середовища //Проблеми охорони здоров'я дитячого населення м. Киева: Сб. під ред.М.І.Хижняка.- К., 1993.- С.124-126.
36. Яруллин А.Х. Медико-демографические показатели и заболеваемость детей в семьях, имеющих факторы социального риска // Казанский мед. журнал.-1994.-N3.-с.245-247.
37. Розповсюдження хвороб органів травлення у дітей дошкільного віку залежно від впливу соціальних, екологічних та медико-біологічних факторів / О.М.Циборовський, М.Ф.Денисова, Т.П.Крепченко та ін.// Педіатрія, акушерство, гінекологія.-1996.-N3.-с.14.
38. Рахманов Т.О. Комплексное социально-гигиеническое исследование состояния здоровья организованных детей дошкольного возраста (от 4 до 7 лет жизни) и пути дальнейшего совершенствования лечебно-профилактической помощи: Диссертация кандидата медицинских наук.- Ташкент, 1993.- 167с.
39. Буштуева К.А., Случанко И.С. Методы и критерии оценки состояния здоровья населения в связи с загрязнением окружающей среды.-М.:Медицина,1979.-160с.
40. Васильев К.Г., Галянченко А.М. Методы эпидемиологического изучения не специфических болезней. -Киев: Здоров’я, 1983.-128 с.
41. Измеров Н.Ф., Гурвич Е.Б., Лебедева Н.В. Социально-гигиенические и эпидемиологические исследования в гигиене труда.- М.: Медицина, 1985.-192с.

42. код доступу: http://pop-stat.mashke.org/ukraine-cities.htm.володимирець.
43. код доступу: https://uk.wikipedia.org/wiki/рокитне.
44. https://uk.wikipedia.org/wiki/%D0%9A%D0%BE%D1%81%D1%82%D0%BE%D0%BF%D1%96%D0%BB%D1%8C/костополь.
45. Ровенская АЭС. Энергоблок № 4 Оценка воздействий на окружающую среду. Том 6. «Оценка воздействий на окружающую социальную и техногенную среду», 2001 г. -76 с.
46. «Вивчення показників здоров'я населення в зв'язку з забрудненням навколишнього середовища», Київ- 1985.
47. «Порядок діяльності санітарно-епідеміологічної служби з оцінки стану здоров'я населення у зв'язку з впливом факторів довкілля», Москва, 1989
48. «Хвороби ендокринної системи, порушення обміну речовин», рубрика E 04, IV клас хвороб, Міжнародна статистична класифікація хвороб та споріднених проблем X перегляду, ВООЗ, Женева, 1998 р.
49. 13th Meeting of the scientific group on methodologies for the safety evaluation of chemicals (SGOMSEC): alternative testing. Methodologies for ecotoxicity / C.Walker, K.Kaiser, W. Kleinetal. // Environment Health Perspectives, Supplements. - 1998, V.106.-Suppl. 2. - P. 441 - 450.
50. Karol M.H. Target organs and systems: Methodologies to assess immune system function // Environment Health Perspectives, Supplements. - 1998, V. 106. - Suppl. 2. - P. 533 - 540.
51. Огир Л.Б. Донозологическая диагностика состояния здоровья детей по комплексу иммунологических, биохимических показателей и накоплению специфических загрязнителей в биосредах // Актуальные проблемы социальной медицины, организации здравоохранения и пути их дальнейшего развития в Украине. - Днепропетровск, 1994. - с. 148- 152.
52. Иммуномикробиологические исследования в медицинском и экологическом мониторинге / Г.А.Шальнова, А.А.Иванов, Н.Н. Варонин и др. // Гигиена и санитария. - 1996. - № 3. - с. 53-55.
53. Biologic markers in immunotoxicology / Washington: D.C., National Academy Press.-1992.- 206 p.
54. Хаитов Р.М., Пинегин Б.В., Истамов Х.И. Экологическая иммунология // М.: ВНИРО, 1995. - 219 с.
55. Сердюк А.М. Чернобыль и здоровье населения Украины // Довкілля та здоров’я. - 1998. - № 2 (5). - с. 30-35.
56. Насьбуллина Г.М., Рябова Н.В., Ползик В.Е. Оценка влияния малых доз облучения населения в зоне Восточно-Уральского радиоактивного следа на состояние здоровья потомков // Гигиена и санитария. - 1999. - № 3. - с. 18-20.
57. Клинико-иммунологическая характеристика детского населения, постоянно проживающего на территориях с радионуклидным загрязнением, в зависимости от величины дозы внутреннего облучения / Р.В.Ленская, Г.Н.Зубрихина, В.М.Чернов и др.// Гематология и трансфузиология. - 1999. - Т. 44, № 2. - с. 34-38.
58. Иммунный, гормональный и витаминный статус детей г.Светлогорска / М.И. Бушма, Л.М. Караедова, С.А. Ляликов и др.// Здравоохранение. -1999.- № 4. - с. 23-25.
59. Баева Е.В., Соколенко В.Л., Базыка Д.А. Модификация экспрессии Т-клеточных активационных маркеров лимфоцитами периферической крови лиц, проживающих на загрязненных радионуклидами территориях // Иммунология. - 1999. - № 1. - с. 54-56.
60. Маркевич В.Є., Загородній М.П. Імунологічна реактивність у дітей, які проживають в умовах дії малих доз іонізуючого випромінювання та промислових викидів // Лікарська справа. - 1999. - № 3. - с. 49-53.

61. О роли иммунологических механизмов в развитии отдаленных последствий ядерных катастроф / В.Ф.Москаленко, Н.В.Васильев, В.И.Мальцев и др. // Лікарська справа. - 1999. - № 4. - с. 3-8.
62. Пинегин Б.В., Чередеев А.Н., Хаитов Р.М. Оценка иммунной системы человека: сложности и достижения // Вестник Российской академии медицинских наук. - 1999. - № 5. - с. 11-15.
63. Бутенко Г.М. Иммунитет при старении // Международный медицинский журнал. - 1999. - № 2. - с. 6-10.
64. Оцінка впливу на навколишнє середовище (ОВНС) завершення будвідництва 4-го блоку Рівненської АЕС / Програма Tacis з ядерної безпеки. Контракт No 97/06/21.00. - Mouchel Consulting Ltd. Environmental Consultancy, 1998. - 311 с.
65. Tronnes D. H. & Seip H. M. Decision making in control of air pollutants posing health risk in Risk assessment of chemicals in environment, ed. H. M. Seid and A. Heiberg, P. 265-297
66. Morioka T. & Chikami S. Basin-wide ecological fate model for management of chemical hazards//Ecological Modelling. - 1986. - Vol. 31. - P. 267-281
67. 38-903.201.001.ОВ. Ривненская АЭС. Энергоблок № 4. Оценка воздействий на окружающую среду. Киев, 2002.
68. Контроль доз критических групп населения зоны наблюдения Ривненской АЭС (при штатном выбросе и сбросе). Методические указания.
69. Звіти з радіаційної безпеки Рівненської АЕС за 2007-2016 роки.
70. Оценка доз внутреннего облучения населения Украины за счет радиоцезия с использованием счетчиков излучения человека:/ Методические рекомендации. Утв.30.12.1994.-19с.
71. Отчет «Изучить нулевой фон в районе строительства Ровенской АЭС» № гос. регистрации 79049434 Инв.№ Б 852957 Моска-Киев.
72. Дозиметрическая паспортизация населенных пунктов Украины, подвергшихся радиоактивному загрязнению после Чернобыльской аварии –Сборник-5.Киев-1995.
73. Допустимі рівні вмісту радіонуклідів ^{137}Cs і ^{90}Sr у продуктах харчування та воді (ДР-97).
74. Марей А.Н., Бархударов Р.М., Новикова Н.Я. Глобальные выпадения цезия-137 и человек Атомиздат, М.,1974, с168.
75. Географічна енциклопедія. 3 т. К.: УРЕ, 1987-99.
76. Архіологічні пам’ятки Української РСР (короткий список). - К.: Наукова думка, 1966. - 459 с.
77. Памятники истории и культуры Украинской ССР. Каталог-справочник. – К.: Наукова думка, 1987. - 636 с.
78. Історія міст і сіл Української РСР. – К.: УРЕ, 1967-1977.
79. Словник-довідник археології. – К.: Наукова думка, 1996. – 430 с.
80. Ровенская АЭС, энергоблок №4. Оценка воздействий на окружающую среду. Том 6. Оценка воздействий энергоблока на окружающую социальную и техногенную среду, 2008., -76 с.
81. Кодекс цивільного захисту України.
82. «Науково-технічний звіт про інженерно-геологічні вишукування (комплексний аналіз стану ґрунтів основ будівель та споруд) 14-349/07-08, 10-439.1».
83. «Науково-технічний звіт з комплексних інженерно-геологічних та геофізичних досліджень. 14-126-08, 10-726-1», 2014 р.
84. ДБН А.2.2-1-2003 «Склад і зміст матеріалів оцінки впливів на навколишнє середовище (ОВНС)».

85. ДБН А.2.2-1-2003 «Посібник до розроблення матеріалів оцінки впливів на навколишнє середовище».
86. Т.А. Павленко, И.П. Лось Существующие дозі облучения населения Украині. Ядерная и радиационная безопасность. № 1, 2009.
87. Закон України «Про електроенергетику», Відомості Верховної Ради України (ВВР), 1998, № 1, ст.1.
88. Доповідь про стан навколишнього природного середовища у Рівненській області у 2016 році. /Департамент екології та природних ресурсів Рівненської області, Рівне, 2017., -224 с.
89. Допустимый газо-аэрозольный выброс радиоактивных веществ Ривненской АЭС (радиационно – гигиенический регламент первой группы). 132-2011-ДВ-ЦРБ, 2011 г.
90. Допустимый водный сброс радиоактивных веществ Ривненской АЭС (радиационно – гигиенический регламент первой группы). 132-2011-ДС-ЦРБ, 2011 г.

Appendix A

EXTRACT FROM REPORT ON ENVIRONMENTAL STATUS OF THE REGION OF RIVNE IN 2016 REGARDING SOCIAL AND ECONOMIC DEVELOPMENT OF THE REGION [88].

The key program document that outlined the main directions and goals for improving the living standards in the Rivne Region in 2016 was the Strategy for Economic and Social Development of the Rivne Region for 2016. The strategy was developed in accordance with the tasks and provisions of the Cabinet of Ministers of Ukraine No. 385 “On Approval of the State Strategy for Regional Development for the Period until 2020” dated 6 August 2014 and No. 558 “On Approval of the Forecast of Economic and Social Development of Ukraine for 2016 and the Major Macroeconomic Indicators of Economic and Social Development of Ukraine for 2017-2019” dated 5 August 2015, as well as the Order of the Chairman of the Regional State Administration No. 612 “On the Strategy for the Development of the Rivne Region until 2020” dated 28 November 2014 and No. 273 “On the Plan for 2015-2017 for the Implementation of the Strategy for the Development of the Rivne Region until 2020” dated 27 May 2015.

Although the region’s share in the industry of Ukraine makes only 1.7 %, the Rivne Region stands out among other regions of Ukraine in the following branches of production:

- electricity (21.6 % of the national electricity generation by nuclear power plants);
- wood chipboard (40.2 %);
- high-quality plywood (64.8 %);
- cement (10.8 %);
- matches (100 %);
- glassware (48 %).

The largest sales volume shares within the industrial complex in the region are due to:

- electricity - 38.8 %;
- production of chemicals and chemical products - 11.1 %;
- food production - 16.0 %;
- production of construction materials and glassware - 13.2 %.

In 2016, the production output was increased at enterprises performing economic activities as follows:

- mining industry and excavation - by 6.1 %;
- textile production - by 6.8 %;
- production of foods, beverages and tobacco - by 6.0 %;
- wood products manufacture, paper production and printing - by 6.5 %;
- manufacture of rubber and plastic products, other non-metallic mineral products - by 5.2 %;
- machine building - by 2.7 %.

The volume of sales in 2016 amounted to UAH 29,579.1 mln, which is 13.2 % more than in 2015 (UAH 26,115.3 mln).

At the same time, the total volume of industrial output in 2016 in the region decreased by 1.9 % compared to 2015.

In 2016, the gross agricultural output by all categories of households amounted to UAH 6.7 billion, incl. UAH 2.3 billion by state agricultural enterprises, which is 5 % and 13.4 % more than in 2015, respectively.

At all categories of households, meat production increased by 0.8 %, milk production by 0.1 % and eggs production by 2.6 %.

Meat production at agricultural enterprises in the region increased by 5.1 %, milk production by 16.8 % and eggs production by 8.2 %. The cattle population has increased by 0.3 %.

In 2016, the richest harvest in the region's history was reaped - 1,299.3 thous. tons, while the average yield was 48.2 centners per hectare (in 2015 the yield was 45 centners per hectare). In particular, the following crops were reaped: wheat - 458.1 thousand tons compared with an average yield of 44.3 centners per hectare (in 2015, the yield made 43.7 centners per hectare), grain maize - 519.8 thousand tons with an average yield of 80.9 centners per hectare (in 2015 - 74.8 centners per hectare), barley - 204.6 thousand tons with an average yield of 40.6 centners per hectare (in 2015 - 39.4 centners per hectare).

Sunflower seeds production increased 3.8-fold, sugar beet production - by 20 %, vegetables production - by 11 %, and potatoes production - by 2 %. 1,228 thousand tons of potato were harvested with an average yield of 178.4 centners per hectare (compared to the yield of 186.6 centners per hectare in 2015).

For the crop of 2017, all categories of households planted winter crops over an area of 123.6 thousand hectares, and the crop area was increased by 2 thousand hectares.

UAH 217.3 million of credit resources were attracted in 2016 to the agricultural sector of the region. UAH 17.5 million from the state budget were allocated for the development of the agricultural sector, which is 2.8 times more than in 2015.

The above funds were invested in modernization of agricultural production, implementation of the latest technologies for cultivation of crops.

UAH 7.9 million were allocated from the state budget for partial compensation of interest rates on loans to agricultural producers.

Last year the cost of 1,357 heads of breeding heifers that were purchased in 2015-2016, in the amount of UAH 9.4 million, was reimbursed from the state budget to two agricultural enterprises in the region.

Within the framework of the regional program for support of the farms, UAH 1.15 million were directed from the region's budget (12 farms received relevant support).

UAH 1.1 million were allocated for the implementation of the program for individual countryside housing construction "Own Home". These funds were used to commission 7 residential buildings with a total area of 0.94 thousand m^2 and to supply 12 households with gas.

The volume of capital investments for 2016 amounted to UAH 4.1 billion UAH, including UAH 1.4 billion for housing construction.

In 2016, 11 projects were implemented at the expense of the state regional development fund for the amount of UAH 101.9 million, and UAH 98.7 million, or 96.9 % of the funds provided for 2016, were financed as of 1 January 2017.

In 2016, a school in the Village of Tynne in the Sarny District (for 1,100 pupils), a school in the Village of Hlynne in the Rokytnivskyi District (for 796 pupils), a water supply line in the Town of Dubno (in the neighbourhoods of Strakliv, Volytsia, and the meat processing plant), boiler houses of Volodymyretskaya CDH and in the Town of Dubno at 170-v Hrushevskyi Str. were commissioned using these funds.

UAH 82.6 million of subventions were allocated in 2016 from the state budget to local budgets for implementation of social and economic development of separate territories in the region, namely for construction and reconstruction of public facilities. As of 1 January 2017, UAH 78.2 million (94.7 %) were financed.

The region received UAH 21.3 million of subventions from the state budget to finance social and economic risk compensation to the population residing in the observation zone, including the share of the regional budget of UAH 6.6 million. As of 1 January 2017, UAH 13.1 million (61.5 %) were financed. These funds were used to complete the foundation works for a school in the Village of Ozertsi in the Volodymyretskyi District, for the construction of the supply warehouse for the Ostroh Psychoneurological Dispensary in the Town of Ostroh and for major repair of the roof at medical departments No. 4, No. 5 of the Ostroh Regional Psychiatric Hospital.

UAH 72.9 million were allocated from the regional development budget for the construction and reconstruction of social facilities, and UAH 69.8 million (95.7 %) were financed. Reconstruction works at Sonechko kindergarten in the Village of Remchytsi in the Sarny District and in the Village of Velykyi Zhytyn of the Rivne Region, at the general practice outpatient clinic of family medicine in Kostopil, endocrinology department of the regional children’s hospital in the City of Rivne, and construction of boiler houses in general education schools in the villages of the Vovkovyi in the Demydivskyi District and Posnykiv in the Mlynivskyi District were completed.

UAH 9.1 million were directed from the regional environmental protection fund, and works worth UAH 6.5 million (71.4 %) were performed. These funds were used to implement measures for the protection and rational use of natural resources as well as for the elimination of environmental pollution, a total of 14 measures. A water development facility in the Village of Syniv in the Hoshchanskyi District was commissioned after the reconstruction, the Ustia River channel was cleared, and protective dams and pumping station of the Ivachkiv polder system in the Zdolbunivskyi District were reconstructed.

In 2016, the World Bank project on improving the efficiency of treatment and prevention of circulatory diseases in the Rivne Region in 2015-2020 was launched in the region for a total cost of USD 25 million. Reconstruction and overhaul of 105 rural outpatient clinics, and purchase of 5 thousand items of medical equipment and 18 ambulances are planned within the framework of the project.

As of 1 January 2017, the total volume of direct foreign investment attracted to the region’s economy, amounted to USD 182.3 million.

The enterprises in the region continue upgrading their production facilities, introducing innovations and advanced technologies, developing new types of competitive products and creating jobs, namely:

- at Consumers-Sklo-Zorya CJSC (Rivne Region), major repair of glass furnace No. 2 and of production lines in the second workshop for the total amount of EUR 12 million was carried out. The main company’s product is premium packaging (made of extra flint glass);

- a project for reconstruction of sawmill-wood processing mill for the production of board lumber in the amount of 300 thousand m^3 per year is being implemented by foreign investors at Ukrainski Lisopylni LLC (Ukrainian Sawmills) (Kostopilskyi District). The planned volume of investments amounts to EUR 25 million. It is planned to process the entire volume of local pine sawtimber, including export. In addition, it is planned to open a similar production in the Sarny District by the end of 2017;

- ODEK Ukraine LLC (Rivne District) is implementing a project to expand the production of plywood by adding a workshop and purchasing new equipment. Namely, the company has purchased three lines: veneer glueing line, pressing line, a plywood grinder and a forklift truck (for the total cost of UAH 6.7 million). In addition, it is planned to purchase Japanese equipment and replace the boiler room equipment;

- Svitovid LTD plant of the UkrTechnoPhos group of companies (Rivne District) with a capacity of 10 thousand tons of fertilizers per month (for the total cost of UAH 50 million) was put into operation.

6 projects for international technical assistance are being implemented on the territory of the region, for the total cost of about EUR 4 million, namely:

- Administrative Services Centre as an innovative tool for interaction between the government and the community;
- Improvement of the training system for the needs of the economy of the Volyn subregion;
- Development of agricultural activities in the Manevytsky District of the Volyn Region and Volodymyretskyi District of the Rivne Region through support from regional programs for soil improvement and public awareness activities (pilot project);
- Ukrainian regional platform for public initiatives;
- Development of rural “green” and ecological tourism as a programmatic component of the economic development of the Bereznivskyi District;
- Community Based Approach to Local Development, phase 3.

UAH 350 thousand were allocated in 2016 from the regional budget within the framework of implementation of the regional program “Community Based Approach to Local Development” for co-financing of 5 microprojects of communities.

Since 2010, an annual regional competition for development projects of territorial communities has been held at the regional level. In 2010-2015, 61 projects were implemented, for a total cost of UAH 4.2 million, of which co-financing from the regional budget amounted to UAH 2.1 million. Based on the results of the meeting of the Competition Board in 2016, 15 winning projects were awarded for the total amount of funding from the regional budget of UAH 724 thousand. Priority was given to projects on energy and resource conservation, organization of social services for the population, and local business development.

In 2016, 133.3 million passengers used the services of passenger transport. The volume of trolleybus passenger transportation amounted to 34.3 million people, and increased by 2.4 % compared to 2015.

Cargo turnover in the region increased by 6.3 %. The volume of road cargo traffic increased by 9.1 %.

The foreign goods trade turnover in 2016 amounted to USD 555.9 million, while the export volume amounted to USD 310.6 million, and import - USD 245.3 million. The positive balance of foreign trade amounted amounted to USD 65.3 million, and the export-import coverage ratio is 1.27.

Foreign goods trade operations were carried out with partners in 107 countries. The share of the European Union countries within the structure of export supplies was 71.2 % versus 62.5 % at the beginning of 2016.

Among the key partner countries, the export of goods to India has increased 10-fold, to the Czech Republic - 2.2-fold, to Belarus - 1.9-fold, to Finland and Slovakia - 1.6-fold, to Hungary and Austria - 1.5-fold, to Bulgaria and Spain - 1.4-fold, and to Germany - 1.2-fold. At the same time, exports to the Russian Federation have decreased by 66.6 %, to China by 65.1 %, to Belgium by 56.6 %, to France by 52.6 %, to Great Britain by 45.9 %, to the Netherlands by 40.5 %, to Moldova by 35.4 %, to Italy by 29 %, and to Turkey by 26.1 %.

The largest share within the commodity structure of exports is due to wood products - 31.7 %, products of vegetable origin - 12 %, articles of stone, plaster, cement - 11.8 %, furniture - 9.8 %, and mineral fertilizers - 8.9 %.

The largest share within the commodity structure of imports is due to machinery and equipment - 21.6 %, polymer materials - 13.7 %, and land vehicles - 8.2 %.

In 2016, the volume of retail sales amounted to UAH 26.4 billion, which is 1.3 % more than in 2015.

In order to meet the needs of the population in food products, 1204 food fairs were held in the settlements of the region, and agricultural producers sold agricultural products for the amount of UAH 111.9 million over the past year.

In 2016, 5.3 thousand enterprises (of these, more than 5.0 thousand were small and 275 were mid-sized business) and 34.7 thousand individual entrepreneurs carried out their activities in the region.

Owning to activities of small businesses, UAH 2.7 billion of contributions went to the consolidated budget of the region in 2016, and UAH 1.9 billion - into local budgets.

In order to ensure the implementation of the Law of Ukraine “On Administrative Services”, administrative services centres (ASC) are available in all districts and cities or towns of regional importance. In 2016 they provided 262 thousand administrative services to the applicants, which is 2.2 times as much as in 2015.

In addition, within the framework of the joint project with the German Society for International Cooperation (GIZ) “Management Reform in the East of Ukraine” and the EU/UNDP project “Community Based Approach to Local Development”, an Administrative Services Centre for a total cost of UAH 1.3 million has been opened at the Myliatska United Territorial Community (using the funds of international technical assistance, state, regional and rural budgets).

Administrative service centres have approved the lists of administrative services, which include social, land services and registration coordination procedures.

A project for international technical assistance of the European Union “Administrative Services Centre as an innovative tool for interaction between the government and the community” is currently being implemented within the framework of the EU Program “Enhancing Local Authorities’ Contributions to Governance and Development Processes”, which envisages the modernization of three ASCs in the cities of Rivne, Dubno and Varash, as well as the introduction of modern technologies and electronic document management systems at all ASCs in the region (for the total cost of UAH 7.3 million).

In 2016, the general fund of the consolidated budget of the region (without transfers) received UAH 8,084.8 million, which is 21 % more than in 2015.

The receipts of payments to the state budget amounted to UAH 5,301.1 million and increased by 10.6 %.

Own revenues of local budgets amounted to UAH 2,783.7 million, which is 1.5 times, UAH 894 million, more than in 2015.

The receipts of a Unified Contribution for Compulsory State Social Insurance in the region amounted to UAH 2,297.4 million as of 1 January 2017. The task is completed by 104.7 %.

The receipts in the budget of the Pension Fund for 2016 amounted to UAH 109.5 million. The task is completed by 101 %.

The average monthly wage of workers in the region amounted to UAH 4,364 in 2016, and increased by 22.1 % compared to 2015. The real wage index was 107.1 %.

In terms of the average monthly salary, the region ranks second among the western regions of Ukraine (after the Lviv Region with UAH 4,558).

As of 1 January 2017, the number of unemployed citizens in the region amounted to 14.4 thousand people, which is 13.8 % less than that as of 1 January 2016.

In 2016, 32.3 thousand people were employed, which is 7.7 % more than in 2015.

Due to the lump-sum unemployment benefit for the development of entrepreneurship, 173 people were employed, with 661 people employed through compensation of expenses to the employer in the amount of a Unified Contribution for Compulsory State Social Insurance.

Professional training was passed by 7.9 thousand people, and 5,300 unemployed persons participated in public works.

The registered unemployment level as of 1 January 2017 was 2 % versus 2.3 % as of 1 January 2016.

In view of the above, the priority task for the next year for all branches of power in the region will be comprehensive support for further development of all areas of industry, improvement of the investment climate in the region and the development of energy and resource saving technologies, which will be key to the sustainable growth of the socio-economic state of the region, increase in general authority and a positive image of the Rivne Region in Ukraine.

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APPROVED

Director of NT Engineering

_______________R. V. Maraikin

"25" December 2018

REPORT

ON

SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 5

Comprehensive measures to ensure environment condition and safety compliance

Version 2

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ABSTRACT

Book 5 of this Report contains 193 pages of text, 20 drawings, 40 tables. The subject is the existing power units, facilities and structures that are part of the process system at the NNEGC Energoatom SS Rivne NPP site, as well as their environmental impact in the area near Rivne NPP.

The sections of this Report contain the assessment of Rivne NPP impact on the "Social Environment" and "Anthropogenic Environment" taking into account a set of all activities of Rivne NPP operation, which is based on the results of implementation of environmental protection measures, long-term results of monitoring and comparison of the NPP environment condition before commissioning and during operation of power units.

Book 5 summarizes impact of SS Rivne NPP site on the environment and considers implemented comprehensive measures that ensure environment condition and safety compliance.

The Report is executed in accordance with the requirements for the composition and content of the environmental impact assessment documentation.

The results of this Report represent environmental justification of the acceptability of the existing Rivne NPP facility operations.

Keywords: SS Rivne NPP, SS RNPP, ENVIRONMENT, COMPREHENSIVE MEASURES, LIMITS, IMPACT, MONITORING, RISK.

Report distribution terms: in accordance with the Agreement.

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LIST OF LEGENDS, SYMBOLS, UNITS OF MEASUREMENT, ABBREVIATIONS AND TERMS

Abbreviation	Name
NPP	Nuclear power plant
ARSMS	Automated radiation state monitoring system
WANO	World Association of Nuclear Operators
VVER-440	Water-water power reactor with a rated power output of 440 MW
VVER-1000	Water-water power reactor with a rated power output of 1000 MW
SS Rivne NPP	Separated Subdivision Rivne Nuclear Power Plant
ARI	Acute respiratory infections
HQ	Head Quarters
SEZA	State Agency of Ukraine on Exclusion Zone Management
PR	Permissible emission (maximum emission level)
PEE	Pre-school educational establishments
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
IRS	Ionizing radiation source
LLR	Long-lived radionuclides
PC^{inhal}	Permissible concentration of radionuclides in the air
PC^{ingest}	Permissible concentration of radionuclides in drinking water
DK UkrDO Radon	State Corporation “Ukrainian State Association Radon”
PI^{inhal}	Permissible intake of radionuclides through the respiratory system
PI^{ingest}	Permissible intake of radionuclides through the digestive system
SE NNEGC Energoatom	State Enterprise “National Nuclear Energy Generating Company Energoatom”
DR-97	Permissible concentrations of ^{137}Cs and ^{90}Sr in food and water
SSE CEMRW	State Specialized Enterprise “Central Enterprise for the Management of Radioactive Waste”
SSE ChNPP	State Specialized Enterprise “Chernobyl Nuclear Power Plant”
CYSS	Children’s and youth sports school
VCL	Vital capacity of lungs
PPE	Personal protective equipment
MM	Mass-media
MA	Monitored area
ID	Immunological deficiency
IRG	Inert radioactive gases
PHI	O. M. Marzeiev Institute for Public Health of the National Academy of Medical Sciences of Ukraine О.М. Марзєєва НАМН України
CUF	Capacity utilization factor
PC Vector	Production Complex Vector
CB	Cubic balance
DPRK	Democratic People’s Republic of Korea

Abbreviation	Name
C/P	Checkpoint
RW CT	Comprehensive treatment of radioactive waste
SRW CT	Comprehensive treatment of solid radioactive waste
MPD	Maximum permissible dose
PTL	Power transmission line
IAEA	The International Atomic Energy Agency
MDA	Minimum detected activity
MoH of Ukraine	Ministry of Health of Ukraine
MDBA	Maximum design basis accident
IWG	Interdepartmental working group
MEI	Maximum estimated earthquake
URC	Unknown radionuclide composition
LLW	Low-level waste
NRBU-97	Norms of Radiation Safety of Ukraine, 1997
NT Engineering	NT Engineering Limited Liability Company
n/a	Not available/applicable
CBH	Complicated biological history
H&S	Fundamentals of health and safety
EIA	Environmental impact assessment
EIA	Environmental impact assessment
RSA	Regional state administration
PSH	Positive social history
PR_i	Permissible release
EDR	Equivalent dose rate
SLE	Earthquake factor
SPM	Scheduled preventive maintenance
PD_i	Permissible discharge
VS	Vocational school
RNPP	Rivne Nuclear Power Plant
RW	Radioactive waste
SES	Sanitary and epidemiological service
SPZ	Sanitary protection zone
PRM	Personal radiation monitor
sett.	Urban type settlement
USSR	Union of Soviet Socialist Republics
SNF DS	Dry storage for spent nuclear fuel
SNiP	Construction norms and rules
TPS	Thermal power station
ToR	Terms of Reference
NT-Engineering LLC	NT-Engineering Limited Liability Company
OTS	Operation technical support
U/S	Ultrasound testing

Abbreviation	Name
I&PR	Office of Information and Public Relations
MOS	Medical and obstetric station
MS	Medical station
CDH	Central district hospital
SNF CS	Centralized storage for spent nuclear fuel
ChNPP	Chornobyl Nuclear Power Plant
NRS	Nuclear and radiation safety
NF	Nuclear facility
E	East
N	North
S	South
W	West
MSK-64	Earthquake repetition scale
RNPP Doses	Software platform for dose calculation for the population based on actual releases and discharges
RODOS	European system for decision-making support in case of radiation accidents
SOARS	Software platform for dose calculation for all settlements in the observation zone in case of emergency situations
^{235}U	Uranium 235

INTRODUCTION

The service of SS Rivne NPP site environmental impact assessment has been provided in accordance with the Agreement No. 347 dated March 27, 2018 between the State Enterprise “National Nuclear Power Generating Company Energoatom” (SE NNEGC Energoatom), its Separate Subdivision Rivne Nuclear Power Plant and NT-Engineering, Limited Liability Company.

Environmental impact assessment (EIA) documents are developed to assess the environmental impact of SS Rivne NPP operation based on the results of environmental protection measures, long-term results of monitoring and comparison of the NPP neighbouring environment condition before NPP commissioning and during operation.

EIA provides environmental feasibility justification for the economic activities of the existing SS Rivne NPP site facilities, as well as determination of environmental safety requirements for future activities.

Information assets used for the service implementation include basic materials, monitoring results, power unit operational experience, implemented and scheduled environment protection measures, etc., on the basis of which calculations and studies have been carried out to asses the impact of SS Rivne NPP site on the environment and population, including transboundary interactions. This document has been developed after the analysis, systematization and unification of the information collected.

EIA has been executed in accordance with the Law of Ukraine “On Environmental Impact Assessment” [1], which establishes legal and organizational principles for environmental impact assessment aimed at preventing any harm to the environment, ensuring environmental safety, environmental protection, rational use and reproduction of natural resources, in the decision making process to conduct the production activity, which can have a significant impact on the environment, taking into account state, public and private interests, DBN A.2.2-1-2003 “Composition and contents of environmental impact assessment documentation (EIA)” [2] and the Guidelines for the development of environmental impact assessment documentation (to DBN A.2.2-1-2003) [3].

Nuclear power is a reliable source of energy supply and plays a leading role to ensure the energy needs of Ukraine. It is especially essential considering the economic crisis in the country, insufficient amounts of natural fuel, no funds available for modernizing the equipment of thermal and hydroelectric power stations, as well as for the development of alternative energy sources. Electricity production by NPPs contributes to keeping the wholesale tariff on electricity at an acceptable level and reduces the emission of greenhouse gases into the atmosphere. NPPs produce almost 50 % of the electricity consumed in the country, which is equivalent to burning about 40 million tons of coal per year.

One of the main principles of state policy in the field of nuclear energy and radiation protection in Ukraine is the priority of protecting people and the environment from the negative effects of ionizing radiation and ensuring nuclear energy safety. In particular, in accordance with the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” [4], Article 8, “observance of norms, rules and standards on nuclear and radiation safety is obligatory for any kind of activity in the field of nuclear energy” and the Law of Ukraine “On Protection of People from Ionizing Radiation” [4].

SS Rivne NPP site environmental impact assessment is executed in 7 books.

Book 5 summarizes the impact of SS Rivne NPP on the environment and considers comprehensive measures implemented at the enterprise to ensure environment condition and safety compliance.

1 GENERAL DESCRIPTION OF SS RIVNE NPP

The reliability and efficiency of power generation produced by nuclear power plants are recognized worldwide. Considering the instability of world markets and rising prices for gas, oil, coal, the importance of nuclear power to fulfil the needs of the manufacturing sector and the population by providing relatively cheap electricity is ever increasing.

SS Rivne NPP is a separate subdivision (unit) of the State Enterprise "National Nuclear Energy Generating Company Energoatom (SE NNEGC Energoatom). SE NNEGC Energoatom carries out activities in accordance with its Articles of Association and is subordinate of the Ministry of Fuel and Energy of Ukraine, which forms the state policy in the field. In accordance with the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" adopted by the Resolution No. 1268 of the Cabinet of Ministers of Ukraine dated 17 October 1996 "On the Establishment of the National Nuclear Power Generating Company Energoatom" [5,6], SE NNEGC Energoatom is assigned with functions of an operating organization responsible for the safety of all nuclear power plants in the country.

Being one of the four operating NPPs in Ukraine, Rivne Nuclear Power Plant is the largest enterprise in the region. Each year, the power plant supplies about 19 billion kilowatt hours of electricity to the country's integrated power system and adds almost UAH 25 million to local budgets for social and economic compensation to the population of the observation zone.

Rivne NPP is located on the Stir River in the northeastern part of the Rivne Region, 80 km from the regional centre, in the Volodymyrets district. Rivne NPP is nearest NPP to the neighbouring countries located approximately 60 km from the border with the Republic of Belarus and 130 km from the Republic of Poland.

Rivne NPP is located in western Polissya, in the north-west of the Rivne Region, near the Stir River. The site choice was preconditioned by several reasons: low fertility of sandy land and great distance from densely populated areas. In 1973, the density of population in this territory was 55 persons/km^2, while today's population in Varash is 3,684 persons/km^2.

SS Rivne NPP uses the following resources for the production needs:

- NPP territory - 482 hectares;
- industrial site territory - 215 hectares;
- special use permit to collect fresh water from surface water reservoirs in the amount of 73,164 thous. m^3 per year;
- auxiliary electric power: 8 % of the total electric-power generation.

According to SNiP P-7-81 "Construction in Seismic Areas" [6], the industrial area of SS Rivne NPP is located in the P3-5, MR3-6 zone. NPP was designed taking into account two levels of seismicity (P3) - magnitude 5 and the maximum estimated earthquake (MRZ) - magnitude 6. The recurrence of earthquakes according to the MSK-64 scale is 1 time in 5000 years [7].

SS Rivne NPP industrial site is located in a moderate climate zone characterized by mild and humid winters, relatively cold and rainy summer, wet autumn and unstable weather during the season transitions.

The terrain is even and open to the wind, which provides good ventilation of the site.

Power delivery to the power system is carried out via:

1 - 750 kV lines;

4 - 330 kV lines;

5 - 110 kV lines.

NPP process water supply is of circulating type, feeding from the Styr River. The Rivne NPP power units cooling system does not include cooling ponds. The entire power units cooling system is designed to use six cooling towers and spray pools. Heat is removed from circulating water via 6 cooling towers with a productivity of 100,000 m^3/h each. Spray pools are used to remove heat from critical consumers.

Each year, SS Rivne NPP generates about 13 % of the total electricity amount generated in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Varash town and Zabolottia village. The design CUF capacity utilization factor is 74.2 %.

See Table 1.1 for information on products (finished and semi-finished products) annually supplied by the enterprise to consumers or services provided in accordance with the accounting data.

Table 1.1. Products of SS Rivne NPP

No	Product (service) type	Annual capacity
1	Electric energy	19 billion kW×h

SS Rivne NPP uses the following resources for the production needs:

- NPP territory;
- industrial site;
- circulating water use;
- evaporation of water for cooling purposes;
- auxiliary electric power;
- diesel fuel (for emergency power supply, etc.);
- lubricants (for turbines, etc.).

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:

- protection safety systems;
- localizing safety systems;
- auxiliary safety systems;
- control safety systems.

SS Rivne NPP power units have been designed, built and installed in accordance with the regulative documents that were in force at that time.

In 1971, the West Ukrainian NPP subsequently renamed in Rivne NPP has entered the design stage. The power plant is designed to cover electrical loads in the western part of the country.

SS Rivne NPP is the first nuclear power plant in Ukraine based on a VVER-440 water-water power reactor. The power plant construction was commenced in 1973. The first two units with VVER-440/213 reactors were put into operation in 1980-1981, and the third power unit, 1000 MW VVER-1000/320 - in 1986.

The construction of the fourth Rivne NPP unit was commenced in 1984, with commissioning scheduled for 1991. However, due to the introduction of the moratorium on the construction of nuclear facilities on the territory of Ukraine by the Verkhovna Rada, the works were suspended at 85 % of the unit's readiness.

Construction was resumed in 1993. Following the withdrawal of the moratorium, Unit 4 was inspected, and a program for its modernization and a completion project dossier were prepared. Power Unit No. 4 at SS Rivne NPP was commissioned on 16 October 2004.

Operating lifetime periods for power units of SS Rivne NPP are given in Table 1.2. Information on SS Rivne NPP power units.

Table 1.2. Information on Rivne NPP power units.

Unit No.	Reactor unit type	Reactor unit series	Power unit connection date to the IPS	Commissioning date	End of design operation period	Operation extension date
RNPP-1	VVER-440	B-213	22.12.1980	22.09.1981	22.12.2010	22.12.2030
RNPP-2	VVER-440	B-213	22.12.1981	29.07.1982	22.12.2011	22.12.2031
RNPP-3	VVER-1000	B-320	21.12.1986	11.12.1987	11.12.2017	22.12.2035
RNPP-4	VVER-1000	B-320	10.10.2004	07.06.2005	07.06.2035	-

As of 2018, four power units are in operation at SS Rivne NPP (see Table 1.2):

- power unit I (VVER-440) with a capacity of 420 MW since 1980;
- power unit II (VVER-440) with a capacity of 415 MW since 1981;
- power unit III (VVER-1000) with a capacity of 1000 MW since 1986;
- power unit IV (VVER-1000) with a capacity of 1000 MW since 2004.

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008, 2009, 2010) and World Association of Nuclear Operators (WANO) (2001, 2004, 2005, 2012, 2014, 2015, 2016, 2018).

A sanitary protection zone (SPZ) is arranged around the nuclear facility. The SPZ is determined based on the limit annual intake of radioactive substances via the respiratory and digestive systems, limit external radiation doses for personnel and population, as well as permissible air and water concentrations of radioactive substances.

SPZ dimensions are determined taking into account radiation situation assessment in the area around the NPP during long-term operation.

The location of SS Rivne NPP and the boundaries of its observation zone and sanitary protection zone are shown in Fig.1.1.

SPZ of SS Rivne NPP is limited within the radius of 2.5 km around radiation-hazardous objects. The size of the observation zone is 30 km.

The dimensions of the SPZ and OZ were officially set in accordance with the SS Rivne NPP document, namely, "Decision on the size and boundaries of the Rivne NPP sanitary protection zone and the observation zone", No. 132-1-R-11-TsRB [8].

NPP safety systems ensuring protection of the population during accidents, including design basis accidents with the most severe consequences, are designed in a way that the values of equivalent individual doses calculated for the worst weather conditions on the SPZ border and beyond it do not exceed 3 mSv/year for thyroid gland in children due to inhalation intake and 1 mSv/year for the entire body in case of external exposure [8].

SS Rivne NPP power units include the following equipment:

- VVER-440 (B-213) reactor - units 1, 2 and VVER-1000 (B 320) - units 3, 4;
- K-220-44 turbine - units 1, 2 (2 pcs per unit) and K-1000-60/3000 - units 3, 4;
- TVV-220 turbogenerator - units 1, 2 (2 pcs per unit) and TVV-1000 - units 3, 4.

According to the design, SS Rivne NPP includes two VVER-440 power units and two VVER-1000 power units. Each power unit, in addition to normal systems, is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

Table 1.3 provides specifications of SS Rivne NPP power units.

Table 1.3. Specifications of SS Rivne NPP power units.

Parameter	Value	
	VVER-440	VVER-1000
Reactor capacity, MW	1375±27	3000
Pressure at 1 k (at active zone discharge) kgf/cm^2 (MPA)	125±1.2 (12.25±0.1)	160±3 (15.7±0.29)
Temperature of coolant at the reactor discharge, °C	300	320
Coolant heating in the reactor, °C	30.3	30.3
Average consumption of coolant for active zone cooling, t/h	42700400	84800^{+400}_{-480}
Steam production for all SG, t/h	2700	5880
Humidity of steam at SG discharge, %	0.25	0.2

Lifetime extension for the operating power units of nuclear power plants is determined by the “Energy Strategy of Ukraine for the period up to 2030” [9] and is a priority direction of SE NNEGC Energoatom activities.

Design lifetime of the operating nuclear power units in Ukraine is 30 years. In 2017, this threshold was crossed by SS Rivne NPP power unit No. 3 having VVER-1000 reactor. In 2012, in the framework of the preparation for the SS Rivne NPP power unit No. 3 lifetime extension, a one-of-a-kind repair of the upper unit sealing surfaces and the main reactor connector was carried out for the first time in Ukraine. Technical assessment of equipment, pipelines, buildings and structures was performed [10].

In 2016, to implement OTS measures at unit No. 3, an extended PEP, lasting for 114 days, has been scheduled and executed. In particular, work has been carried out on the implementation of the reactor unit diagnostics system, installation of hydrogen burn-up equipment for accidents and other measures.

Besides, a number of post-Fukushima measures has been implemented during PEP, which were aimed at makeup water supply using mobile pumping units, cooling pool, steam generators to ensure operation of process water consumers in case no water is present in spray pools, as well as a measure related to potential complete deenergizing of the NPP has beep planned and implemented by commissioning of a mobile diesel generator. After implementation of all the above-mentioned measures, it is planned to obtain a license for the safe operation of the Unit No. 3 reactor beyond its design life.

According to DSP 6.177-2005-09-02 [11] the category of the enterprise that uses radiation or nuclear technologies is determined by the degree of potential danger to the population in the design mode of operation and in the event of a radiation accident.

To determine the enterprise's potential hazard, the possibility of personnel and population exposure resulting from a radiation accident at this enterprise is considered. Three categories of enterprises and facilities are defined.

production activity of SS Rivne NPP or in case of an accident on its territory, the radiation impact on the population is possible, therefore the enterprise belongs to category I according to Basic Sanitary Rules for Radiation Safety DSP 6.177-2005-09-02 [11].

Rivne NPP includes main, auxiliary and warehouse buildings and structures.

Fig. 1.1. SS Rivne NPP location area

The observation zone includes the area in which the radioactive releases and emissions from the radiation nuclear facility (NPP) are likely to occur with monitoring performed.

Radiation monitoring within the OZ is carried out as per Rivne NPP Radiation Control Regulations 132-1-R-TsRB [12], approved by Senior Vice-President, Chief Technology Officer of SE NNEGC Energoatom on 2 February 2016 and agreed by letter from State Nuclear Regulatory Inspectorate of Ukraine No. 15-28/7070 dated 25 October 2016 as approved by Head of Varash Interdistrict Department of Rivne Regional Laboratory Centre of State Sanitary and Epidemiologic Service of Ukraine HQ on 8 July 2016 and by Director General of SS Rivne NPP on 5 July 2016.

The major priority of the activity is safe generation of environmentally friendly thermal and electric energy.

SS Rivne NPP implements annual safety improvement plans and international projects.

Rivne NPP ensures preservation of jobs in other fields, which is vitally important for stability and revival of Ukraine’s economy.

The process of economic operations, including all environmental impact factors and technical solutions, is intended to eliminate or reduce harmful releases, discharges, leaks and radiation in the environment.

SS Rivne NPP project is based on the modular configuration principle: each power unit, in addition to normal operating systems, is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

VVER-440 and VVER-1000 reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel.

Power units operate in a two-loop cycle: first (hot) loop is a water circuit with direct heat extraction from the reactor; second (cold) loop is a steam circuit with heat energy extracted from the first loop and converted into mechanical energy of turbine rotation, and then into electrical energy in a turbine generator.

The main building with 4 operating power units (two VVER-440 and two VVER-1000 units) includes a reactor room.

Main process equipment of reactor unit:

- reactor;
- steam generators;
- main circulation pumps;
- pressurizer;
- emergency core cooling tank;
- connecting pipelines arranged under the containment in boxes with solid walls of heavy concrete or reinforced concrete.

Key performance indicators of Rivne NPP as of 19 June 2018 are shown in Table 1.4.

Table 1.4. Key performance indicators of Rivne NPP.

Indicators	Power unit No. 1	Power unit No. 2	Power unit No. 3	Power unit No. 4	NPP
Electric energy generated per current day, mln kW·h	4.5	4.5	n/a	10.8	19.9
Electric energy generated per current month, mln kW·h	182.5	183.3	n/a	437.6	803.4
Electric energy generated per previous month, mln kW·h	309.5	308.6	n/a	736.9	1355
Electric energy generated year-to-date, mln kW·h	1346.8	1292.6	0	4061.9	6701.4
Capacity utilization factor (CUF) per current month, %	98	99.6	n/a	98.6	63.9
Capacity utilization factor (CUF) per previous month, %	99	99.9	n/a	99	64.2
Capacity utilization factor (CUF) year-to-date, %	78.9	76.6	0	99.9	58.1

Electric energy generation by the Rivne NPP units started in 1981. Fig. 1.2. shows the amount of electric energy generated by Rivne NPP by years, in bln kW×h.

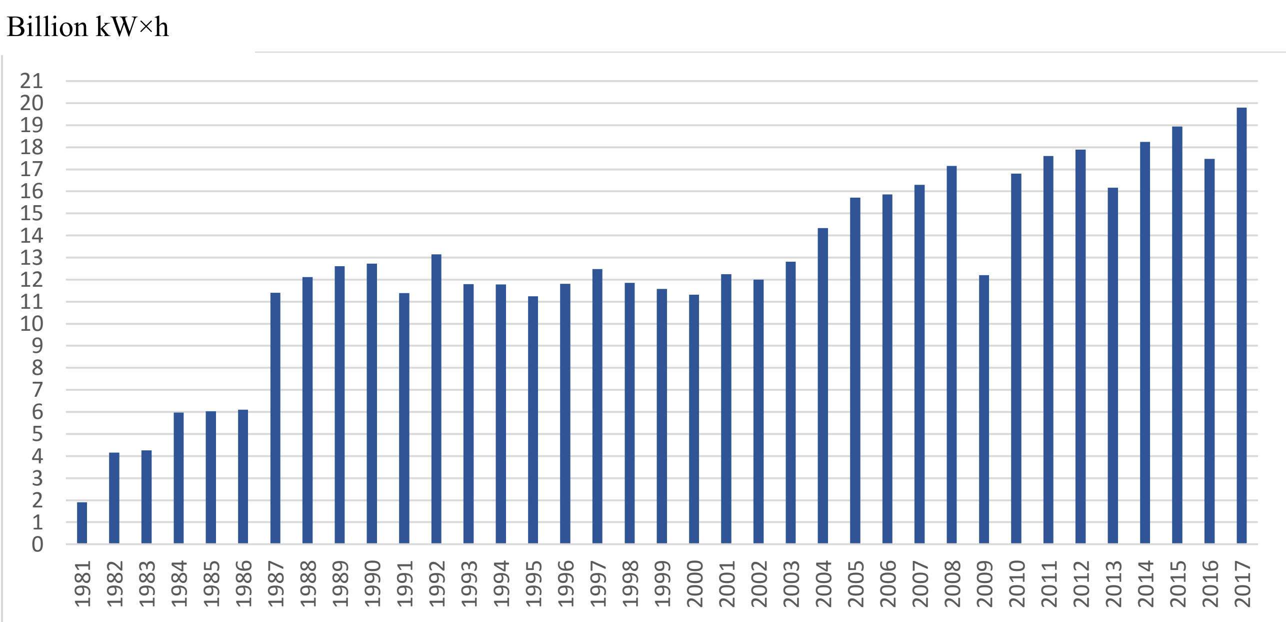

Fig. 1.2. Amount of electric energy generated by SS Rivne NPP by years.

Impacts of nuclear and thermal power plants may be compared to justify the above. Thermal power plants (TPP) have a considerably greater impact on the environment as compared to nuclear power plants (NPP). TPP stack emissions contain nitrogen and residual oxygen as well as carbon dioxide (CO_2), water vapour, sulphur dioxide (SO_2), nitrogen oxides and fly ash that were not trapped by electrostatic filters.

Solid waste from coal-fired TPP, e. g. ash and slag, is a critical issue of impact. Vast areas of land are allocated for solid waste storage.

When stored for a long time, ash and slag form leachables that penetrate into groundwater.

Emissions of carbon compounds have the greatest impact on the atmospheric air leading to a "greenhouse effect" that may result in global warming in future. In turn, global warming will result in events as follows:

- increase in the number of storms and hurricanes;
- flooding of lowlands (water level rise by 1 meter will flood the territory populated by 1 billion people);
- shifting of fertile areas and reduction in yields due to droughts and soil erosion in some regions and overwetting in others;
- extinction of certain animal and plant species;
- loss of freshwater resources in some regions, formation of deserts.

Substances formed during organic combustion - sulphur dioxide and nitrogen oxides - have an adverse environmental impact. When interacting with water drops from clouds and rain, they form acids followed by formation of acid salts that are often toxic. These compounds fall to the ground in the form of acid rains that affect flora, overacidify water reservoirs and soils. Design and actual values of NPP radioactive contamination demonstrate that additional impact is low as compared with natural background radiation and makes one-tenth of the permissible value.

Ventilation air released through vent stacks of the NPP is thoroughly decontaminated and is virtually free of substances that may change the air composition.

As soon as a RW treatment complex is commissioned, the state policy program in the field of radioactive waste (RW) handling will be implemented, with a focus on protecting the environment, life and health of the population against ionizing radiation, improving facility operating conditions and rejuvenating obsolete equipment.

Implementing a solid radioactive waste treatment complex (SRW TC) project will result in: reduced amount of RW in temporary storage at SS Rivne NPP site; beginning of SRW repositories emptying process; rational use of available SRW repositories; reduced personnel radiation exposure; obtaining SRW packings that meet the requirements of SRW acceptance for storage as per regulations currently in force in Ukraine.

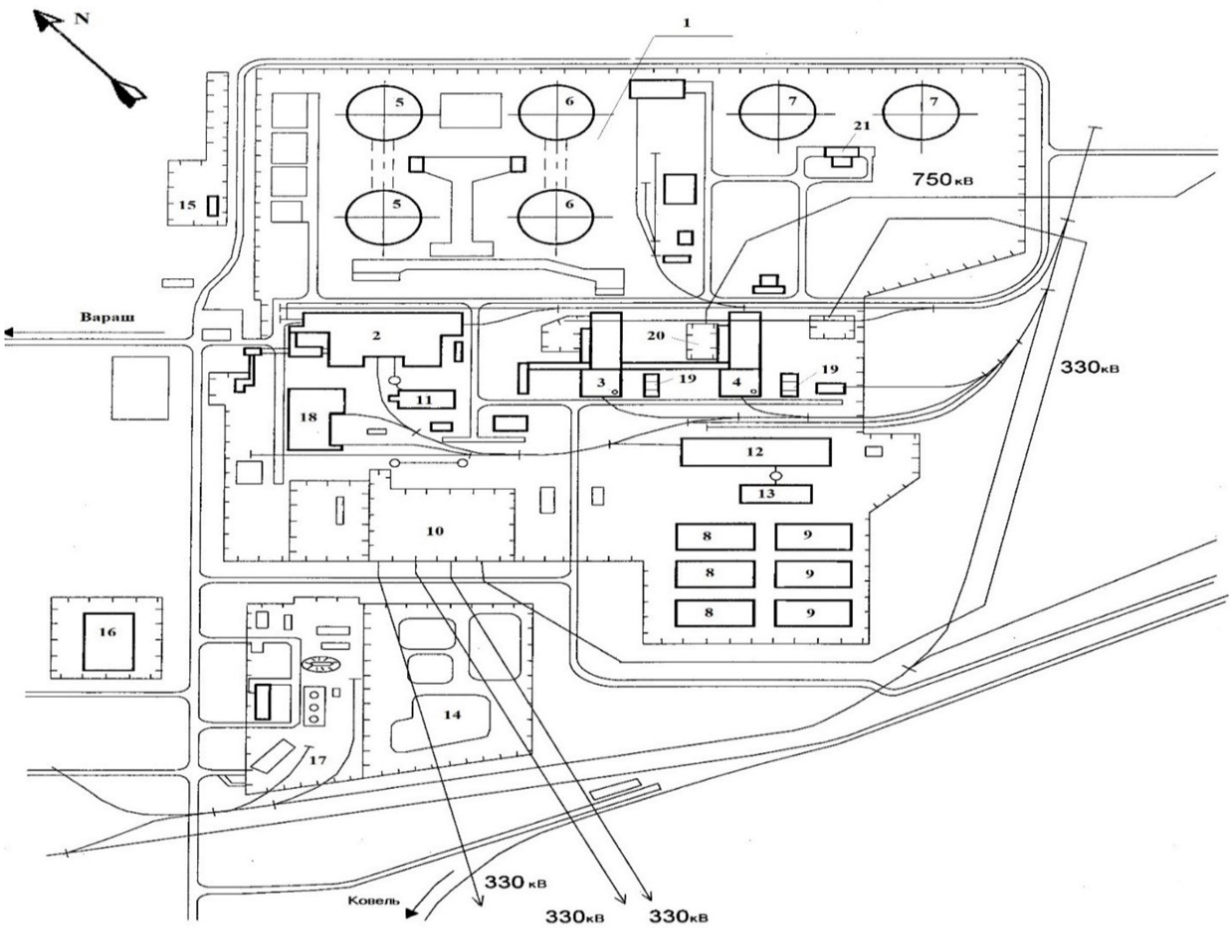

Fig. 1.3 Schematic layout of buildings and structures at the SS Rivne NPP industrial site

Operation of buildings and structures at
SS Rivne NPP

1. NPP industrial site
2. Power units No. 1 and 2
3. Power unit No. 3
4. Power unit No. 4
5. Cooling towers of power units No. 1 and No. 2
6. Cooling towers of power unit No. 3
7. Cooling towers of power unit No. 4
8. Sprinkler pools of group “A” consumers cooling system of power units No. 3 and 4
9. Sprinkler pools of group “B” consumers cooling system of power units No. 3 and 4, including a standby one.
10. 110-330 kV outdoor switchgear
11. Special-purpose building for power units No. 1 and 2
12. Special-purpose building for power units No. 3 and 4
13. RW processing and storage building
14. Slam collecting tank
15. Fire depot
16. Structures for auxiliary water treatment
17. Start-up and standby boiler house
18. Combined auxiliary building
19. Auxiliary diesel generating station
20. Outdoor switchgear

2 COMPREHENSIVE MEASURES TO ENSURE ENVIRONMENT CONDITION AND SAFETY COMPLIANCE

To ensure reliable protection of the personnel, population and the environment from the effects of ionizing radiation and the maximum possible reduction of the influence of anthropogenic factors on the environment, SE NNEGC Energoatom has implemented a number of general measures at SS Rivne NPP:

- compliance with the requirements of environmental legislation of Ukraine, international agreements, standards and regulations in the field of nuclear energy use, management of natural resources and environmental protection;
- planning of activities in the field of environmental protection and monitoring of environmental impact compliance;
- environmental support for NPP power units operation;
- creation and implementation of a management system for environmental protection;
- observance of production process parameters at the SS Rivne NPP industrial sites;
- taking into account quantitative and qualitative indicators of pollutant releases into the atmosphere, discharges into natural water bodies, waste management for the rational use of natural resources;
- implementation of environmental policy by organizing environmental education of personnel, raising the level of environmental training;
- meaningful interaction on environmental safety issues with supervision agencies, public organizations involved in safety compliance monitoring.

2.1 Resource-saving measures

2.1.1 Main environment protection measures implemented at SS Rivne NPP

Resource-saving measures include the use of land, water, as well as fuel and energy resources:

- most efficient use of the territory allotted for permanent use by SS Rivne NPP;
- location of SS Rivne NPP at sufficient distance from the residential area, objects of the nature reserve fund, historical and cultural objects;
- use of circulating process water supply;
- storage of spent nuclear fuel in specially designated locations for the purpose of possible future use.

Protective measures include:

- use of localization barriers in accordance with the multilevel protection concept;
- use of closed radioactive media circuits;
- circuit I systems under pressure are located inside the containment;
- use of intermediate cooling water circuit;
- industrial premises are divided into strict and free regime zones;
- ventilation systems are divided into strict and free regime zones;
- collection and treatment of radioactive leaks;
- collection of liquid and solid radioactive waste;
- radiation and climatic conditions are maintained in industrial premises using the ventilation systems;
- reactor compartment accident localization system;

- special localization systems preventing spreading of radioactive substances into the environment;
- SPZ arrangement and outfitting;
- control of the radiation state in the SPZ and OZ;
- monitoring of pollutant releases;
- monitoring of radioactive aerosols concentration;
- air purification to remove gaseous radioactive contamination;
- specific activity monitoring of the process water leaving emergency core cooling system heat exchangers with alarming at the operator’s console;
- use of stainless steel pipes for special-purpose sewerage system;
- sewage treatment in the special water treatment system and further re-use within the power plant;
- regular preventive maintenance of the water supply facilities at the NPP;
- operation of drainage and water drawdown systems at the SS Rivne NPP industrial site;
- gutter systems for buildings and industrial sewage system for the site;
- technological processes are executed according to technological instructions;
- maintenance and preventive works are performed according to schedules;
- hermetic process, gas-cleaning equipment and duct systems;
- timely and regular cleaning of GTU;
- continuous monitoring of the ventilation systems condition;
- containers with acids, ammonia, sodium hydroxide, lime, as well as fuel and lubricants are installed on drip pans;
- wet cleaning of industrial premises;
- monitoring and cleaning of power unit roofs from snow during the winter;
- lightning protection of the industrial site buildings and structures;
- individual protective equipment for the SS Rivne NPP personnel;
- land improvement of the SS Rivne NPP territory.

Restorative and compensatory measures.

Every year the SS Rivne NPP industrial site territory undergoes vegetation restoration by reconstructing lawns, planting trees, bushes and flowers.

The following economic measures are employed to stimulate activities aimed at reducing the impact on the environment as well as provide their compensation:

- establishment of limits on the use of natural resources, emissions of pollutants;
- establishment of tariffs for the use of natural resources, emissions of pollutants;
- indemnification of damages caused by violation of the current legislation in accordance with the established procedure;
- promotion of local economy, small and medium-sized businesses, providing direct or indirect services related to the SS Rivne NPP activity;
- receiving profits from certain investments made by SS Rivne NPP in infrastructure of the satellite-town of Varash.

Safety measures include monitoring of the territory influenced by the SS Rivne NPP operations and the warning system for the relevant authorities and the population.

2.1.2 Land resources

The land plot with an area of 217.895 hectares intended for operation of electricity production and distribution facilities is provided for permanent use by SE NNEGC Energoatom and is certified by the State Act YaYa series No. 252100 (ЯЯ № 252100) on the right of permanent use of the land plot dated 01.07.2006, issued on the basis of Decision No. 433 of the Kuznetsov City Council dated 28.04.2005. № 433.

In addition to the land plot for SS Rivne NPP power units, additional land plots with the total area of 161.3 hectares located in the territory of the Varash City Council and Volodymyrets and Manevytsky districts are allotted for permanent use by SE NNEGC Energoatom for operation of industrial and social facilities.

Conservation and rational use of land resources is ensured by the most efficient use of the allotted area. The territory is levelled, the area with power units is tidy and landscaped. Additional allocation of land for power units No. 1-4 lifetime extension is not required.

2.1.3 Water resources

SS Rivne NPP is the largest consumer of water from natural sources. Under the permit terms, the nuclear power plant has the right to take water from the Stir River in the amount of 73.164 million m^3 per year without inducing damage to the environment. In fact, the power station uses smaller water amounts. Each cubic meter of river water is used up to one hundred times in the Rivne NPP cooling system.

Water use at SS Rivne NPP is carried out on the basis of permit for special water use UKR No. 1/Rvn (УКР №1/Рвн) dated 06.08.2015, which is valid till 06.08.2020.

Process water supply to cover losses in the circulating water supply system (evaporation in cooling towers and from water surfaces of canals, losses due to ventilation and filtration, system purging) is carried out from the Styr River at the auxiliary water pumping station (water intake limit is 73,164 thous. m^3 per year, 267,840 m^3 per day, 2.32 m^3 per second). Water loses are negligible due to specially taken measures (water trapping devices, slope of the territory towards the cooling towers).

At an average annual wind speed of 3.9 m/s, water loses at cooling towers amount to 0.15 % of the circulating water, from sprinkling basins - 2 % (in total - 0.23 % of the circulating water consumption). Tap water supply for SS Rivne NPP is carried out from the underground water intake Rafalivske-1 (Ostriv village), which has 9 wells (with water intake limit of 3386 thous. m^3 per year, 9277 m^3 per day).

The enterprise has developed "Rates of average annual water consumption and drainage per unit of production".

SS Rivne NPP cooling water supply system consists of circulating water systems, circulating cooling systems for critical consumers (ensuring safety of SS Rivne NPP) and non-critical consumers (normal operation equipment).

Water loses are negligible due to specially taken measures (water trapping devices, slope of the territory towards the cooling towers). At an average annual wind speed of 3.9 m/s, water loses at cooling towers amount to 0.15 % of the circulating water, from sprinkling basins - 2 % (in total - 0.23 % of the circulating water consumption).

The amount of water used for purging of the cooling towers is 0.42 % of the circulating water. Presently, six single-type cooling towers are in operation. Losses of the circulating water for power units No. 1, 2 amount to 91,000 m^3/h per unit, for power units No. 3, 4 - 188,920 m^3/h per unit.

To ensure the rational use of natural resources, waste water contaminated with petroleum products is reused after treatment, as well as the rainwater.

The volumes of process water taken, used, lost (due to evaporation from cooling towers and water surfaces, entrainment by wind, filtration into the soil), reused, circulating water, discharged (returned) to the Styr River are accounted and displayed in the statistical reporting documentation, form 2-TP (water management).

Amounts of surface water from the Styr River, waste water discharge depending on electricity generation, circulation water supply, re-used water for the period from 2010 to 2017 are given in Table 2.1.

Table 2.1. Data on the use of surface water from the Styr River over the past 7 years.

Year	Electricity production, million kW×h	Water withdrawal from the Styr River, thous, m^3	Discharge of sewage to the Styr River, thous. m^3	Circulation water supply, thous. m^3	Reused water, thous. m^3
2010	16841.2	51003.7	13838.6	3672402.4	981.438
2011	17551.7	55011.2	13061.9	4023911.9	1347.2
2012	17891.9	55066.5	12952.6	4131547.5	1846.3
2013	16158.8	48746.9	10875.8	3912077.3	1790.3
2014	18238.9	54547.3	13774.6	4160324.5	1744.3
2015	18932.0	55848.7	12512.0	4235410.4	1501.7
2016	17468.2	50063.0	11505.6	3853860.1	1495.3
2017	19792.8	58493.3	12788.3	4235537.0	1623.1

SS Rivne NPP extracts drinking underground fresh water for centralized and non-centralized water supply (except for the production of packaged fresh water) from the Rafalovske-1 field, which is located on the western outskirts of the Ostriv village, Volodymyrets district, Rivne region. The subsoil use is carried out on the basis of special permit No. 22633 dated 09.10.2000 with validity term of 20 years, which was re-issued on 19.06.2015 in connection with the change of legal address of SE NNEGC Energoatom (street renamed).

The primary withdrawal is performed from 9 wells with a depth of 130 to 350 m. The water taken is being recorded and accounted. 2 clean water tanks with a volume of 1000 m^3/each are installed at the secondary withdrawal station. Limit for withdrawal of underground water from artesian wells at the Ostriv village is 3386.0 thous. m^3 per year. In addition, underground drinking water from artesian wells is extracted on the territory to ensure tap water needs of “White Lake” rehabilitation and recreational complex with a water withdrawal limit of 12.8 thous. m^3 per year.

Artesian water is used exclusively for domestic and drinking needs.

2.1.4 Fuel and energy resources

SS Rivne NPP utilizes 8 % of the total electric-power generation for auxiliary needs. In order to reduce these costs certain measures are taken at SS Rivne NPP: energy-saving lamps are installed, consideration of the possibility of replacement of the existing equipment with more energy-efficient (pumps).

In order to further reduce energy consumption, the NPP also takes measures to reduce fuel consumption by transport vehicles.

2.2 Protective measures

SS Rivne NPP was designed in accordance with the requirements of the regulatory documents and the emergency response system is in operation, which is an interconnected set of technical means and resources, organizational, technical, radiation and hygienic measures implemented by SE NNEGC Energoatom to prevent or reduce radiation exposure to personnel, the population and the environment in the event of a nuclear or radiation accident at the NPP, as well as to provide civil defence.

According to the document [13], the emergency preparedness and response system (ERS) of SS Rivne NPP is defined as a component of the Preparedness and Response System of SE NNEGC Energoatom for the event of accidents and emergencies on NPPs of Ukraine, which is an interconnected set of technical means and resources, organizational, technical, radiation and hygienic measures implemented by the operating organization to prevent or reduce radiation exposure to personnel, population and the environment in the event of a nuclear or radiation accident at the NPP.

ERS has two interrelated levels:

- Level of SE NNEGC Energoatom Directorate (Company's Management level ERS);
- NPP level (NPP ERS).

The main goals of SS Rivne NPP ERS are:

- maintenance of the required level of SS Rivne NPP emergency preparedness;
- response to accidents and emergency situations at SS Rivne NPP including implementation of measures to protect personnel, population and the environment.

The main SS Rivne NPP ERS measures to maintain the required level of emergency preparedness are:

- development and timely review of the emergency plan;
- outfitting and maintaining the technical support centre and internal and external crisis centres in good working condition;
- arrangement of interaction with the SE NNEGC Energoatom crisis centre, centre for organization of interaction and assistance to NPPs, Information Centre of the State Regulatory Authority for Nuclear and Radiation Safety, and regional and local authorities of the territorial and functional subsystems of the unified civil defence system;
- maintaining in good working condition and improving the system for collecting, processing, documenting, storing, displaying and transmitting data from SS Rivne NPP crisis centres, alarming and communication systems;
- timely creation and maintaining the preparedness state of the emergency system: control and measuring devices and equipment, personal protective equipment, decontamination and sanitation means, tools, devices and other emergency means;

- training of emergency personnel, emergency training, including plantwide emergency training, development of schedules and training programs;

- maintaining and updating regulative, organizational and process documentation for emergency preparedness and response;

- ensuring accident response readiness in case of commissioning of new radiation-hazardous objects at SS Rivne NPP.

The main accident and emergency response measures at SS Rivne NPP ERS are:

- identification and classification of accidents and other hazardous events at SS Rivne NPP;

- alarming for SS Rivne NPP management and personnel, the population of the neighbouring town, responsible persons of the operating organization, the state regulatory body for nuclear and radiation safety, central and local executive authorities, local self-government bodies, other bodies, institutions and organizations participating in emergency response, informing them about the occurrence of an accident and initiated countermeasures;

- introduction of the emergency plan, cancellation of actions according to this plan;

- support of the main control room personnel, operational staff of SS Rivne NPP related to beyond design basis accident management;

- estimation and forecasting of accident scenarios, consequences, estimation of radioactive substances releases and discharges, monitoring and prediction of radiation condition changes, personnel exposure doses;

- implementation of works on the accident consequences elimination, including urgent emergency construction, repair and other works;

- logistic support of emergency measures;

- implementation of measures for the protection of SS Rivne NPP, radioactive contamination zones;

- interaction with the state regulatory body for nuclear and radiation safety;

- interaction with management bodies and forces of the “Nuclear power and fuel and energy complex” functional subsystem of the Ministry of Energy and Coal Industry of Ukraine, other territorial and functional subsystems of the unified civil defence system involved in emergency response;

- documenting the accident conditions and emergency response measures. The main ERS measures for personnel protection are:

- personnel radiation protection measures;

- delivery of health care.

The main ERS activities for the protection of population and the environment are:

- in-depth monitoring of radiation parameters for the environmental objects and population exposure doses within the OZ;

- prediction of population radiation exposure doses within the OZ;

- informing central and local executive authorities, as well as local self-government, about the results of monitoring and exposure dose prediction;

- providing recommendations to central and local executive authorities as well as local self-government bodies on countermeasures to protect the population.

Emergency response actions performed by the NPP with the exception of measures for the protection of the population and the environment are limited to the NPP site and the sanitary protection zone. The population and the environment protection measures performed at the NPP are limited to the observation zone.

2.3 Compensation measures

2.3.1 Compensation for environmental damage

During the last years, the legal management of SS Rivne NPP has not received any materials that should be interpreted as claims requesting for compensation for environmental damage, or these claims were not acknowledged in the procedure established by law. Cases of penalty payment by the accounting department of SS Rivne NPP for violating the legislation on environmental protection. These amounts were deducted in full from the wages of employees in accordance with Article 132 of the Labour Code of Ukraine.

2.3.2 Social and economic management of risk for population within the observation zone around the NPP

SS Rivne NPP is not only an environmentally friendly site for the production of thermal and electric energy, it also has an annual social guarantee in the form of a state subvention, which adds to budgets of settlements within the nuclear facility observation zone.

In accordance with the current legislation of Ukraine, the population permanently residing within the 30-kilometre observation zone around NPP has the right to receive social and economic compensation for risks caused by operation of NPP, which particularly includes: development and maintenance of a special-purpose social infrastructure in good condition, preferential tariffs for the consumed electric energy set in accordance with the Law of Ukraine “On Electricity” [14].

According to the Resolution of the Cabinet of Ministers of Ukraine, the distribution of state subventions between local budgets of settlement within the observation zones of nuclear power plants is as follows:

- 30 % - for regional budgets;
- 55 % - for district and regional subordination city budgets;
- 15 % - for budgets of satellite-towns of nuclear facilities.

These funds are used exclusively for the purposes and in the manner established by the Cabinet of Ministers of Ukraine.

Subventions are directed, first of all, for:

- construction, reconstruction, capital and current repair of facilities of special social infrastructure and protective structures of civil defence;
- purchase of respiratory protective equipment and stable iodine pills;
- population training on the use of protective equipment and civil defence facilities.

Control over the purposeful use of funds by local authorities and local self-government bodies is carried out in accordance with the current legislation.

Taking into account the subvention amounts for socio-economic compensation for risks to the population within the observation zone, Rivne NPP is the main budget-forming enterprise in the region contributing to its sustainable economic development.

In 2017, the government directed more than 32 million hryvnias (UAH) of state subsidies to finance social and economic compensation measures for the population living in the OZ of SS Rivne NPP.

Distribution of subventions to local budgets in 2017 was as follows:

- Rivne region (regional share) - UAH 7 million 18.3 thousand;
- Volyn region (regional share) - UAH 2 million 757.9 thousand;
- Manevitsky district (Volyn region) - UAH 7 million 227.6 thousand;
- Volodymyrets district (Rivne region) - UAH 9 million 895.9 thousand;
- Sarny district (Rivne region) - UAH 646 thousand;
- Kostopilsky district (Rivne region) - UAH 153.6 thousand;
- Town of Varash (Rivne region) - UAH 4 million 888.1 thousand.

2.4 Protection measures

2.4.1 Radioactive fallout protection measures

Warning or mitigation of radioactive emissions is ensured by the following technical solutions:

- cleaning of air containing radioactive substances by means of filters;
- using closed loops to prevent leaks of liquid substances containing radioactive components;
- arrangement of a special system for collecting and storing LRW and SRW;
- establishment of SPZ and OZ;
- ongoing monitoring of emissions into the air, as well as levels of radioactive contamination of soils, flora and water in the SPZ and OZ.

2.4.2 Non-radiation impact protection measures

Appropriate organizational measures taken to ensure stable operation of SS Rivne NPP power units are as follows:

- hydrological station has been put into operation on the Styr River in Varash (downstream of the water intake and discharge of Rivne NPP);
- power units regime schedule based on condition of the Styr River has been developed; the Styr River.
- purification of one hundred percent of added water for feeding water circulation systems at the make-up water treatment facilities (MWTF);
- minimum sanitary water consumption from the Styr River during the low-water months of the year;
- the following instrumental measurements are carried out by a certified laboratory: industrial emissions into the atmosphere from stationary sources; circulation and surface waters; soils, underground waters and atmospheric air in the areas of waste disposal sites. The results are recorded in the primary accounting documents;
- hazardous waste is removed, as well as secondary raw materials are sold;
- civil liability insurance to cover environmental accidents at SS Rivne NPP and insurance for hazardous goods transportation;
- subdivisions carry out primary accounting of emissions, water use, wastes, develop and submit environmental protection reports to the management of SS Rivne NPP, SE NNEGC Energoatom, tax inspectorate, as well as state statistics, management and supervision bodies;
- maintenance, repair and reconstruction of production assets related to environmental protection is carried out;

- in-house supervision, including instrumental and laboratory supervision, is ensured as well as inspections of the environmental protection legislation compliance at SS Rivne NPP by state supervisory bodies;

- environmental tax and rent payments for the use of natural resources (water) are calculated and paid.

Scheduled environment protection measures are carried out in due time; work progress monitoring system is established and operating. The industrial activity of SS Rivne NPP does result in any adverse changes in the environment.

2.4.2.1 Monitoring of SS Rivne NPP environmental effect due to non-radiation factors

SS Rivne NPP has a process model of an integrated management system. The owner of the "Ecological Management" process, which covers non-radiation impact of SS Rivne NPP on the environment, is the head of the environmental protection service (EPS). In addition to environmental protection service, the process participants are:

- production and technical service, which fills 2-TP form (water management) based on primary data on water collected from natural sources and discharged into the water bodies;

- buildings and structures operation service, which monitors the hydrogeological regime of groundwater;

- hydraulic engineering shop that supervises and monitors the hydrological state of the Styr River at the hydrological station;

- maintenance department that carries out collection and removal of household waste, as well disposal of non-radioactive industrial waste at the SS Rivne NPP landfill;

- other subdivisions related to aspects of non-radiation impact on the environment.

The result of the "Environmental Management" process is the implementation of Integrated Management System of SS Rivne NPP. Environmental protection program 083-1-25-QA-02/2017 [15] aimed at ensuring environmental safety, monitoring the impact of SS Rivne NPP on environment, management of household and industrial wastes (generation, transportation, disposal), etc.

2.4.2.2 Air protection

Emissions of pollutants into the air from stationary sources are based on the permits issued by regional representatives of the Ministry of Environmental Protection of Ukraine No. 5620881201-1 and permits issued by the Department of Ecology and Natural Resources of the Rivne Regional State Administration No. 5610700000-8 dated 30.05.2018 (valid for 10 years), 5610700000-11 dated 05.12.18 (valid for 10 years), 5610700000-12, 5610700000-13 dated 24.10.2014 (unlimited validity), 5610700000-14 dated 24.10.2014 (valid for 10 years) and permit No 5610700000-16 dated 24.10.2014 (without limitation as to period of validity) [16].

SS Rivne NPP has 240 stationary sources of pollutant emission into the atmospheric air, 14 of them outfitted with gas treatment modules. The largest sources of air pollution of SS Rivne NPP are auxiliary facilities: Start-up and standby boiler house (SSB), diesel generators, as well as transportation means. SS Rivne NPP owns 142 diesel and 148 gasoline vehicles, as well as 4 diesel locomotives, 1 rail crane, 1 gasoline locomotive and 1 motor trolley. The transport shop has a diagnostic station for measuring the toxicity and smoke content in the exhaust gases. Diagnostics is conducted quarterly with corresponding records made in accounting journals.

Data on emission of pollutants into the atmosphere from stationary sources for 2016 according to the statistical reporting form No. 2-TP (air) are given in Table 2.2.

Table 2.2. Emissions of pollutants into the atmosphere from stationary sources.

Contaminant, greenhouse gas and group code	Contaminants	Emissions from the beginning of the year, t
00000	Total for the enterprise (excluding carbon dioxide)	34.785
01000	Metals and their compounds	0.203
03000	Substances in a form of suspended solid particles (micro particles and fibres)	2.237
04000	Nitrogen compounds	8.582
05000	Dioxide and other sulphur compounds	1.510
06000	Carbon monoxide	3.356
11000	Non-metallic volatile organic compounds	18.810
12000	Methane	0.004
15000	Chlorine	0.012
16000	Fluorine and its compounds (expressed in fluorine)	0.034
18000	Freons	0.037
07000	Carbon dioxide, additionally	109.691

To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for emissions into the air by stationary sources has been developed and approved.

According to the concluded agreement with the state institution Rivne Regional Laboratory Centre of the Ministry of Health of Ukraine, measurement of the pollutant contents in the scheduled emissions from stationary sources during the reporting period was carried out at the SS Rivne NPP (Record No. 45 dated 07.06.2016).

In 2017, mobile sources of SS Rivne NPP utilized 507.072 t of diesel fuel and 397.989 t of unleaded petrol.

The volumes of emissions into the atmosphere over the past 6 years are given in Table 2.3, based on which the emission dynamics diagram is formed (Fig. 2.1).

Table 2.3. Dynamics of volumes of pollutant emissions into the atmosphere from stationary sources

Pollutant name	Pollutant emissions, t/year				
	2013	2014	2015	2016	2017
Total for the enterprise (excluding carbon dioxide)	37.283	37.799	35.359	33.827	34.785
Metals and their compounds	0.099	0.332	0.146	0.307	0.203

Pollutant name	Pollutant emissions, t/year				
	2013	2014	2015	2016	2017
Substances in a form of suspended solids (particles and fibres)	2.697	2.425	1.765	1.380	2.239
Nitrogen compounds	5.668	5.690	6.698	6.574	8.582
Dioxide and other sulphur compounds	2.652	1.819	1.744	1.417	1.510
Carbon monoxide	2.649	2.365	2.723	2.561	3.356
Non-methane volatile organic compounds	23.428	25.037	22.181	21.463	18.815
Chlorine	0.012	0.005	0.006	0.003	0.004
Methane	0.011	0.012	0.014	0.0120	0.012
Fluorine and its compounds (expressed in fluorine)	0.034	0.067	0.043	0.076	0.035
Freons	0.026	0.044	0.039	0.0342	0.037
Carbon dioxide, additionally	212.98	125.43	159.69	88.565	109.22

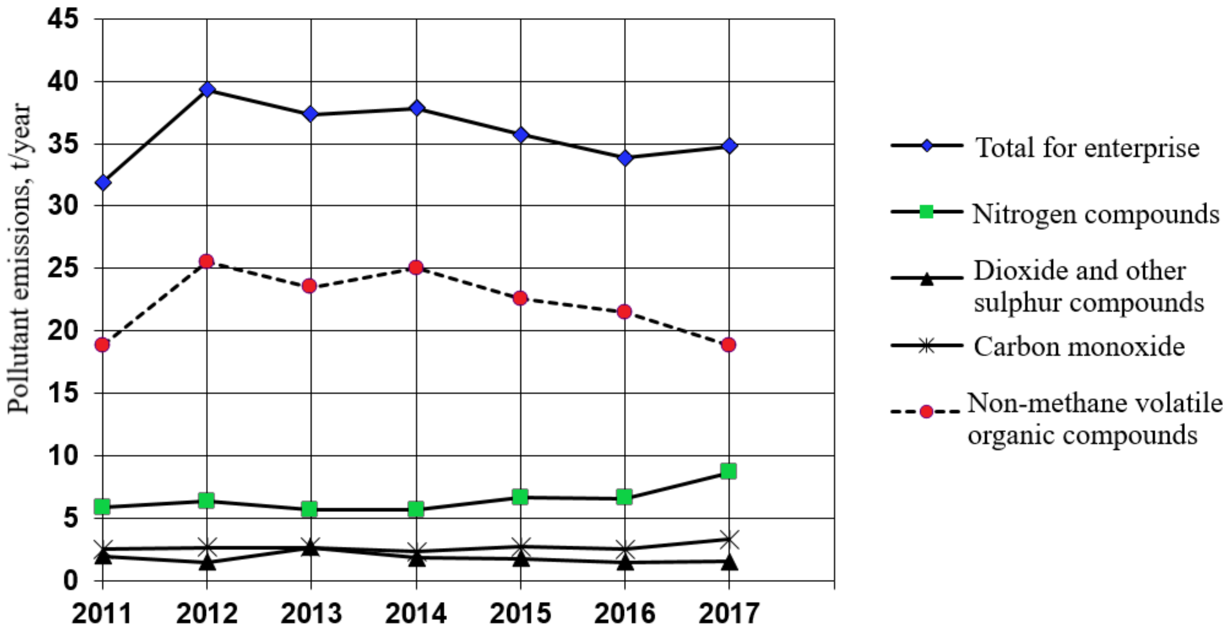

Fig. 2.1 Dynamics of volumes of pollutant emissions into the atmosphere from stationary sources

“White Lake” rehabilitation and recreational complex with 1 air emission source - a woodworking machine equipped with a cyclone separator - was in operation during summer months of the year.

No emissions of pollutants into the atmosphere from “White Lake” rehabilitation and recreational complex has been made in 2017. The dynamics of emission volumes for 2010-2017 period - in Table 2.4.

Table 2.4. Dynamics of volumes of pollutant emissions into the atmosphere from stationary sources for SS Rivne NPP "White Lake" rehabilitation and recreational complex.

Pollutant name	Pollutant emissions, t/year						
	2011	2012	2013	2014	2015	2016	2017
Total for the enterprise (excluding carbon dioxide)	0.023	0.009	0.005	0.003	0.003	0.001	0.000
Metals and their compounds	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Substances in a form of suspended solids (particles and fibres)	0.023	0.0087	0.005	0.003	0.003	0.001	0.000
Nitrogen compounds	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dioxide and other sulphur compounds	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Carbon monoxide	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Non-metallic volatile organic compounds	0.000	0.000	0.000	0.000	0.000	0.000	0.,000
Methane	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluorine and its compounds (expressed in fluorine)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Freons	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Carbon dioxide, additionally	0.000	0.000	0.000	0.000	0.000	0.000	0.000

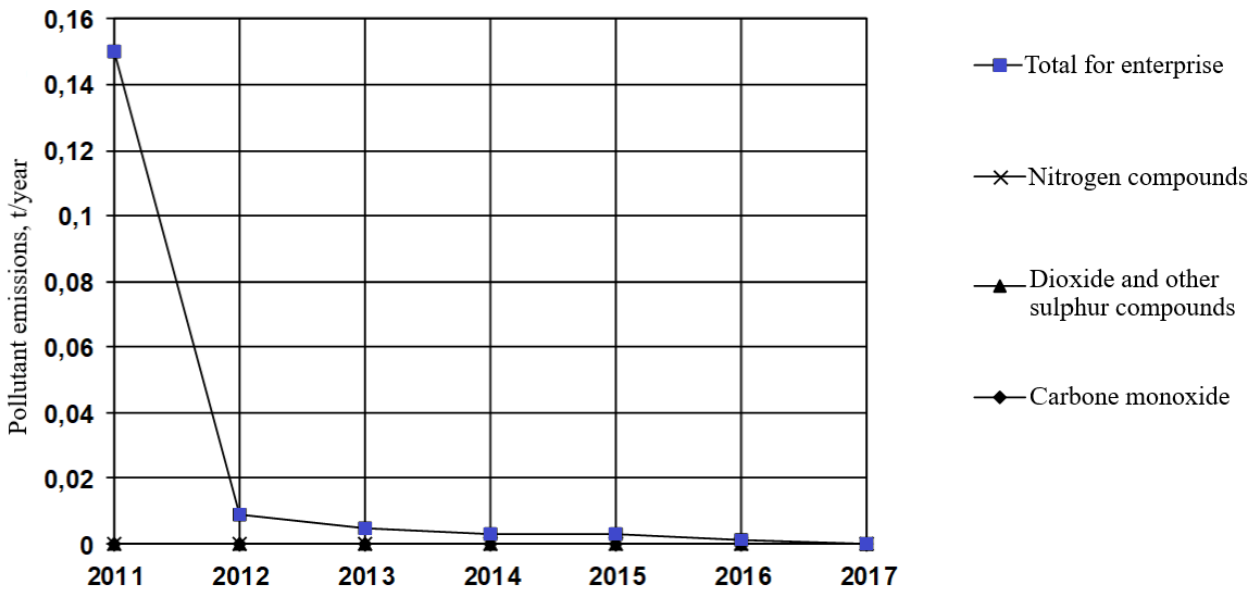

Fig. 2.2 Dynamics of volumes of pollutant emissions into the atmosphere from stationary sources for SS Rivne NPP "White Lake" rehabilitation and recreational complex

Small amount of air emissions from “White Lake” rehabilitation and recreational complex since 2012 is due to the replacement of coal boilers by electric heaters.

Emissions of pollutants into the atmosphere at SS Rivne NPP comply to the requirements of the emission permits. The amount of raw materials and other resources used in 2017 does not exceed the values established by the regulating documents.

2.5 Water use

Water use at SS Rivne NPP is carried out in accordance with Special permit for water use UKR No. 1/Rvn (УКР № 1/Рвн) dated 06.08.2015 (valid till 06.08.2020). The limit of water withdraw from the river is 73,164 thous. m^3 per year (267.840 thous. m^3 per day), from underground horizons - 3386.0 thous. m^3 per year (9277.0 m^3 per day) [16].

SS Rivne NPP water supply for feeding circulation systems and other process needs is carried out from the Styr River.

Household and drinking water supply is carried out from the Rafalovske-1 field water intake of Osrtriv village. Water intake has 9 artesian wells.

Water intake from the Styr River is outfitted with stationary electric voltage gradient fish protection and revolving grids together with a protective curtain. Accounting of the collected water is carried out with the help of water meters: two Ergomer-120 ultrasonic liquid meters on water pipes and two KS-2-004 diaphragm type backup devices on the pump head. Withdrawn water is recorded in logs according to the standard form POD-11.

In 2017, 58,573,110 m^3 of water was taken from the Styr River. From that volume, 58,493,393 m^3 was used for the production needs.

First belt sanitary protection zones are specifically allocated and fenced. Water accounting is performed at the second intake station by three Vzlet RS-U URSV-010 ultrasonic water meters. 2 clean water tanks with a volume of 1000 m^3/each are installed at the secondary withdrawal station. Withdrawal of underground water from artesian wells at the Island village for 2017 amounted to 1,607,663 thous. m^3.

Summary data on the use of river (process) and underground (drinking) water by SS Rivne NPP, as well as data on drainage are given in Table 2.5. Tap water for the needs “White Lake” rehabilitation and recreational complex is supplied from the artesian well. The water withdrawal limit is 12.8 thous. m^3 per year. 6.25 thous. m^3 of underground water was withdrawn in 2017 according to the form 2-TP (water management).

Table 2.5. Summary data on water use by SS Rivne NPP [16].

No	Water and source type	Limit, thous. m^3	Withdrawn by quarter, thous. m^3	Withdrawn year-to-date, thous. m^3	Actually used by quarter, thous. m^3	Actually used year-to-date, thous. m^3
1	Process water from the Styr River	73164	14420.540	58573.110	14414.318	58493.393
2	Artesian water from Ostriv village	3596	392.678	1607.663	119.069	583.636

No	Water and source type	Limit, thous. m^3	Withdrawn by quarter, thous. m^3	Withdrawn year-to-date, thous. m^3	Actually used by quarter, thous. m^3	Actually used year-to-date, thous. m^3
3	Artesian water from “White Lake” rehabilitation and recreational complex	12.8	-	6.25	-	6.25

Water from SS Rivne NPP industrial site is discharged through a gravity header of industrial/storm sewerage (ISS) via a single outlet into the Styr River as water compliant to regulatory quality parameters without purification. According to the form 2-TP (water management) the discharge of return water into the Styr River made 12,788.332 thous. m^3 in 2017.

In addition to the industrial/storm sewage system, the following non-radioactive waste water is collected from the territory of the NPP industrial site by other sewage systems: domestic sewage, waste water, polluted with petroleum products, rainwater. Treatment plants for drainage water contaminated with petroleum products and settling tank for rainwater collected from the industrial site (except for rainwater from the territory of power units No. 1, 2) are not connected with the river. Drainage water purified in these structures is used in circulating systems.

Domestic sewage from the industrial site is fed to treatment facilities with a capacity of 700 m^3 per day. Treatment facilities consist of an inlet chamber, two sand separators, primary settling tanks, aerotanks, secondary settling tanks and sludge ponds. After purification, waste water is fed to the municipal waste water treatment plant. Water discharged after treatment in the municipal waste water treatment plant amounted to 120.738 m^3 in 2017.

The number of pollutants discharged into the water body with the return water from SS Rivne NPP is given in Table 2.7.

Table 2.6 Pollutants in return waters excluding background concentrations

No	Parameter	Water body, receiver of return water	Approved permissible concentrations, mg/dm^3	MPC t/year	Average concentration (ISS - background) mg/dm^3	Total water withdrawn per year thous. m^3	Actual discharge of contaminants, t
1	BOD-5	Styr River	5.75	105.9	0.068	12788.332	0.869607
2	Suspended matter		15.0	276.1	2.510	12788.332	32.09871
3	Mineralization		1000	18409	325.486	12788.332	4162.423
4	Chlorides		200.0	3681.8	41.458	12788.332	530.1787
5	Sulphates		250	4602.3	132.860	12788.332	1699.058
6	Ammonium nitrogen		1.08	19.88	0.131	12788.332	1.675271
7	Nitrates		40.04	737.1	17.212	12788.332	220.1128
8	Nitrites		0.197	3.627	0.000	12788.332	0.0000
9	Petroleum products		0.32	5.861	0.009	12788.332	0.115095
10	Ferrum		0.502	9.241	0.041	12788.332	0.524322

11	Zinc		0.031	0.571	0.003	12788.332	0.038365
12	Copper		0.301	5.541	0.152	12788.332	1.943826
13	Phosphates		3.12	57.44	0.096	12788.332	1.22768
14	Synthetic surface active substances		0.200	3.682	0.011	12788.332	0.140672
15	Oxyethylene diphosphonic acid		0.9	16.57	0.226	12788.332	2.890163
16	Monoethanolamine		0.010	0.184	0.005	12788.332	0.063942
17	Na polyacrylate		4.0	73.64	-	-	-

Waste water from "White Lake" rehabilitation and recreational complex is fed to a pumping station with built-in biological treatment unit, which was put into operation in 2006.

The treated and disinfected water undergoes tertiary treatment at the bioengineering facility (biopond), then enters the reclamation channel and then - the Styr River. According to the results of the departmental environment protection chemical laboratory, the treatment facilities of "White Lake" rehabilitation and recreational complex operated efficiently in 2017. The discharge of treated waste water to the reclamation channel made 6.25 thous. m^3.

Amounts of pollutants discharged into the water body with the return water from SS Rivne NPP "White Lake" rehabilitation and recreational complex is given in Table 2.7.

Table 2.7. Amounts of pollutants discharged into the water body with the return water from SS Rivne NPP "White Lake" rehabilitation and recreational complex.

No.	Parameters	Water body, receiver of return water	Approved permissible concentrations, mg/dm^3	MPC t/year	Average concentration, mg/dm^3	Total water discharged, thous. m	Actual contaminants discharge, t
1	BOD-5	p. Styr River	19.60	0.2352	4.276	6.25	0.00428
2	Suspended matter		23.25	0.2790	9.342	6.25	0.00934
3	Chlorides		150.0	1.800	3.882	6.25	0.00388
4	Sulphates		100.0	1.200	18.884	6.25	0.11803
5	Ammonium nitrogen		4.09	0.0491	0.716	6.25	0.00072
6	Nitrates		20.00	0.2400	1.651	6.25	0.00165
7	Nitrites		3.300	0.0396	0.175	6.25	0.00018
8	Petroleum products		0.1000	0.00120	0.046	6.25	0.00005
9	Ferrum		0.6760	0.00811	0.261	6.25	0.00026
10	Phosphates		6.860	0.08232	0.627	6.25	0.00063
11	Synthetic surface active substances		0.200	0.0024	0.006	6.25	0.00001

Data on water use at SS Rivne NPP for the last 6 years are given in Table 2.9.

Table 2.9. Dynamics of water use volumes at SS Rivne NPP

Water supply source	Consumed water, thous. m^3					
	2012	2013	2014	2015	2016	2017
Process water	55066	48746	54547	55848.763	50145.260	58573,110
Artesian water	1914/321*	1744/344*	1705/361*	1700/385*	1632/531*	1607/583*

/ * - water taken from the water supply source/used at the enterprise

In general, water use at SS Rivne NPP is carried out in accordance with the established limits, as well as special water use and MPC requirements. The volumes of river and artesian water used, expressed as percentage of the limit, is given in Table 2.10.

Table 2.10. Volume of river water used

Water	% of limit					
	2012	2013	2014	2015	2016	2017
Volume of river water used	75.26	66.74	75.01	76.8	68.84	80,05
Volume of artesian water used	53.22	53.56	55.87	59.87	82.62	44,68

2.6 Protection of water resources

Technical design solution on cooling of process water in cooling towers and spray pools (instead of a cooling pond) allowed minimizing adverse impact of the plant on the ecosystem and preserving the valuable floodplain of the Styr River with its meadow, shrub, and forest animal complexes. SS Rivne NPP cooling water supply system consists of circulating water systems, circulating cooling systems for critical consumers (ensuring safety of SS Rivne NPP) and non-critical consumers (normal operation equipment).

Water loses are negligible due to specially taken measures (water trapping devices, slope of the territory towards the cooling towers). At an average annual wind speed of 3.9 m/s, water loses at cooling towers amount to 0.15 % of the circulating water, from sprinkling basins - 2 % (in total - 0.23 % of the circulating water consumption). The amount of water used for purging of the cooling towers is 0.42 % of the circulating water.

Water from the circulation system purging and other return water from the NPP industrial site is collected by the industrial-storm sewage system and is discharged into the river through one outlet, which is located 30 m downstream of the water intake. Special permit for water use includes discharge of up to 18409.0 thous. m^3 of water per year.

In fact, in 2017, SS Rivne NPP discharged 111.106 thous. m^3 of water that complies with the regulatory quality parameters.

Chemical composition of the return water, river water upstream of the SS Rivne NPP water intake, as well as downstream of the discharge is monitored by the certified laboratory stations. Laboratory of the Heating and Underground Utilities workshop takes and analyses samples at least 6 times a day (for petroleum products and pH). The environment protection and chemical laboratory of the environmental protection service (EPS) has conducted 7011 laboratory tests of surface water and return (sewage) water in 2017. The analysis results for the parameters being monitored indicate that the allowable discharge limits (in tonnes) were not exceeded in 2017, and operation of SS Rivne NPP does not introduce significant changes into the quality of surface water.

Average surface water quality indicators for 2017 are given in Table 2.11.

Table 2.11. Average indicators of surface water condition [16].

No	Item	MPC_{year}, mg/dm^3	Approved permissible concentrations, mg/dm^3	ISS mg/dm^3 per year	River (upstream of the NPP) mg/dm^3 per year	River (downstream of the NPP), mg/dm^3 per year
1	Mineralization	Not specified	1000	693.01	367.52	399.5
2	Sulphates	100	250.0	192.98	60.12	61.28
3	Chlorides	300	200.0	56.14	14.68	14.23
4	Calcium	180	-	130.06	102.00	96.99
5	Magnesium	40	-	34.90	22.25	23.96
6	Ammonium nitrogen	0.39	1.08	0.551	0.482	0.536
7	Nitrites (NO^2)	0.08	0.197	0.046	0.082	0.066
8	Nitrates (NO^3)	40.0	40.04	26.38	9.165	9.802
9	Phosphates	2.14	3.12	0.506	0.420	0.417
10	Ferrum	0.10	0.502	0.257	0.249	0.267
11	Copper	0.001+ background	0.301	0.160	0.008	0.006
12	Zinc	0.01	0.031	0.008	0.006	0.006
13	Dissolved oxygen	4	4	8.67	10.53	10.17
14	Suspended matter	25.00	15.0	11.65	9.39	10.65
15	Petroleum products	0.05	0.32	0.054	0.066	0.068
16	Synthetic surface active substances	0.25	0.200	0.021	0.010	0.012
17	BOD5	3.00	5.75	1.73	2.39	2.51
18	COD	50.00	116.4	73.30	39.16	43.48
19	pH, units	6.58.8	6.5-9.0	8.63	8.23	8.27
20	Oxyethylene diphosphonic acid	0.90	0.9	0.399	0.180	0.185
21	Monoethanolamine	0.01	0.01	0.005	-	-
22	Transparency	-	> 20 cm	> 20 cm	27.99	27.90
23	Temperature, °C	Not specified	25 °C (winter) 41 °C (summer)	24.24	10.92	11.09

Analysis at the sites of slurry reservoir and landfill for construction and industrial waste of SS Rivne NPP was carried out by ecological and chemical laboratory of the EPS, which is authorized to perform measurements of the chemical composition of underground water (wells). Average underground water quality indicators for wells near waste disposal sites are shown in Table 2.12.

Table 2.12. Average underground water quality indicators for wells near waste disposal sites [16].

22.11.2017	Well of the slurry reservoir		Landfill well	
	Background 38H	25н	Background 140н	1н
Temperature °C	7.2	7.0	7.0	7.5
pH	7.92	6.08	8.01	8.24
Solids mg/dm^3	201.50	150.00	1771.50	238.50
Ca, mg eq./dm^3	2.813	1.746	2.425	1.067
Mg, mg eq./dm^3	10.616	3.539	8.257	8.257
N NH4+, mg/dm^3	0.200	0.600	0.900	2.600
NO2-, mg/dm^3	0.091	0.012	0.463	0.019
NO3-, mg/dm^3	0.392	0.102	28.095	9.770
Ferrum, mg/dm^3	0.500	0.475	2.000	0.800
Copper, mg/dm^3	0.000	0.000	0.002	0.000
Zinc	0.544	0.071	0.045	0.003
Chlorides	21.272	11.345	13.472	11.699
Anionic surface active agent	0.028	0.019	0.024	0.021
Sulphates	22.350	22.200	32.950	29.867
Petroleum products	0.055	0.052	0.114	0.041

Heating and Underground Utilities workshop and EPS of SS Rivne NPP carry out quality monitoring of underground water withdrawn from water intake of Ostriv village according to the schedule. Average underground water quality indicators for 2017 are given in Table 2.13.

Table 2.13. Average indicators of underground water quality

Sampling date	Well No.	pH, pH units	Solids, mg/dm^3	Total hardness, mg eq./dm^3	Anions, mg/dm^3			Cations, mg/dm^3			
					CL^-	SO_4^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
24.10.2017	4	7.37	309.60	3.25	60.60	18.50	164.70	61.20	2.43	29.00	8.00
24.10.2017	9	9.00	281.00	0.23	46.46	12.20	158.60	3.00	0.91	90.00	1.20
07.11.2017	10	8.22	321.00	0.17	85.68	9.60	146.40	1.80	0.97	112.00	0.45
under repair	11										
18.10.2017	12	8.90	292.60	0.35	52.23	10.50	164.70	5.21	1.09	91.00	0.50
18.10.2017	13	6.94	304.40	0.12	48.48	10.50	176.90	1.60	0.42	100.00	0.60

24.10.2017	14	9.10	306.00	0.20	52.52	19.96	164.70	2.20	1.09	98.00	1.90
18.10.2017	15	8.50	610.40	0.50	191.90	11.45	251.93	9.01	0.60	211.00	2.60
18.10.2017	16	8.40	304.60	0.30	50.50	13.20	170.80	3.90	1.27	98.00	0.90
18.10.2017	Pump of intake II	8.3	375.40	0.75	80.80	17.50	189.1	12.00	1.82	114.00	2.00

The analysis results for the parameters being monitored indicate that operation of SS Rivne NPP does not introduce significant changes into the quality of surface water. In 2017, the condition of water in the Styr River (the control section) remained at the level of values of the previous years. Quality dynamics of surface water of the Styr River (downstream of the NPP) in terms of pollutants content for the last 5 years is given in Table 2.14.

Table 2.14. Quality dynamics of surface water of the Styr River (downstream of the NPP) (by pollutant content).

Chemical pollutants	Content of pollutants/chemicals, mg/dm^3					
	2012	2013	2014	2015	2016	2017
Mineralization	351.9	411.2	339.32	393.90	414.50	374,350
Sulphates	30.093	28.711	23.79	24.52	35.90	61,281
Chlorides	16.49	12.97	13.93	15.19	17.75	14,232
Calcium, mg eq./dm^3	4.47	4.45	4.73	4.27	4.52	4,844
Magnesium, mg eq./dm^3	1.86	1.03	1.07	1.34	1.19	1,974
Ammonium nitrogen	0.45	0.487	0.391	0.442	0.46	0,536
Nitrites	0.079	0.069	0.107	0.086	0.103	0,066
Nitrates	4.652	5.35	6.96	5.74	6.63	9,802
Phosphates	0.29	0.223	0.284	0.296	0.49	0,417
Ferrum	0.512	0.422	0.400	0.394	0.269	0,267
Copper	0.013	0.002	0.004	0.008	0.006	0,006
Zinc	0.017	0.015	0.011	0.006	0.008	0,006
Dissolved oxygen	10.10	9.54	9.84	10.65	10.37	10,174
Suspended matter	6.69	6.99	7.69	9.11	9.76	10,653
Petroleum products	0.10	0.069	0.084	0.044	0.05	0,068
Synthetic surface active substances	0.025	0.01	0.016	0.018	0.013	0,012
BOD_5	2.3550	1.500	1.91	2.82	2.84	2,518
COD	41.16	42.44	45.62	54.63	39.66	43,477
pH, units	8.140	8.04	8.20	8.35	8.35	8,269
Temperature, °C	12.48	13.0	12.14	11.91	0.082	11,092

2.7 Soil protection

An area of 418.1533 ha in the territory of Kuznetsovsk (Varash) and 62.06 ha in the territory of the Volodymyretskyi District are allotted for use by SS Rivne NPP.

Table 2.15. Brief characteristics of the land used by SS Rivne NPP.

Soil types	ha
Total	480.2761
built-up land	468.7507
including:	
land for construction and maintenance of residential buildings	12.0312
public land	3.9162
land for commercial use	0.3455
land used for technical utilities	433.8881
land used for recreation purposes and other open land	30.0951

Areas allotted to SS Rivne NPP outside the city for stations of the Automated Radiation State Monitoring System (ARSMS) in village councils of the Volodymyretsky district are given in Table 2.16.

Table 2.16. Areas allotted to SS Rivne NPP outside the city.

No.	Item	Total area, ha	Permanent usage	Documentary allocation justification
1	Lozkivska village council	0.0700	0.0700	State Certificate ЯЯЯ No. 272079 dated 29 June 2006
2	Polytska village council	0.0400	0.0400	State Certificate II-PB No. 001898 dated 20 November 2000
3	Velykozholudska village council	0.1100	0.1100	State Certificate II-PB No. 001899 dated 20 November 2000
4	Lyubakhivska village council	0.0770	0.0770	State Certificate II-PB No. 001900 dated 20 November 2000
5	Bielsko-Vilska village council	0.0500	0.0500	State Certificate ЯЯЯ No. 272073 dated 29 June 2006
6	Sopachivska village council	0.0520	0.0520	State Certificate II-PB No. 001901 dated 20 November 2000
	Total:	0.3990	0.3990	

SS Rivne NPP records green planting in the territory. The total number of landscape objects assigned to Rivne NPP is given in Table 2.17.

Table 2.17. Accounting for green areas in the territory of SS Rivne NPP.

Landscape objects	2017
Lawns	9.0 ha
Flower beds	1310 $м^2$
Hedge	4,350 m
Separate bushes	2101 pcs
Trees	4571 pcs

2.8 Hydrogeological observations

Hydrogeological observations of groundwater regime.

Hydrogeological observations of groundwater regime were performed according to the schedule at 193 wells of the stationary observation hydrogeological network in accordance with the Integrated Program for Monitoring of the Geological and Natural and Man-Made Environment at SS Rivne NPP [17] (including 21 wells for level and temperature monitoring only: WRP), including:

- for the Quarternary aquifer (groundwater) - 123 pcs;
- for the Upper Cretaceous aquifer - 54 pcs;
- for the Upper Proterozoic aquifer - 13 pcs;
- for temporary perched water - 3 pcs.

In the period from 1 January until 30 March 2017 (Q1), increase in the level of groundwater by 0.15 m on the average was observed at the industrial site of Rivne NPP and the adjoining territory.

As of 31 March 2017, the groundwater mound was located at the territory of power units Nos. 3 and 4 (between the inlet channel of power unit No. 3, turbine hall of power unit No. 3, cooling tower No. 6, and rainwater collection tank of power unit No. 4) and had permeative boundary with a mild “top” near well No. 350н, which is located near the open channel of power unit No. 4 at an absolute elevation of 180.65 m.

In the period from 1 April until 30 June 2017 (Q2), increase in the level of groundwater by 0.13 m on the average was observed at the industrial site of Rivne NPP and the adjoining territory.

As of 31 June 2017, the groundwater mound was located at the territory of power units Nos. 3 and 4 (between the inlet channel of power unit No. 3, turbine hall of power unit No. 3, cooling tower No. 6, and rainwater collection tank of power unit No. 4), and had permeative boundary with a mild “top” near well No. 349н, which is located near the open channel of power unit No. 4 at an absolute mark of 180.77 m.

In the period from 1 July until 30 September 2017 (Q3), decrease in the level of groundwater by 0.15 m on the average was observed at the industrial site of Rivne NPP and the adjoining territory.

As of 30 September 2017, the groundwater mound was located at the territory of power units Nos. 3 and 4 (between the inlet channel of power unit No. 3, turbine hall of power unit No. 3, cooling tower No. 6, and rainwater collection tank of unit No. 4), and had permeative boundary with a mild “top” near the well No. 350н, which is located near the open channel of power unit No. 4 at an absolute elevation of 180.68 m.

In the period from 1 October until 30 December 2017 (Q4), increase in the level of groundwater by 0.14 m on the average was observed at the industrial site of Rivne NPP and the adjoining territory.

As of 30 December 2017, the groundwater mound was located at the territory of power units Nos. 3 and 4 (between the inlet channel of power unit No. 3, turbine hall of power unit No. 3, cooling tower No. 6, and rainwater collection tank of power unit No. 4), and had permeative boundary with a mild “top” near the well No. 350н, which is located near the open channel of power unit No. 4 at an absolute elevation of 180.84 m.

Temperature regime.

From 1 January till 30 March 2017 (Q1), the temperature field of ground waters with a background temperature of 12.0-14.0 °C was recorded.

From 1 April to 30 June 2017 (Q2), the temperature field of ground waters with a background temperature of 12.0-14.0 °C was recorded.

From 1 July to 30 September 2017 (Q3), the temperature field of ground waters with a background temperature of 12.0-14.0 °C was recorded.

From 1 October to 30 December 2017 (Q4), the temperature field of ground waters with a background temperature of 12-14 °C was recorded, which corresponds to seasonal variations of the environmental air temperature.

Hydrological observations - condition of the Styr River.

Hydrological station of the Hydraulic Engineering workshop (HEW) is arranged on the Styr River downstream of the water intake within the built-up area of Kuznetsovsk town to monitor hydrological condition of the Styr River and to prevent water flows below the minimum allowable (sanitary) flow of 8.8 m^3/sec in accordance with the permit for special use of water UKR No. 1/Rvn dated 6 August 2015. (valid till 06.08.2020).

Observations were made in accordance with [18, 19].

Measurement of level and temperature of the Styr River is performed twice a day (except weekends) at 8:00 and 16:00; determination of water flaw in the river - in case of the level change by 10-15 cm but at least once every 10 days. Hydrological measurements for determination of water flaw are performed at the intake point of the hydrological station. Water flaw is not determined during the flood period, at a water level above the mark of 160.15 m. Hydrological observations of water flow in the Styr River are listed in Table 2.18.

Average annual water temperature in the Styr River for 2017 is 11.1 °C.

Average annual flow is 29.9 m^3/sec. Annual amplitude of water fluctuation is 1.7 m.

Table 2.18. Hydrological observations of water flow in the Styr River.

Parameter (quarter)	Average temperature, °C			Average flow m^3/sec	Range of fluctuations, cm	Minimum flow m^3/sec	Maximum flow m^3/sec	Min. absolute elevation, m	Max. absolute elevation, m	Absolute elevation m
1	2.3			50.8	1.22	29.8	59.4	158.71	159.93	159.90
	0.1	0.7	6.1			24.01.17	23.03.17	06.01.17	28.03.17	31.03.17
2	16.0			29.7	1.5	13.1	57.5	158.37	159.87	158.37
	10.5	16.3	21.2			27.06.17	05.04.17	30.06.17	03.04.17	30.06.17
3	20.6			13.3	0.35	11.3	19.0	158.29	158.64	158.64

Parameter (quarter)	Average temperature, °C			Average flow m^3/sec	Range of fluctuations, cm	Minimum flow m^3/sec	Maximum flow m^3/sec	Min. absolute elevation, m	Max. absolute elevation, m	Absolute elevation m
	22.1	22.9	16.7			31.08.17	29.09.17	21.08.17	29.09.17	29.09.17
4	5.7			37.9	1.28	25.3	54.5	158.71	159.99	159.99
	10.1	4.9	2.1			06.10.17	22.12.17	02.10.17	29.12.17	29.12.17

2.9 Meteorological observations

Meteorological observations at the meteorological station of ARSMS of SS Rivne NPP were conducted by MAWS-301 automatic weather station, using Kyiv time. The meteorological station is registered with the State Hydrometeorological Service (registration certificate No. 02/05 GM dated 26 October 2005).

Meteorological parameters for 2017 are given in Table 2.19.

Table 2.19. Meteorological parameters of SS Rivne NPP for 2017.

Параметри	Місяці												Рік		
	01	02	03	04	05	06	07	08	09	10	11	12	Середнє	Макс.	Мін.
Середня температура повітря, º С	-5.10	-1.92	6.29	8.12	14.17	18.67	19.07	20.63	14.65	8.53	3.63	1.91	9.12	34.0	-21.5
Середня відносна вологість повітря, %	85.3	81.5	76.6	67.0	63.3	63.0	70.1	67.3	76.4	85.6	88.9	88.5	76.1	98.9	17.6
Сума атмосферних опадів, мм	17.6	25.0	40.4	31.0	41.2	40.8	123.0	44.8	97.4	90.0	41.4	61.4	654.0		
Середній атмосферний тиск, гПа	1000.7	999.5	994.1	994.2	995.8	992.2	992.7	997.2	995.3	993.8	995.4	991.0	995.1	1020.5	955.3
Середня швидкість вітру, м/с	2.96	3.22	2.91	3.04	2.30	2.57	2.19	2.30	2.70	3.00	2.61	3.01	2.73	21.0	0.0
Переважаючий напрямок вітру, румб	SW	SW	W	W	NE	W	W	SE	ENE	SW	SSE	SW	SW		

Measurement of the soil surface temperature and the snow cover height by the meteorological station

2.10 Environmental measures

In the period from 24 July 2017 to 4 August 2017, compliance with environmental legislation requirements at SS Rivne NPP was verified by state supervisory authorities (namely, the State Environmental Inspectorate in the Rivne Region). According to inspection results, an order for elimination of 8 comments discovered during the inspection was issued. As of 1 January 2018, all the comments were closed.

In addition, unscheduled inspections for compliance of SS Rivne NPP with environmental legislative requirements were performed by the State Environmental Inspectorate in the Rivne Region on 22-28 March 2017 and 19-22 December 2017. No violations were detected in the course of those inspections.

During 2017, the following audits were performed in regard of EPS operations:

- internal audit of the Integrated Management System “Environmental Management” at SS Rivne NPP;

- technical supervision and recertification audit of performance and compliance of the integrated environmental management system at SS Rivne NPP with the requirements of ISO 14001-2015 by certification body International Management Service LLC.

Table 2.20. Information on the implementation of measures based on audit results.

Type of audit	Measures (quantity)	Completed (quantity)	Not completed (quantity)
Verification of compliance with the environmental legislative requirements (State Environmental Inspectorate in the Rivne Region)	8	8	-
Internal audit of Ecological Management IMS by SS RNPP	5	3	2 - the deadline has not come
Total:	13	11	2 - the deadline has not come

During 2017, no accidents that would cause non-radiation pollution of the environment took place at SS Rivne NPP.

Table 2.21. Data on progress in implementation of environmental measures by SS Rivne NPP (Integrated Plan for 2017 (Order No. 1 dated 1 March 2017).

Measure number and description	Deadline
1 1 6 Instrumental and laboratory measurements at the facilities of SS Rivne NPP.	completed
1.1.7. Assessment of SS Rivne NPP reverse water toxicity using biotesting methods	completed

Table 2.22. Data on implementation of the Environmental Protection Programme of SE NNEGC Energoatom PM-D.0.03.195-10.

No.	Description of the environmental measure (according to Annex A)	implementation status		costs, thous. UAH		Causes of non-fulfilment / corrective measures
		plan	actual	plan, thous. UAH	actual, thous. UAH	
2.1	Ensuring operability of group “A” consumers of the process water system in case of drying of spray pools. Power units Nos. 1, 2	0	0	0	0	Power unit No. 2: the measure was completed (equipment was put into trial operation). Power unit No. 1: works performed during scheduled maintenance PPR-2017–PPR-2018
2.2	Implementation of “in-run” cleaning system for process water spray pools plots of essential consumers	0	0	0	0	Tender documentation is under consideration by the EBRD
2.3	Ensuring operability of group “A” consumers of the process water system in case of drying of spray pools of power units No. 3, 4	0	0	14045	14045	Power unit No. 3: the measure was completed (equipment was put into trial operation). Works at power unit No. 4 were performed during scheduled maintenance PPR-2017. Tender for the procurement of mobile pumping units (type MNU) under preparation.
2.12	Construction phase 1. Slurry dewatering line	48,471	17,948	21,031	23,381	Expected accounts payable for the works performed as of 1 January 2018: UAH 16,328 thous. In addition, funds for the construction of make-up water treatment

No.	Description of the environmental measure (according to Annex A)	implementation status		costs, thous. UAH		Causes of non-fulfilment / corrective measures
		plan	actual	plan, thous. UAH	actual, thous. UAH	
						facilities (MWTF) were not used due to the refusal of Manotik LLC from an advance payment in the amount of UAH 10,357.2 thous. under banker's guarantee provided by terms of the contract for the delivery of a pressure filter.
2.17	Assessment of the reverse water toxicity using biotesting methods	16800	0	0	14000	Measure completed.
2.18	Instrumental and laboratory measurements of emission parameters of pollutants from stationary sources	17000	4.3	0	4.2	Measure completed.
2.19	Development of the inventory of emission sources	72750.0	0	0	44.7	Measure completed.

Planned environmental measures are carried out in accordance with the terms of financing.

Table 2.23. Integrated plan for 2017 (Order No. 1 dated 2 January 2018 for SS Rivne NPP)

Measure number and description	Deadline
1 1 5 Instrumental and laboratory measurements at the facilities of SS Rivne NPP	September 2018
1.1.6. Assessment of SS Rivne NPP reverse water toxicity using biotesting methods	November 2018

2.11 Radiation control of the environment

In accordance with the current environmental legislation, environmental monitoring system was established in the location area of SS Rivne NPP; the system operates at all stages of the nuclear power plant development and during its normal operation, repair, decommissioning, and accidents [20, 21].

2.11.1 SS Rivne NPP environment radiation state monitoring

The radiation control system of SS Rivne NPP develops and undergoes constant upgrading. Accordingly [22] reconstruction of the radiation control system (RCS) is planned.

Reconstruction of the RCS is carried out in two directions:

- replacement of AKRB 03 system;
- expansion of RCS functions.

Performance of works and activities in the first direction includes replacement of technical means with expired lifetime by new up-to-date means with implementation, for the most part, of the existing RCS functions. Works in the first direction must result in creation of a modern automated system for measuring radiation parameters, collection and processing of data.

The second direction of works and activities is aimed at bringing RCS of the NPP power units in full compliance with requirements and provisions of regulations currently in force, primarily through the introduction of new measuring channels.

The following activities are performed for implementation of both directions:

- reconstruction of radiation control of volume activity for the primary circuit coolant;
- reconstruction of radiation control for the emergency core cooling system (ECCS);
- reconstruction of radiation control for water treatment systems (WPS);
- reconstruction of radiation control of activity for the component cooling loop;
- reconstruction of radiation control for process water of essential and non-essential consumers;
- reconstruction of radiation control of activity for gas purification systems;
- reconstruction of radiation control of the mains water;
- reconstruction of radiation control in the containment shell (CtSh);
- reconstruction of radiation control of gas-aerosol emissions through the ventilation system (VS) of power unit (PU) and VS of special purpose building (SPB);
- reconstruction of radiation control in the ventilation systems of power unit;
- reconstruction of radiation control of inert radioactive gases (IRG), aerosols, and iodine in reactor room and special purpose building;
- reconstruction of radiation control boards;
- introduction of radiation control of reference radionuclides for the primary circuit;
- introduction of radiation monitoring of SG leakage for Nitrogen-16;
- introduction of radiation control of the exposure dose rate (EDR) of neutrons in civil defence facilities (CDF), fresh fuel storage facility (FFSF);
- implementation of radiation control at unit control room (UCR) and emergency control room (ECR);
- upgrading of radiation control over non-proliferation of radioactive substances;
- replacement of detecting units with modern ones;

- introduction or functionality expansion of the automated radiation state monitoring systems (NPP ARSMS);

- full introduction of automated radiation dose accounting systems and control of the stay time within the SS NPP area for personnel.

Completion of the above activities is planned by the end of 2020.

At the moment, a step-by-step reconstruction of the Unit 3 RCS has been performed in the part of replacement of all elements of the upper level, as well as a number of measuring channels. In order to bring it fully in line with the requirements and provisions of the regulatory documents currently in force, functionality of the RCS of power unit No. 3, including ARSMS, has been substantially expanded through the introduction of additional measuring channels and subsystems.

At present, within the framework of implementation of the "Integrated Program on Improvement of Safety of Power Units of Ukrainian NPPs" No. 14401 "Revamping of the Radiation Control System (RCS)" [23] at SS Rivne NPP, works on modification and replacement of the lower and upper level equipment of ARCS of power unit No. 3 and special purpose building No. 2, including equipment and instruments for monitoring emissions and discharges, are currently in progress (deadline: 2018).

A sanitary protection zone (SPZ) is arranged around the nuclear facility. The SPZ is determined based on the limit annual intake of radioactive substances via the respiratory and digestive systems, limit external radiation doses for personnel and population, as well as permissible air and water concentrations of radioactive substances.

SPZ dimensions are determined taking into account radiation situation assessment in the area around the NPP during long-term operation.

SPZ performs important functions of radiation protection of the population from exposure to impact of nuclear facility both during normal operation and under conditions of radiation accidents. SPZ is the territory around the nuclear and radioactive waste management facilities, in which the level of exposure for people under normal conditions of operation may exceed the limit dose rate for the population.

SPZ dimensions shall be determined to ensure that the limit dose rate for the population outside its borders is not exceeded during normal operation, violation of normal operation, and decommissioning of NPPs, as set out in cl. 5.5.4. of NRBU-97 [24] - 80 μSv/year: 40 μSv/year due to atmospheric emissions and 40 μSv/year due to liquid discharges. The value of the limit dose rate is approximately 10 times below the dose received by the population from natural sources.

It was calculated that even during the MDBA and permanent residence at the border of the SPZ (2.5 km away from the power unit in emergency), the estimated dose of radiation from the unit's emissions is about 3 mSv for 70 years.

At present there are no residents within the SPZ, as well as enterprises, structures etc., except those that are related to the NPP. Only subsidiary buildings and structures that service the NPP are located in the SPZ.

Radiation control is carried out in the SPZ.

Legal status of establishment and operation of the SPZ of nuclear power plants is regulated by the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" [5] and the Law of Ukraine "On Energy Land Plots and Legal Regime of Special Areas of Energy Facilities" [25].

According to Article 45 of the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” [5], a special regime of the territory in the locations of nuclear facilities and radioactive waste management facilities is established:

- sanitary protection zone and observation zone are established in the locations of nuclear facilities or radioactive waste management facilities;
- residence of the population within the sanitary protection zone is not allowed; restrictions are set for the production activity other than those related to the nuclear facility or radioactive waste management facilities, and radiation monitoring is performed;
- it is prohibited to locate residential and public buildings, children’s and health-improving establishments, as well as industrial enterprises, public catering facilities, auxiliary and other structures within the sanitary protection zone, except those related to the operation of the nuclear facility or radioactive waste management facilities;
- agricultural use of lands and reservoirs located within the SPZ is only allowed subject to permission of the state regulatory body for nuclear and radiation safety that shall be agreed with the operating organization, and provided that the mandatory radiological control of the products being produced is implemented.

According to requirements of Article 25 of the Law of Ukraine “On Energy Land Plots and Legal Regime of Special Areas of Energy Facilities” [25], compliance with established restrictions on the use of land within special zones is the responsibility of all owners and users of land plots, local authorities, and local self-government bodies, as well as enterprises that operate energy facilities.

Order No. 8 of 16 January 2012 issued by the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) approved the “Procedure for the issuance of permits for the use of lands and water bodies located within the sanitary protection zone of a nuclear facility or radioactive waste management facilities, and uranium facility” NP 306.4.181-2012. The Procedure was approved to ensure the effectiveness of state regulation in the field of nuclear energy use.

Permit for the use of lands and water bodies located within the SPZ of a nuclear facility, RW management facilities, and uranium facility (UF), is issued to legal entities or individual entrepreneurs intending to use lands or water bodies located within the SPZ of a nuclear facility for the organization of industrial enterprises, public catering establishments, auxiliary and other facilities related to the activities of the NF. Economic activities without the permit are prohibited. No fee is charged for issuance of the permit.

To obtain a permit, a legal entity or an individual intending to use lands or water bodies located within the SPZ of a nuclear facility submits a request for the issuance of a permit to the SNRIU in accordance with the established form and documents as per the established list.

The procedure for the approval by the operating organization is determined by the “Regulation on the procedure for approval of the intention to use lands and water bodies within the sanitary protection zones of SE NNEGC Energoatom NPPs for economic purposes by the Operating Organization” PL-D.0.28.597-13.

Within the SPZ and OZ, radiation control is carried out within the framework of the “Radiation Control Regulation” approved by the Chief State Sanitary Inspector of the facility and the State Nuclear Regulatory Inspectorate of Ukraine. According to the Regulation, about 2500 environmental samples are taken and measured during the calendar year.

The observation zone includes the area in which the radioactive releases and emissions from the radiation nuclear facility (NPP) are likely to occur with monitoring performed.

In accordance with [11], during normal operation of a facility, the OZ shall be, as a rule, 3-4 times larger than the SPZ; at the same time, no restrictions on the use of the territory near the OZ are established.

Currently, the OZ with a radius of 30 km is established for SS Rivne NPP [8, 26].

Radiation control within the OZ is carried out as per Rivne NPP Radiation Control Regulations 132-1-P-TsRB [27] approved by Senior Vice-President, Chief Technology Officer of SE NNEGC Energoatom on 2 February 2016 and agreed by letter from State Nuclear Regulatory Inspectorate of Ukraine No. 15-28/7070 dated 25 October 2016 agreed with the Head of Varash Interdistrict Department of Rivne Regional Laboratory Centre of State Sanitary and Epidemiologic Service of Ukraine HQ on 8 July 2016 and Director General of SS Rivne NPP on 5 July 2016.

Apart from the laboratory control of the radiation impact of SS Rivne NPP on environment and population, continuous monitoring has been carried out since April 2007 using the automated radiation state monitoring system (ARSMS).

13 ARSMS control stations were installed within the SPZ and the OZ.

The purpose of the RC of the environment is monitoring of release of radioactive substances into the environment, radiation state in the SS Rivne NPP location area and radioactive contamination of the natural environment locations. The RC of the environment is provided by measurements given in Tables 2.24 to 2.30 in accordance with the “Regulations on Radiation Control of Rivne NPP” [27].

Table 2.24. Activity and radionuclide composition of the scheduled (organized) releases of radioactive aerosols, iodine radionuclides, IRG, and tritium.

Name of the radiation parameter	Frequency	Measurement method
Intensity of release of IRG, radioactive aerosols, and iodine radionuclides	Continuously	ARCS, gas-aerosol release (GAR) of SPB, ARSMS channels
Activity of LLN release, radionuclides of iodine and tritium	Regularly (daily sampling for LLN and iodine; weekly sampling for tritium)	Laboratory control
Radionuclide composition and activity of LLN release	once per month	Laboratory control

Table 2.25 VA and radionuclide composition of liquid discharge into the environment.

Name of the radiation parameter	Frequency	Measurement method
VA and radionuclide composition in RWMT after RWT (radioactive water treatment)	Regularly, as refilled	Laboratory control

Name of the radiation parameter	Frequency	Measurement method
VA in the pits of household faecal sewage, ISC1	Continuously (during discharge to the environment)	ARCS and ARSMS channels
VA and radionuclide composition of liquid discharges of radioactive substances, including tritium	Regularly (2 times/week)	Laboratory control
VA and radionuclide composition LRW	Regularly (once per quarter)	Laboratory control

Table 2.26. Activity and radionuclide composition of SRW.

Name of the radiation parameter	Frequency	Measurement method
VA and radionuclide composition of SRW	Regularly, upon request of DD	Laboratory control
SRW activity in primary packaging	Regularly, with accumulation at the waste collection sites	SEG-001m spectrometer

Table 2.27. Activity and radionuclide composition of radioactive leakages from SSRW, SLRW, RR, spray pools.

Name of the radiation parameter	Frequency	Measurement method
VA and radionuclide composition of water samples from observation wells	Regularly (once per quarter)	Laboratory control
VA and radionuclide composition of water samples from piezometric wells	Regularly (2 times/year)	Laboratory control

Table 2.28. EDR in the territory of the SPZ and OZ.

Name of the radiation parameter	Frequency	Measurement method
Integral dose in the SPZ and OZ area	once per quarter (when replacing TLD)	TLD
EDR in the SPZ and OZ area (at the locations of ARSMS CS)	Continuously	ARSMS
EDR control in the SPZ and the OZ, including settlements	once a year (when replacing TLD)	TLD, portable devices
EDR control at industrial facilities	Regularly (once a month)	Portable devices

Table 2.29. Volumetric activity of radioactive aerosols in the air in the vicinity of SS Rivne NPP.

Name of the radiation parameter	Frequency	Measurement method
VA of radioactive aerosols in the air in the vicinity of the NPP	Regularly (sampling for 7-12 days)	Laboratory control

Table 2.30. Activity in natural environment locations.

Name of the radiation parameter	Frequency	Measurement method
Samples from natural environment locations	Regularly (according to cl. 6.1 and 6.2 [27])	Laboratory control

Assessment of the NPP impact on the environment is organized by controlling the radiation parameters at the control stations (CS). A network of sedimentation stations has been adopted as reference control stations. This network is chosen taking into account the winds diagram at the location of SS Rivne NPP. In accordance with requirements laid down in the “Recommendations on Dosimetric Control in the Vicinity of a Nuclear Power Plant”, control of soil and vegetation is performed at the same locations.

Samples of grain crops, vegetables, and milk are taken in 12 reference locations. Background control is performed in Manevychi town. The list of control stations is given in Table 2.31 and Table 2.32. Sampling points are shown in Table 2.33.

The location of control stations and the names of settlements in the OZ are shown in Fig. 1.1.

Table 2.31. Dose rate and integral dose rate control points in the zone of SS Rivne NPP.

Name of settlement	Distance, km	Azimuth	Radius of location
Checkpoint (C/P) of power units Nos. 3, 4	0.4	243	A
Checkpoints of power units Nos. 1, 2	0.5	335	A
Polonne	1.3	208	A
MWPS	1.4	238	A
Equipment Department	1.5	267	A
CCS (central CS) of ARSMS	3.1	300	B
Zabolottia	3.8	122	B
Ostriv	4.1	159	B
Airport	4.2	25	B
Tsmyny	4.5	227	B
Sukhovolia	5.4	69	B
Stara Rafalivka	5.5	343	B

Name of settlement	Distance, km	Azimuth	Radius of location
Chudlia	6.0	56	B
Pidtsarevychi	5.9	287	B
Velyka Vedmezhka	6.8	255	B
Kolodyn	7.0	305	B
Lozky	8.1	71	B
Sobyshchytsi	8.0	344	B
Nova Rafalivka	8.8	104	B
Maiunychi	9.0	155	B
Pidhattia	9.3	232	B
Kostiukhnovka	9.6	288	B
Sopachiv	9.7	359	B
Staryi Chartoryisk	10.6	182	C
Liubakhy	10.9	59	C
Vovchytsk	13.1	274	C
Polytsi	14.0	122	C
Velykyi Zholudsk	14.0	96	C
Bilska Volia	13.9	337	C
Lisove	14.6	245	C
Velyka Osnytsia	15.3	164	C
Dovhovolia	15.4	53	C
Zelenytsia	15.6	28	C
Zhelkino	17.6	80	C
Rudka	17.7	226	C
Berezino	18.6	310	C
Volodymyrets	19.2	61	C
Bile Ozero	20.7	335	D
Manevychi	25.5	261	D
Ozertsi	27.9	326	D
Antonivka	28.2	90	D
Kolky	29.3	213	D
Telkovychi	30.6	8	D
Note: A — distance of 0-3 km; B — distance of 3-10 km; C — distance of 10-20 km; D — distance of 20-30 km			

Table 2.32. Location of control wells in the territory of the industrial site of SS Rivne NPP.

Location	Control well numbers
Power unit No. 1	267, 268
Power unit No. 2	270, 271, 272
Power unit No. 3	241, 242, 243, 244, 245, 246
Power unit No. 4	Пс-1, Пс-2, Пс-3а, Пс-4

Location	Control well numbers
SPB-1	261, 262, 263, 264, 265, 266, 11316н
SPB-2	247, 248, 249, 250, 251, 252, 253, 254,
Industrial waste storage	273, 274, 275
SSRW	49H, 50H

Table 2.33. Sampling points at location of SS Rivne NPP.

Sampling point	Distance, km	Azimuth, ⁰	Radius of location	Atmospheric air	Atmospheric precipitation	Soils	Vegetation	Snow	Conifer	Grain crops	Vegetables	Dairy
Checkpoint (C/P) of power units Nos. 3, 4	0.4	140	A	■	■	■	■	■	■			
Checkpoints of power units Nos. 1, 2	0.7	270	A	■	■	■	■	■	■			
Polonne	1.2	172	A		■	■	■	■				
MWPS	1.4	190	A	■	■	■	■	■	■			
Equipment Department	1.6	200	A		■	■	■	■				
CCS (central CS) of ARSMS	3.3	298	C	■	■	■	■	■	■			
Zabolottia[1]	3.8	122	C	■	■	■	■	■	■	■	■	■
Ostriv	3.9	140	C		■	■	■	■	■	■	■	■
Airport	4.3	20	C	■	■	■	■	■	■			
Tsmyny	4.6	218	C		■	■	■	■	■	■	■	■
Sukhovolia	5.4	80	C	■	■	■	■	■	■			
Stara Rafalivka	5.6	342	C		■	■	■	■	■	■	■	■
Velyka Vedmezhka	6.9	254	C	■	■	■	■	■	■	■	■	■
Nova Rafalivka	8.7	108	C		■	■	■	■	■			
Kostiukhnovka	9.7	290	C	■	■	■	■	■	■	■	■	■
Sopachiv	9.8	0	C	■	■	■	■	■	■	■	■	■
Staryi Chartoryisk	10.5	180	C	■	■	■	■	■	■	■	■	■
Liubakhy	10.9	57	C	■	■	■	■	■	■	■	■	■
Polytsi	13.8	118	C	■	■	■	■	■	■	■	■	■
Velykyi Zholudsk	13.9	93	C	■	■	■	■	■	■			
Bilska Volia	14.0	340	C	■	■	■	■	■	■	■	■	■
Manevychi	26.2	263	D	■	■	■	■	■	■	■	■	■
Total control points				16	22	22	22	22	20	12	12	12
Note [1]: Atmospheric air is sampled at OPEN SG-750 (distance: 1.4 km; azimuth: 96°, radius of location: A).												

2.11.2 ARSMS Organization and Structural Diagram

In order to carry out continuous automatic remote control of the radiation conditions at the industrial site of SS Rivne NPP, the automated radiation state monitoring system (ARSMS) in the sanitary protection zone and the observation zone of the NPP is used at all operating modes of the plant, including design basis and beyond design basis accidents.

ARSMS provides control of the radiation state at the industrial site of SS Rivne NPP and the territory of 3,000 km^2 with about 130,000 residents in 90 settlements.

ARSMS is a geographically distributed two-level system, which elements are located at the industrial site (IS) of the NPP and in the SPZ and the OZ.

Block diagram of ARSMS is shown in Fig. 2.3.

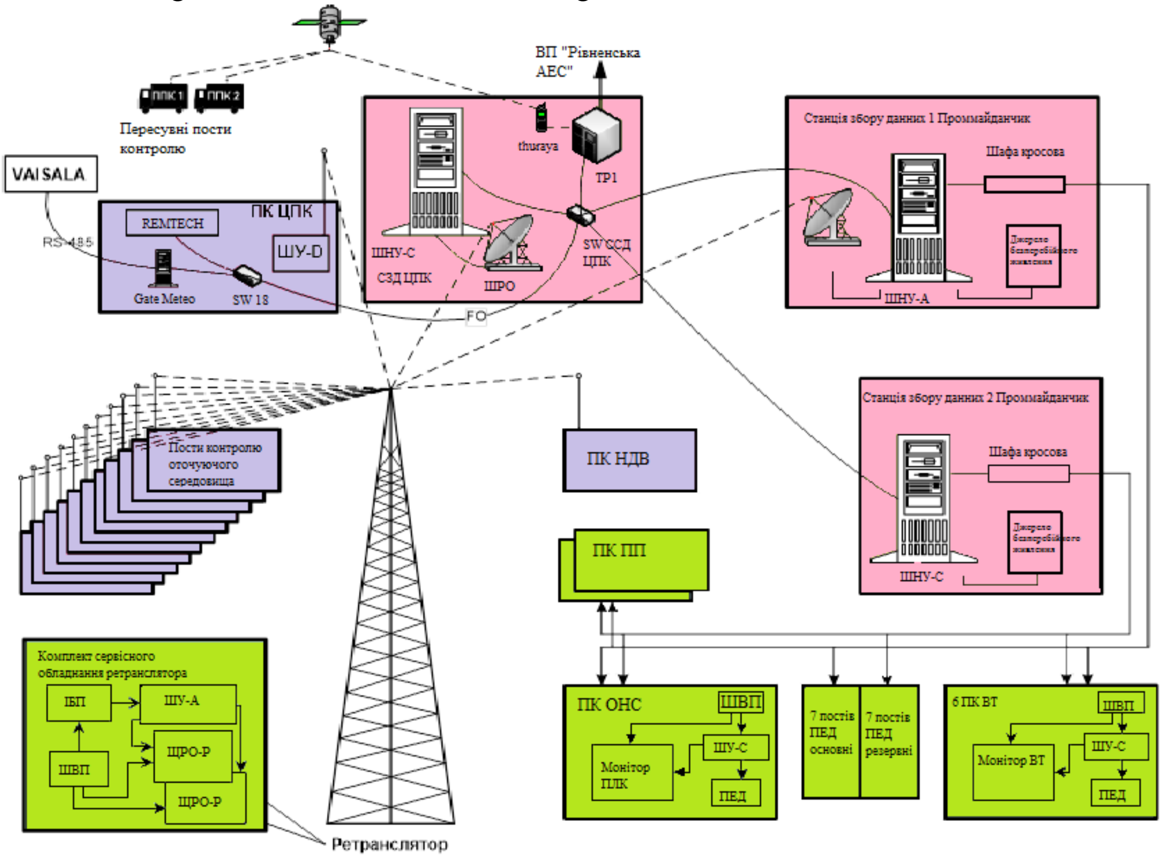

Fig. 2.3. Block diagram of ARSMS

In accordance with the requirements of Section 5.3 of DSTU 95.1.01.03.024-97 [28] ARSMS is designed as a centralized IT system with distributed data collection and processing. In accordance with [29] ARSMS includes:

- central control station;
- backup CCS for monitoring the radiation state parameters at the industrial site of SS Rivne NPP, including control of gas-aerosol releases and liquid discharges;
- control stations for monitoring the radiation state parameters in the SPZ and the OZ;
- mobile radiation laboratories (MRL);
- meteorological complex.

The main function of ARSMS is the automation of measurements, as well as collection, processing, displaying, archiving and storage of data on radiation state parameters at the industrial site and at the location of the nuclear power plant based on the distributed network of automatic control stations.

ARSMS provides control of emergency emissions of radioactive substances, determines the dose of radiation due to radioactive precipitation, predicts dispersion of radionuclides in the environment under given meteorological conditions, and provides information for the population and officials.

ARSMS ensures its functions during normal operation of the NPP, design basis accidents and beyond design basis accidents, and in case of decommissioning of the NPP.

Technical means of ARSMS are divided into two subsystems by hierarchy levels:

- lower level subsystem;
- upper level subsystem.

Technical means of the lower level subsystem include:

- measurement of radiation parameters in the observation zone;
- measurement of meteorological parameters;
- collection and initial processing of data from all measurement equipment;
- data exchange;
- display of data.

Technical means of the upper level subsystem include:

- data processing and forecasting of changes in the radiation state in the control zone;
- display of data;
- date archiving and recording;
- exchange of data with adjacent systems.

Technical means of the lower level of ARSMS are integrated into fully functional units that perform basic functions of ARSMS, regardless of the working capacity of the upper level technical means.

The structure of the lower level subsystem includes:

- control stations of different versions designed for placement both inside buildings at the industrial site and within the SPZ and OZ in special purpose structures (containers);
- data collection, processing, and visualization subsystems (DCPV), which can be located both in the territory of the industrial site and in the building of the central control station;
- mobile control stations (MCS).

16 control stations are located in the IS of SS Rivne NPP, and 13 control stations - in the SPZ and the OZ.

Control stations for monitoring of radiation parameters in the SPZ and the OZ include:

- 11 control stations for monitoring of radiation parameters of the environment (Env CS);
- one control station for monitoring of radiation parameters of the environment and liquid discharges in ISC system in the area of control station at make-up water pumping station (MWPS CS);
- one control station for monitoring of radiation and meteorological parameters in the territory of the central control station of ARSMS in Varash (CS CCS).

Control stations for the monitoring of radiation parameters at the industrial site include:

- control stations of radiation parameters for releases from ventilation stacks (VS SC, 6 station);
- control station for liquid discharges (LD CS, 1 station);

- control stations for dose limit (DL) monitoring on the roofs of buildings and structures (DL CS, 9 posts).

The radiation state is monitored continuously in automatic mode, which allows for prompt acquisition of data from CSs, systematic data analysis, and forecasting the radiation state for all settlements within the 30-kilometer observation zone.

ARSMS also includes 2 mobile control stations (MCP) built on the base of all-terrain vehicles.

MCPs are equipped with a set of equipment for controlling radiation, chemical, and meteorological parameters, as well as equipment for sampling, field measurements, and autonomous functioning. MCPs are equipped with GPS receivers and GSM mobile communication systems with satellite channels, which allows for operation at any point of the SS Rivne NPP observation zone.

Fig. 2.4 shows layout of stationary ARSMS control stations within the SPZ and OZ; layout of ARSMS control stations within the NPP industrial site is given in Fig. 2.5.

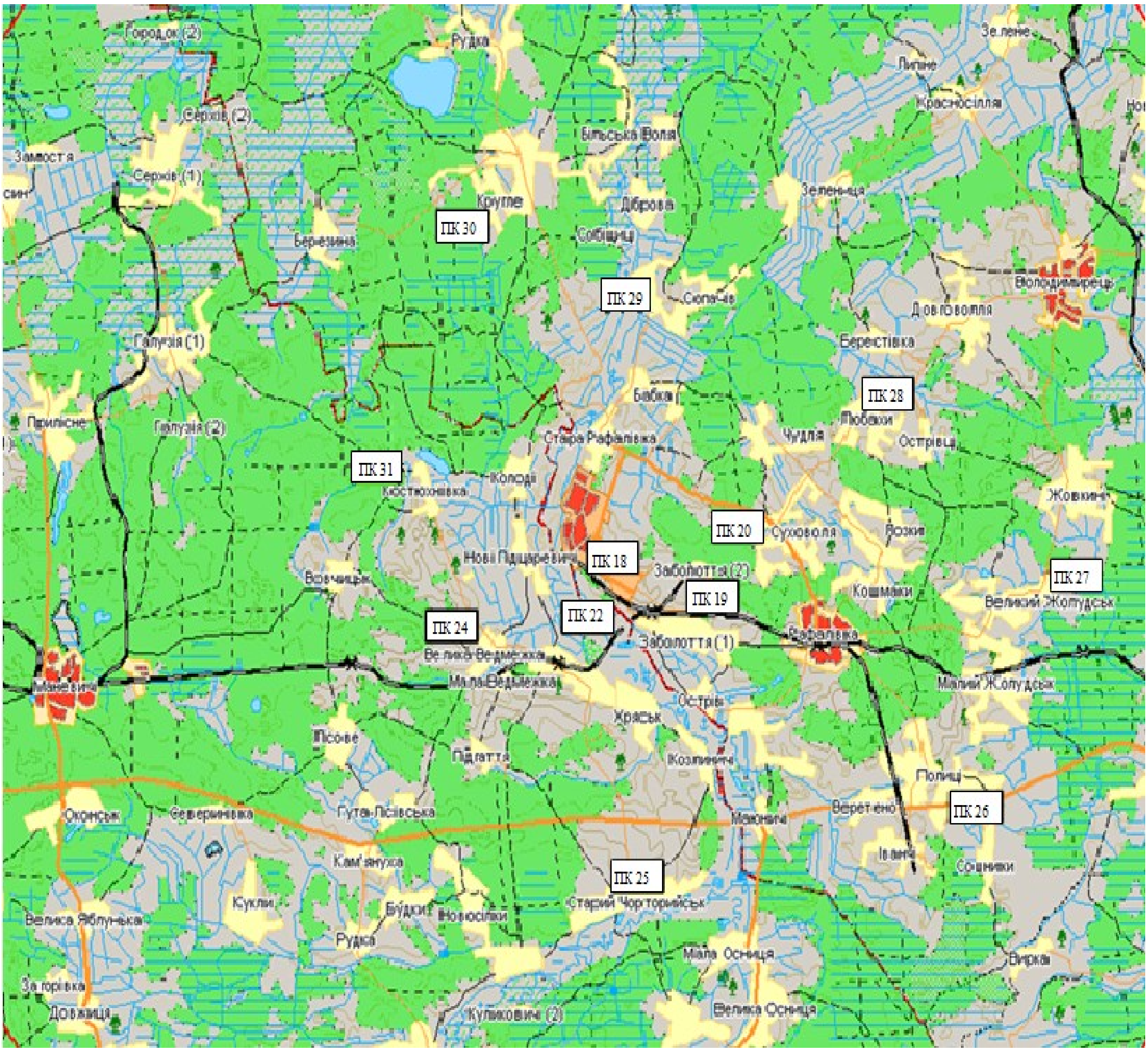

Fig. 2.4. layout of stationary ARSMS control stations within the SPZ and OZ of SS Rivne NPP

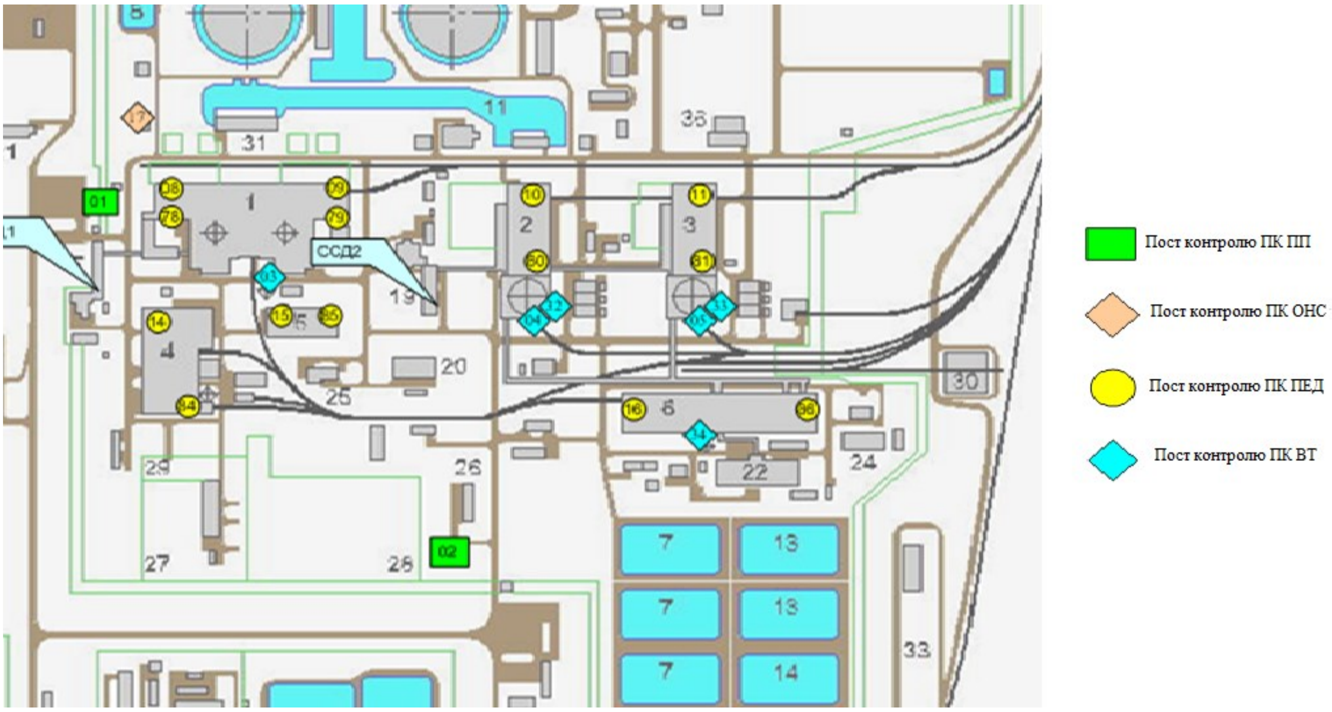

Fig. 2.5. Layout of control stations at the site of SS Rivne NPP

The list of environmental parameters controlled by ARSMS CS in different ARSMS operating modes is provided in Table 2.34.

Table 2.34. List of environmental parameters controlled by ARSMS CS.

Item	Env CS	CCS CS	KM CS	VS SC	LD CS	DL CS
DL						
Volume activity of radioactive aerosols in the air					-	-
Volume activity of iodine radionuclides					-	-
Volume activity of the IRG	-	-	-		-	-
Volume activity of radionuclides in liquid discharges	-	-	-	-		-
Meteorological parameters	-		-	-	-	-

- the parameter is controlled in all operation modes of ARSMS

– the parameter is controlled only in the full control mode

- – the parameter is controlled by this type of CS

ARSMS system has two modes of operation, which depend on the radiation state in the system control zone:

- ARSMS system operation mode under normal radiation conditions (NOM);
- ARSMS system operation mode under emergency radiation conditions (EOM).

ARSMS personnel works during the day shift only under NOM. Control of ARSMS equipment operation and analysis of information during the night time is performed by the operational personnel of the Workshop on Radiation Protection (WRP).

MCS under NOM is used for on-site sampling and for conducting field spectrometric measurements in accordance with the tasks of the laboratory for environmental radiation control (LEnvRC).

Under EOM, ARSMS personnel works around the clock. ARSMS is switched to EOM control mode automatically when dose rate of one of the measured channels exceeds the specified threshold value, or manually by command from CCS AWS or DCS1 AWS (automated working station of data collection subsystem-1).

The list of parameters controlled by ARSMS channels in the territory of the industrial site and the observation zone of SS Rivne NPP and locations of the signalling equipment are given in Table 2.35 based on the data provided in [27]

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Table 2.35. Layout of signalling equipment of ARSMS measuring channels.

BD, UD type	Controlled parameter	BD, UD installation site	Units of measurement	Threshold value		Channel No.
				VRG	VAG	
Gamma TRACER	EDR	CS[1] No. 1 C/P of PU 1÷2	Sv/h	5.59E-03	1.355E+04	8AXS0102
RAM31	VA of aerosols		Bq/m^3	130	1300	8AXS0109
RIM14	VA of radioiodines		Bq/m^3	1000	10000	8AXS0116
Gamma TRACER	EDR	CS No. 2 C/P of PU 3÷4	Sv/h	5.59E-03	1.355E+04	8AXS0202
RAM31	VA of aerosols		Bq/m^3	130	1300	8AXS0209
RIM14	VA of radioiodines		Bq/m^3	1000	10000	8AXS0216
Gamma TRACER	EDR in VS of PU-1,2	CS No. 3 room BT-04	Sv/h	2.127E+03	1.355E+04	8AXS0301
RAM31	VA of aerosols in VS of PU-1,2		Bq/m^3	130	1300	8AXS0307
RIM14	VA of radio-iodine in VS of PU-1,2		Bq/m^3	1000	10000	8AXS0314
RGM02	VA of IRG in VS of PU-1,2		Bq/m^3	1.63E+07	1.8E+08	8AXS0341
Gamma TRACER	EDR in VS-1 RO PU-3	CS No. 4 room A-1017	Sv/h	2.127E+03	1.355E+04	8AXS0401
RAM31	VA of aerosols in VS-1 of PU-3 RR		Bq/m^3	130	1300	8AXS0407
RIM14	VA of radio-iodine in VS-1 PU-3 RR		Bq/m^3	1000	10000	8AXS0414
RGM02	VA of IRG in VS-1 PU-3 RR		Bq/m^3	1.63E+07	1.8E+08	8AXS0441
Gamma TRACER	EDR in VS-1 PU-4 RR	CS No. 5 room A-1017	Sv/h	2.127 E+03	1.355E+04	8AXS0501
RAM31	VA of aerosols in VS-1 PU-4 RR		Bq/m^3	130	1300	8AXS0507

BD, UD type	Controlled parameter	BD, UD installation site	Units of measurement	Threshold value		Channel No.
				VRG	VAG	
RIM14	VA of radio-iodine in VS-1 PU-4 RR		Bq/m^3	1000	10000	8AXS0514
RGM02	VA of IRG in VS-1 PU-4 RR		Bq/m^3	1.63E+07	1.8E+08	8AXS0541
Gamma TRACER	EDR in VS-2 PU-3 RR	CS No. 32 room A-1017	Sv/h	2.127E+03	1.355E+04	8AXS3201
RAM31	VA of aerosols in VT-2 PU-3 RR		Bq/m^3	130	1300	8AXS3207
RIM14	VA of radio-iodine in VS-2 PU-3 RR		Bq/m^3	1000	10000	8AXS3214
RGM02	VA of IRG in VS-2 PU-3 RR		Bq/m^3	1.63E+07	1.8E+08	8AXS3241
Gamma TRACER	EDR in VS-2 PU-4 RR	CS No. 33 room A-1017	Sv/h	2.127E+03	1.355E+04	8AXS3301
RAM31	VA of aerosols in VS-2 PU-4 RR		Bq/m^3	130	1300	8AXS3307
RIM14	VA of radio-iodine in VS-2 PU-4 RR		Bq/m^3	1000	10000	8AXS3314
RGM02	VA of IRG in VS-2 PU-4 RR		Bq/m^3	1.63E+07	1.8E+08	8AXS3341
Gamma TRACER	EDR in VS of SPB-2	CS No. 34 room VS of SPB	Sv/h	2.127E+03	1.355E+04	8AXS3401
RAM31	VA of aerosols in VS of SPB-2		Bq/m^3	130	1300	8AXS3407
RIM14	VA of radio-iodine VS of SPB-2		Bq/m^3	1000	10000	8AXS3414
RGM02	OA IRG in VS of SPB-2		Bq/m^3	1.63E+07	1.8E+08	8AXS3441
Gamma TRACER	EDR on the roof of PU-1 TR	CS No. 8 roof of PU-1 TR	Sv/h	5.59E-03	1.355E+04	8AXS0801
Gamma TRACER	EDR on the roof of PU-1 TR		Sv/h	5.59E-03	1.355E+04	8AXS7801
Gamma TRACER	EDR on the roof of PU-2 TR	CS No. 9 roof of PU-2 TR	Sv/h	5.59E-03	1.355E+04	8AXS0901
Gamma TRACER	EDR on the roof of PU-2 TR		Sv/h	5.59E-03	1.355E+04	8AXS7901
Gamma TRACER	EDR on the roof of PU-3 TR	CS No. 10 roof of PU-3 TR	Sv/h	5.59E-03	1.35E+04	8AXS1001
Gamma TRACER	EDR on the roof of PU-3 TR		Sv/h	5.59E-03	1.355E+04	8AXS8001
Gamma TRACER	EDR on the roof of PU-4 TR	CS No. 11 roof of PU-4 TR	Sv/h	5.59E-03	1.355E+04	8AXS1101
Gamma TRACER	EDR on the roof of PU-4 TR		Sv/h	5.59E-03	1.355E+04	8AXS8101
Gamma TRACER	EDR on the roof of JAB	CS No. 14 roof of JAB	Sv/h	5.59E-03	1.355E+04	8AXS1401

BD, UD type	Controlled parameter	BD, UD installation site	Units of measurement	Threshold value		Channel No.
				VRG	VAG	
Gamma TRACER	EDR on the roof of JAB		Sv/h	5.59E-03	1.355E+04	8AXS8401
Gamma TRACER	EDR on the roof of SPB-1	CS No. 15 roof of SPB-1	Sv/h	5.59E-03	1.355E+04	8AXS1501
Gamma TRACER	EDR on the roof of SPB-1		Sv/h	5.59E-03	1.355E+04	8AXS8501
Gamma TRACER	EDR on the roof of SPB-2	CS No. 16 roof of SPB-2	Sv/h	5.59E-03	1.355E+04	8AXS1601
Gamma TRACER	EDR on the roof of SPB-1		Sv/h	5.59E-03	1.355E+04	8AXS8601
Gamma TRACER	EDR on the roof of ONS-1	CS No. 17 OHC-1	Sv/h	5.59E-03	1.355E+04	8AXS1701
Gamma TRACER	EDR	LC No. 18 CCS (central CS) of ARSMS	Sv/h	3.908E+03	1.355E+04	8AXS1802
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS1806
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS1807
Gamma TRACER	EDR	LC No. 19 Open SG-750	Sv/h	5.59E-03	1.355E+04	8AXS1902
ABPM 201-L	VA of aerosols		Bq/m^3	13	130	8AXS1906
IM 201-L	VA of radioiodines		Bq/m^3	100	1000	8AXS1907
Gamma TRACER	EDR	LC No. 20 Village of Sukhovolia	Sv/h	3.908E+03	1.355E+04	8AXS2002
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2006
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2007
Gamma TRACER	EDR	LC No. 21 (Airport)	Sv/h	3.908E+03	1.355E+04	8AXS2102
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2106
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2107
Gamma TRACER	EDR	LC No. 22 MWPS	Sv/h	5.59E-03	1.355E+04	8AXS2202
ABPM 201-L	VA of aerosols		Bq/m^3	13	130	8AXS2206
IM 201-L	VA of radioiodines		Bq/m^3	100	1000	8AXS2207
Gamma TRACER	EDR	LC No. 24 Village of Velyka Vedmezhka	Sv/h	3.908E+03	1.355E+04	8AXS2402
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2406
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2407
Gamma TRACER	EDR	LC No. 25 Village of Staryi Chartoryisk	Sv/h	3.908E+03	1.355E+04	8AXS2502
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2506

BD, UD type	Controlled parameter	BD, UD installation site	Units of measurement	Threshold value		Channel No.
				VRG	VAG	
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2507
Gamma TRACER	EDR	LC No. 26 Village of Polytsi	Sv/h	3.908E+03	1.355E+04	8AXS2602
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2606
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2607
Gamma TRACER	EDR	LC No. 27 Village of Velykyi Zholudsk	Sv/h	3.908E+03	1.35E+04	8AXS2702
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2706
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2707
Gamma TRACER	EDR	LC No. 28 Village of Liubakhy	Sv/h	3.908E+03	1.355E+04	8AXS2802
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2806
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2807
Gamma TRACER	EDR	LC No. 29 Village of Sopachiv	Sv/h	3.908E+03	1.355E+04	8AXS2902
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS2906
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS2907
Gamma TRACER	EDR	LC No. 30 Village of Bilska Volia	Sv/h	3.908E+03	1.355E+04	8AXS3002
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS3006
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS3007
Gamma TRACER	EDR	LC No. 30 Village of Kostiukhnivka	Sv/h	3.908E+03	1.355E+04	8AXS3102
ABPM 201-L	VA of aerosols		Bq/m^3	2	110	8AXS3106
IM 201-L	VA of radioiodines		Bq/m^3	14	870	8AXS3107

2.11.3 Technical means of radiation state control

ARSMS technical means include the following equipment and instruments for controlling the radiation state:

- GammaTracer dosimeter (Genitron, Germany): measurement of the equivalent dose rate in the range of 20 nSv/h - 10 Sv/h. Option of data readout via infrared interface;

- Gas-aerosol release monitoring device (RADOS, Italy):

  - ✓ RGM-02: measurement of IRG concentration in gas-aerosol releases in the range 10^3-10^{13} Bq/m^3;
  - ✓ RIM-14: I-131 activity measurement in the range 0.27-2×10^5 Bq/m^3. Automatic filter replacement system Capacity: 31 filters;
  - ✓ RAM-31: measurement of β-aerosols activity in the range of 0.15-4×10^7 Bq/m^3. Automatic filter replacement system Capacity: 92 filters;

- ✓ Tritium sampler for gas-aerosol releases;

- Liquid discharge monitoring device (RADOS, Italy):

- ✓ RWM-02: concentration of basic radionuclides in liquid discharges 370-3.7×10^{10} Bq/m^3;
- ✓ Tritium sampler for NPP discharges;

- Equipment for measuring concentration of iodine and aerosols in atmospheric air (MGPI, France):

- ✓ RIM-201: measurement of I-131 concentrations in the range of 3.7-3.7×10^6 Bq/m^3;
- ✓ AVRM-201: measurement of β-aerosols concentrations in the range of 1.0-1.0×10^7 Bq/m^3.

- Control stations: containers (INEK, Ukraine) built on the basis of marine containers. control stations are equipped with equipment for measuring:

- ✓ dose rate;
- ✓ concentration of iodine and aerosols in the atmospheric air in case of a radiation accident;
- ✓ meteorological parameters in the vicinity of the nuclear power plant;
- ✓ concentrations of ^{137}Cs, ^{60}Co; volume of discharged water; sampling for determination of tritium concentration.

Sampling of aerosols in the atmospheric air, atmospheric fallout for laboratory control is performed.

The stations are equipped with climate-control equipment, autonomous power supply, security system, and fire alarm.

- Mobile control stations (Favorit-Plus, Ukraine): GAZ-3308 “Sadko” all-terrain vehicle are fitted with the following is equipment:

- ✓ GammaTracer dosimeter (Genitron, Germany);
- ✓ PIM Light monitor (MGPI, France) as part of the ABPM-201 and IM-201 measurement channels;
- ✓ MAWS-110 meteorological complex (Vaisala, Finland);
- ✓ RA-0 meteorological complex (Remtech, France);
- ✓ GEM-40 gamma spectrometric complex with a specially clean germanium detector (Ortec, USA);
- ✓ gas analyzer for determining oxygen, chlorine, and ammonia levels (OLDHAM, Germany);
- ✓ AKSA power plant;
- ✓ PVP-4 air samplers (SRE “Dose”, Russia);
- ✓ Thuraya satellite package, which transmits measurement data from the MCS, determines its location and automatic displays it on the map of the area;
- ✓ a set of equipment for field survey;

- ARSMS consists of four meteorological complexes:

- ✓ two meteorological complexes (MAWS-110, SODAR PA-5 + RASS) installed permanently in the territory of the central control station of ARSMS;
- ✓ two complexes (MAWS-110, SORAD PA-0) are operated as part of mobile control stations.

Meteorological complexes are able to do much more than just determine meteorological parameters. They are capable to perform remote sensing of the atmosphere up to an altitude of 3000 meter.

Meteorological information is used to calculate doses for critical groups of the population during normal operation of the NPP, as well as to predict the radiation state for potential radiation situations.

Specifications of ARSMS devices for measuring meteorological parameters are shown in Table 2.36.

Table 2.36. Meteorological parameters and specifications of ARSMS measuring instruments.

Parameter name	Type (MAWS-301 (MAWS-110)	Measuring range
Air temperature	QMH102	-40 to +60 °C
Wind speed	WAA151	0.4 to 75 m/sec
Wind direction	WAV151	0 to 360°
Air pressure	PMT16A	600 to 1100 hPa
Relative air humidity	QMH102	0 to 100%
Intensity of solar radiation	QMS101	0 to 2000 W/m^2
Precipitation	RG13H	above 0.2 mm
Precipitation rate	PWD11	0.00 to 999 mm/hour
Radiation balance	QMN101	-2,000 to +2,000 W/m^2
Category of atmospheric stability	SODAR complex	A to F

Radiation control with the use of technical means for monitoring of the radiation state is carried out by the operational personnel of WRP in accordance with methods given in Table 2.37.

Table 2.37. The list of methods used by the personnel of WRP during radiation control.

Designation of the document	Document title
МИ-2143-91	Activity of radionuclides in bulk samples. Measurement procedure for gamma spectrometer
171-18-М-ВРХЛ-ХЦ	Measurement procedure. Measurement procedure for determination of total beta activity of technological environments of RNPP
	Measurement procedure for determination of specific activity of radionuclides using half-conductor γ-spectrometers.
	Guidelines for analysis of waste waters of the NPP and groundwater of the industrial site.
	Methodical recommendations on sanitary control over the content of radioactive substances in natural environment locations.

Designation of the document	Document title
PNAE, G, direction 2	Recommendations for dosimetric control in the vicinity of nuclear power plants.
DR-97	Permitted levels of Cs-137 and Sr-90 radionuclides in food and drinking water.
	Control over the radiation state caused by discharge of waste waters that contain radioactive substances into water bodies.
	Control over the radiation state caused by atmospheric air pollution by radioactive substances
	Sr-90 mono-oxoacetyl ether methylphosphoric acid extraction
	Methods of lifetime determination of radionuclides in the human body

In 1978, 2 years prior to the commissioning of the first power unit, an external radiation monitoring laboratory was set up at Rivne NPP. The laboratory is responsible for determining the radiation impact due to operation of power units of SS Rivne NP on the population and natural environment. Laboratory of the automated radiation state monitoring system (ARSMS) was created in 2001.

The radiation control of the environment is conducted in accordance with the "Regulation on Radiation Control" 132-1-R-TsRB [27] approved by the Chief State Sanitary Inspector of the facility and the State Nuclear Regulatory Inspectorate of Ukraine. In accordance with the Regulation, sampling and measurement of about 2500 environmental samples of the environment of the location of SS Rivne NPP are conducted during the year.

In the course of monitoring, control of radioactive releases into the atmosphere, atmospheric air, precipitation, vegetation, needles, soil, agricultural products, dose rates, liquid discharges, water, bottom sediments, fish and algae of the Styr River. In general, radiation monitoring covers 43 of the 110 settlements within the OZ of SS Rivne NPP.

The NRBU-97 [24] establishes the dose limits for personnel directly involved in operations with sources of ionizing radiation (category A of exposed persons) for the entire population (category C).

Dose limit is the main radiation and hygienic standard, which purpose is to limit the personnel and population exposure to all industrial sources of ionizing radiation in practical activities. The population dose limit for radiation from industrial sources is 1 mSv/year, which is several times less than the dose of radiation of natural origin. Out of this limit, the NPP has a quota of 8 % for the operation of all power units, regardless of their number.

Regulation and control of population exposure are based on the calculations of annual effective and equivalent radiation doses for critical population groups. A critical group is a portion of the population that, based on its sex and age, social and occupational conditions, place of residence and other features, receives or can receive the highest levels of radiation from a given source.

The limitation of category B exposure is carried out by regulating and monitoring the activity environmental media (water, air, etc.), gas-aerosol releases and liquid discharges during the NPP operation. Permissible levels of gas-aerosol releases and liquid discharges have been determined, for which the total annual effective dose in a critical population group representative due to all radionuclides present in releases and discharges does not exceed the dose limit. The established levels are regularly reviewed and agreed with the Ministry of Health of Ukraine.

In order to limit the personnel and population exposure below the above dose limits, based on the actual achievable level of radiation well-being, reference levels (RL) are determined for the NPP. The reference levels are based on the analysis of actual releases and discharges over the past 5 years.

In order to react promptly to changes in the activity of releases and discharges, the operating organization, SE NNEGC Energoatom has set additional indicators: administrative and technological levels. Release levels are set for each power unit during power operation and repairs.

In the process of operation, continuous monitoring is performed for exceedance of administrative and technological, reference and permissible release and discharge levels at SS Rivne NPP, and the activity of anthropogenic radionuclides is compared to the “zero background” value.

Since 2000, the external radiation control laboratory is certified to operate in the field of the environment radiation control. The last regular certification took place in 2015. The validity and adequacy of hardware and methodological support, staffing and personnel classification, workplace setup and compliance with the sanitary requirements were checked. The laboratory is equipped with the up-to-date instruments and tools from the world’s leading manufacturers. The laboratory is subject to regular inspections with the participation of representatives of the State Committee for Technical Regulation and Consumer Policy of Ukraine. Supervision is carried out through the Sanitary and Epidemiological Service, Nuclear Regulatory Inspectorate of Ukraine, and the State Ecology Department in the region.

Apart from the laboratory control of the radiation impact of SS Rivne NPP on environment and population, continuous monitoring has been carried out since April 2007 using the ARSMS system.

ARSMS includes:

- 16 control stations at the industrial site of SS Rivne NPP:
  - ✓ 6 stations for gas-aerosol emissions control to measure the dose rate in ventilation stacks, concentrations of IRG, iodine, aerosols; carry out sampling to determine tritium concentration in the emissions;
  - ✓ 2 stations at the industrial site to measure the dose rate, iodine and aerosol concentration in the air;
  - ✓ 7 stations located on the roofs of primary buildings of the industrial site to measure the dose rate.
- 13 stations within the SPZ and OZ to measure:
  - ✓ dose rate;
  - ✓ iodine and aerosol air concentrations in case of a radiation accident;
  - ✓ sampling of aerosols in atmospheric air, atmospheric fallout for laboratory control;
  - ✓ based on the ISS system, ^{137}Cs, ^{60}Co activities, discharged water volume are measured, and water is sampled to determine the concentration of tritium.

ARSMS system also includes 2 mobile control posts that perform a complex of measurements in the volume of stationary control posts, as well as equipped with additional equipment for locating, conducting field γ-spectrometric measurements, and determination of meteorological parameters; sampling of the environment.

Mobile stations are fitted with equipment for data transmission via satellite channels and through mobile carrier networks.

With the help of four meteorological complexes, more than 50 meteorological parameters are determined in the surface layer of the atmosphere, and meteorological parameters are determined at altitudes of up to 3,000 meters.

Radiation and meteorological information is used in software systems for calculating doses of population from actual emissions and discharges (RNPP Doses) and doses for all settlements in the observation zone in case of emergency situations (SOARS). Complexes were developed by the Institute of Radiation Protection of the Academy of Technical Sciences of Ukraine.

Methods of calculation are agreed with the Ministry of Health of Ukraine. In 2017, the European system for predicting the effects of radiation accidents (RODOS) was put into operation.

Real-time information on the radiation and meteorological situation is available to the personnel of SS Rivne NPP and is transferred as part of the technological parameters of SS Rivne NPP to the crisis center of SE NNEGC Energoatom, the crisis center of the State Inspectorate for Nuclear Regulation of Ukraine, the Rivne Oblast State Administration, and the Regional Department of the State Emergency Service.

Systematic measurements of concentrations of radioactive substances in the atmospheric air, soils, vegetation, and foodstuffs in the sanitary protection zone and the observation zone confirm the absence of significant exposure of the population and the environment to SS Rivne NPP.

The content of radionuclides in the atmospheric air of the observation zone of SS Rivne NPP during the entire time of operation of the plant was at the average level of annual concentrations that is typical of the tolerance period.

Indicators of γ-radiation levels in the surrounding settlements have not changed since the commissioning of SS Rivne NPP, and the radiation impact of SS Rivne NPP, as compared with the natural background, is impossible even with the help of the most up-to-date measuring equipment.

Information on the activity of emissions to allowable values set by the Ministry of Health of Ukraine is presented in the chart (Fig. 2.6).

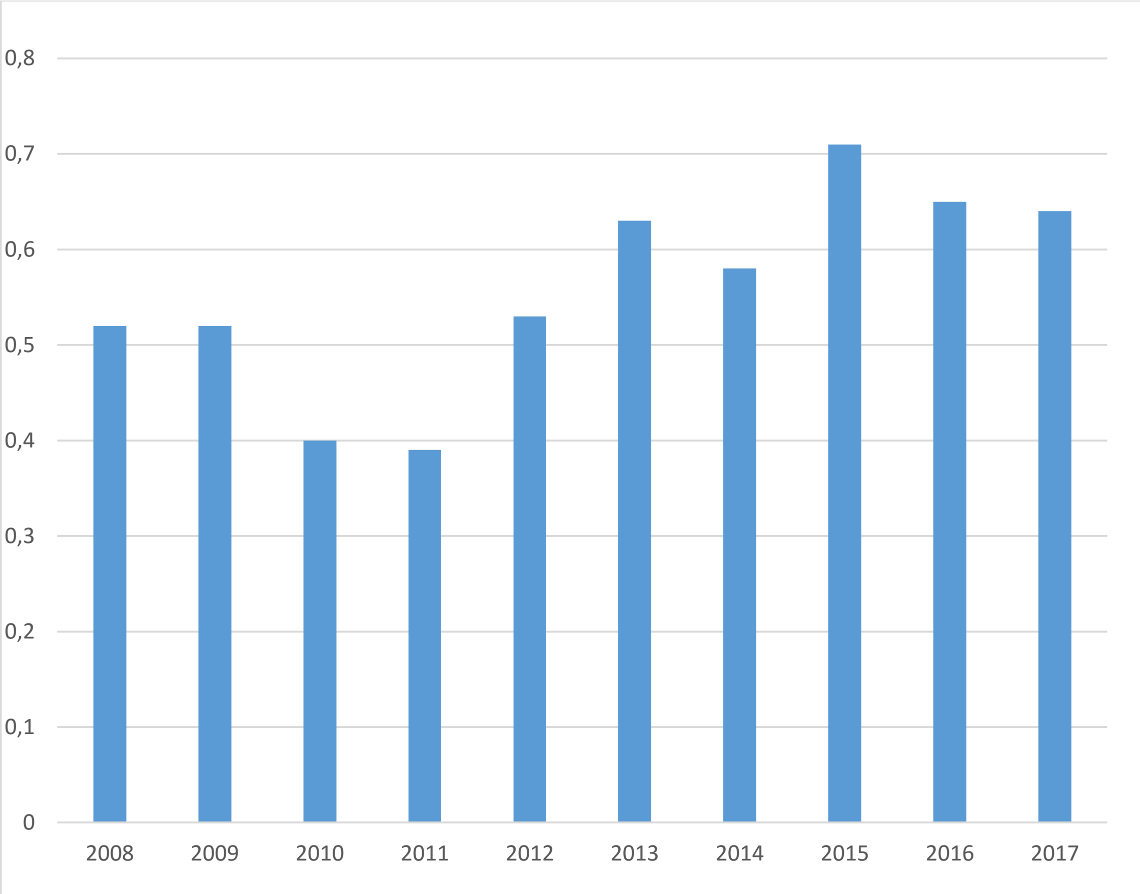


Fig. 2.6. Index of gas-aerosol emissions of SS Rivne NPP in relation to allowable emissions.

The main indicator characterizing the effect of the NPP on the population of the OZ is the maximum possible dose at the boundary of the SPZ (dose for a critical group of population). In NRBU-97, the quota is set at the level of 80 μSv/year (the limit of the annual dose of radiation for the population from emissions and discharges of the NPP).

Since January 2006, SS Rivne NPP has been operating a software package for controlling the doses of a critical population group, which is designed to calculate radiation doses formed by actual gas-aerosol discharges and liquid discharges at the SPZ border during a calendar year.

The calculation methodology is approved by the Ministry of Health of Ukraine. Calculation results shown in the chart (Fig.2.7.) indicate that the actual radiation exposure of the population to SS Rivne NPP over the past 10 years have not exceeded 0.5% of the dose limit quota set by NRBU-97 and is hundreds of times below the natural radiation sources.

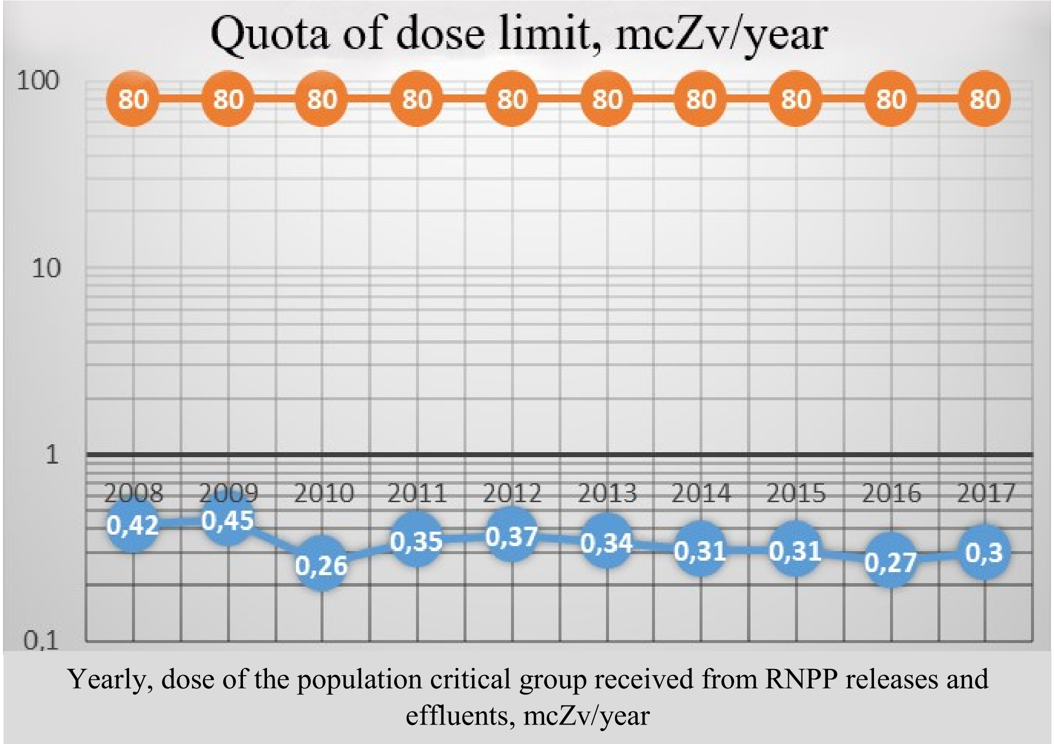


Fig. 2.7. Comparative characteristic of the dose limit quota and dose quota for the critical group of people from emissions and discharges of SS Rivne NPP, μSv/year

2.12 INES violation analysis

The International Nuclear Event Scale (INES) is used to inform the public about the safety relevance of radiation-related events.

Within the scale, events are classified as “accidents,” “incidents,” and “anomalies.” Events that are not significant in terms of security are classified as “events below the scale/level 0.” General criteria for classification of events on the INES scale are given in Table 2.38.

In terms of impact, events are divided into three different classes: impact on people and the environment; impact on radiological barriers and control at installations; and impact on deep-seated protection.

Radiological purpose means non-exceedance of limits of radiation exposure of personnel, population, and the environment during normal operation, violations of normal operation and design basis accidents, established by the sanitary norms. At the same time, conditions are ensured for the specified radiation exposure to be at the minimum possible level taking into account economic and social factors.

Defence-in-depth is a combination of consistent physical barriers to the propagation of radioactive substances and ionizing radiation in combination with technical means and organizational measures aimed at preventing deviation from normal operating conditions, preventing accidents, and limiting their consequences.

Table 2.38. General criteria for classification of events on the INES scale.

Event description and INES level	People and environment	Radiological barriers and control	Defence-in-depth
Major Accident Level 7	Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.		
Serious accident Level 6	Significant release of radioactive material likely to require implementation of planned countermeasures.		
Accident with wider consequences Level 5	Limited release of radioactive material likely to require implementation of some planned countermeasures. Several deaths from radiation.	Severe damage to reactor core. Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.	
Accident with local consequences Level 4	Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. At least one death from radiation.	Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.	
Serious incident Level 3	Exposure in excess of ten times the statutory annual limit for workers. Non-lethal deterministic health effect (e.g., burns) from radiation.	Exposure rates of more than 1 Sv/h in an operating area Severe contamination in an area not expected by design, with a low probability of significant personnel exposure.	Near-accident at a nuclear power plant with no safety provisions remaining. Lost or stolen highly radioactive sealed source. Misdelivered highly radioactive sealed source without adequate procedures in place to handle it.

Incident Level 2	Exposure of a member of the public in excess of 10 mSv. Exposure of a worker in excess of the statutory annual limits.	Radiation levels in an operating area of more than 50 mSv/h. Significant contamination within the facility into an area not expected by design.	Significant failures in safety provisions but with no actual consequences. Found highly radioactive sealed orphan source, device or transport package with safety provisions intact. Inadequate packaging of a highly radioactive sealed source.
Anomaly Level 1			Overexposure of a member of the public in excess of statutory annual limits. Minor problems with safety components with significant defence-in-depth remaining. Low activity lost or stolen radioactive source, device or transport package.
	No safety significance (below scale/level 0)		

2.13 Informing the public about the impact of the operation of power units on the environment

Rivne NPP adheres to the principles of prompt and reliable notification of the public, as well as implements a number of social projects and relics aimed at popularizing nuclear power in Ukraine in order to realize the right of citizens and their associations to obtain complete and reliable information on the activity of a nuclear facility. These tasks are performed by the department of information and public relations (I&PR) of SS Rivne NPP, which informs the public through the following means:

- the information center of Rivne NPP “Polissya,” which is a platform for the implementation of various forms of work with the population, including through the organization of excursions. Visits to the institution: up to 5 thousand people a year (both Ukrainians and foreigners). I&PR specialists are concerned about establishing a dialogue with ecological and public organizations, administrations of settlements of the observation zone, implementation of image-making events and social campaigns.

Internet: daily activity of SS Rivne NPP is highlighted in press releases on the website of SS Rivne NPP: www.npp.rv.ua. The web site displays real-time radiological monitoring results in the 30-kilometer zone. SS Rivne NPP also has pages on Facebook and Youtube.

Broadcasting: the Energoatom TV channel is the only TV channel of the satellite city of SS Rivne NPP and the only one in the country owned by an NPP. Notification of the population is held through television and radio programs. Also, one can hear about Rivne NPP daily in the news on the local FM radio station “Radio Track.”

Newspapers: Rivne NPP informs the population and the staff weekly through its own newspaper “Energia,” which is issued in 2,000 copies. In addition, information on activities of SS Rivne NPP is regularly posted on the pages of district newspapers: “Volodymyrets Visnyk,” “Nova Doba,” “Sarnensky Novyny,” as well as in the regional “Visti Rivnenshchyny” and “Tviy Vybir,” in order to inform the general public about the specific issues of the company's activities, these also include publications with results of water quality monitoring near the outlet from the NPP to the Styr River.

Printing products: books, banners, and themed brochures about Rivne NPP.

Public events, press conferences, meetings, outgoing social discussions, exhibitions.

Autoinformator phone: (03636 64-8-64): the system is updated on a daily basis, providing information on the current state of electricity production and on the radiation level, fire and environmental state at SS Rivne NPP and its adjacent 30-kilometer zone.

3 ASSESSMENT OF SS RIVNE NPP OPERATIONAL RESTRICTIONS RELATED TO THE CONDITIONS OF ENVIRONMENTAL, SOCIAL, ANTHROPOGENIC ENVIRONMENT

The work of SS Rivne NPP is regulated by environmental and sanitary-epidemiological restrictions, which are stipulated by the regulatory documents on environmental safety.

The enterprise set limits on the following main criteria:

- the size of the sanitary protection zone (SPZ);
- internal and external exposure of staff and population;
- maximum permissible radioactive and non-radioactive releases and discharges in the environment;
- level of exposure of open sources of ionizing radiation;
- methods of utilization and storage of liquid and solid wastes must comply with regulatory requirements and permit documents.

The observation zone (OZ) is an area where the effects of discharges and emissions of nuclear power stations are possible and where radiation monitoring is carried out, which includes a measurement of the determination of the content of radionuclides in the objects of the environment, foodstuffs etc.

The sanitary protection zone is the territory around the NPP, where the level of exposure to humans may exceed the dose limit quota for the category C. In the SPZ, the residence of population is prohibited; restrictions on production activities other than those related to the NPP are established, and radiation control is carried out [11].

The size of the SPZ of SS Rivne NPP is 2.5 km; the size of the OZ is 30 km. The dimensions of the SPZ and OZ were officially set in accordance with the SS Rivne NPP document, namely, "Decision on the size and boundaries of SS Rivne NPP sanitary protection zone and the observation zone," No. 132-1-R-11-TsRB [8].

Boundaries of SPZ and OZ are set by the following criteria:

- internal and external exposure of personnel and population;
- maximum permissible radioactive releases and discharges in the environment.

According to DGN 6.6.1-6.5.001-98 (NRBU-97) [24], the categories of persons exposed to radiation are established:

- category A (personnel): persons who permanently or temporarily work with sources of ionizing radiation;
- category B (personnel): persons who are not directly involved in work with sources of ionizing radiation but may be exposed to additional radiation due to the location of workplaces in premises and industrial sites of objects with radiation and nuclear technology;
- category C: all population.

The numeric values of external radiation doses per calendar year based on the organ or tissue group, as well as total external and internal radiation doses based on requirements of DGN 6.6.1-6.5.001-98 (NRBU-97) [24] are given in Table 3.1.

Table 3.1. Limit radiation doses (mSv/year).

Organ or tissue	Exposed category		
	A	B	C
LDE (limit effective dose)	20	2	1
Limit external dose equivalents:			
- LDlens (for crystalline lens)	150	15	15
- LDskin (for skin)	500	50	50
- LDextrem (for hands and feet)	500	50	-
[1] On average for any successive 5 years, but not more than 50 mSv per year			

The list of radionuclides, permissible air release values and limit annual discharge of radioactive substances are specified in the documents currently in force at Rivne NPP:

- Permissible gas-aerosol release of radioactive substances from Rivne NPP (group 1 radiation and hygienic regulation) 132-2011-ДВ-ЦРБ approved by letter No. 7.03-58/56 of the MoH of Ukraine dated 23 February 2012;
- Reference levels of gas-aerosol release and liquid discharge from SS Rivne NPP (group 1 radiation and hygienic regulation) 132-2016-КР-ЦРБ approved by letter No. 7.03-58/171-16/29017 of the MoH of Ukraine dated 9 November 2016.

In accordance with the Basic Sanitary Rules of Radiation Safety of Ukraine (OSSPU-2005) [11], design doses as set out in Table 3.2 are established for all premises in the strict regime zone of the NPP, the SPZ, and the OZ, for the purpose of protection of personnel against external radiation during the process of conducting the power process and the repair work.

Table 3.2. Equivalent dose value used when designing protection from external ionizing radiation.

Exposed category	Designation of premises and zones	Duration of radiation, man/hour	Dose value, μSv/hour
A	Room for permanent staffing.	1700	14
	Premises in which the staff remains for no more than half of the working time.	850	29
B	Premises, institutions, and territory of the SPZ of presence of persons classified as category B.	2000	1.2
	Any premises and territories within the OZ.	8800	0.3

Permissible annual limits of external exposure of personnel living near the NPP are regulated by the sanitary rules of the NPP [31]. Dosage limits established by these rules for different sources and for different groups of critical organs are given in Table 3.3.

Table 3.3. Annual exposure levels of the population living near the NPP.

Sources of radiation exposure	Group of critical organs		
	I	II	III
Gas-aerosol emissions	0.2	0.6	1.2
Radioactive substances with liquid discharges (effects on all kinds of water use: fishing, fish farming, irrigation, drinking water supply etc.)	0.05	0.15	0.3
Heat supply	0.01	-	-

NPP safety systems ensuring protection of the population during accidents, including design basis accidents with the most severe consequences, are designed in a way that the values of equivalent individual doses calculated for the worst weather conditions on the SPZ border and beyond it do not exceed 3 mSv/year for thyroid gland in children in case of inhalation intake and 1 mSv/year for the whole body in case of external exposure [31].

According to the same document [31] Daily average permissible emissions (PE) of gas-aerosol radionuclides are given in Table 3.4.

Table 3.4. Permissible daily emissions.

Nuclides	N = 1,000-6,000 MW (el) $\frac{\text{Cu}}{\text{day}\cdot 1{,}000\ \text{MW (el).}}$
IRG (any mixture)	500
Iodine-131 (gas+aerosol phase)	0.01
Long-lived radionuclides (LLR) mix	0.015

Average monthly permissible emissions of radioactive aerosols are given in Table 3.5 (permissible emissions do not apply to the amount but to each radionuclide separately). If radionuclides found at NPPs are not listed in Table 1.5 and their values are above 15 $\frac{mCi}{montsGW(el)}$ they must be monitored.

Table 3.5. Average monthly permissible emissions of radioactive aerosols.

Emission	Radionuclide					
	^{90}Sr	^{89}Sr	^{137}Cs	^{60}Co	^{54}Mn	^{51}Cr
N=1,000-6,000 MW(el) (mCu)/(month·1,000 MW (el))	1.5	15	15	15	15	15

Household sewage may contain discharged radioactive wastewater with a concentration that does not exceed the DC_B for water by no more than 10 times, provided its ten times' dilution with non-radioactive wastewater in the NPP collector. Reference level for the discharges at SS Rivne NPP is 1.5×10^{-10} Cu/dm^3.

Numerical values of permissible emissions and discharges, reference and administrative-technological levels are given in Tables 3.6. and 3.7.

Table 3.6. Permissible, reference, and administrative and technological emission levels.

Radionuclide (a group of radionuclides)	Control, Gbq/day
Long-lived radionuclides (LLR)	0.37
Inert radioactive gases (IRG)	67,000
Iodine radionuclides	5.5
^{51}Cr	620
^{54}Mn	3.0
^{59}Fe	9.9
^{58}Co	9.4
^{60}Co	0.17
^{89}Sr	23
^{90}Sr	0.48
^{95}Zr	13
^{95}Nb	25
^{110m}Ag	0.49
^{134}Cs	0.40
^{137}Cs	0.35
^{3}H	930

Table 3.7. Permissible, reference, and administrative and technological discharge levels.

Radionuclide (a group of radionuclides)	Control, Gbq/hour
^{3}H	2,400,000
^{51}Cr	53,000
^{54}Mn	490
^{59}Fe	290
^{58}Co	450

Radionuclide (a group of radionuclides)	Control, Gbq/hour
^{60}Co	52
^{65}Zn	270
^{89}Sr	6,700
^{90}Sr	130
^{95}Zr	200
^{95}Nb	2,600
^{106}Ru	840
^{110m}Ag	2,900
^{131}I	1,200
^{134}Cs	57
^{137}Cs	83
^{144}Ce	310

In accordance with requirements of DGN 6.6.1-6.5.001-98 [24], reference levels are set with the purpose of fixing the achieved level of radiation safety at the radiation-nuclear facility, in the settlement, and in the environment on the basis of information on the radiation state at the facility for its individual premises, the SPZ, the OZ, and other facilities for the planning of protective measures and operational monitoring of the radiation state. Reference levels are established by the administration of the radiation-nuclear facility with the obligatory agreement with the state regulatory bodies.

In addition to reference levels of gas-aerosol emissions and water discharges of radioactive substances into the environment, the operating organization establishes administrative and technological levels (ATL), which in essence are levels of research, in order to identify the causes of uncontrolled growth of emissions and discharges of the NPP. Excessive ATL do not belong to the category of violations of norms and rules in effect at NPPs and do not require reporting to state regulatory bodies. ATL compliance facilitates the optimization of technological processes, the development of organizational and technical measures aimed at reducing the level of aerosol discharges and water discharges of the NPP into the environment, as well as preventing the company from achieving the established reference levels of emissions and discharges of radioactive substances.

Regulation and control of population exposure (Category C) are based on the calculations of annual effective and equivalent radiation doses for critical population groups. Limit dose rates for population are specified for relevant nuclear radiation facilities. Permissible discharge (PD) and permissible release (PR) values are specified based on the limit dose rates for each facility. Limit dose rates for NPP release and discharge values are given in Table 3.8.

Table 3.8. Limit dose rate to determine PD and PR values.

Radiation-nuclear facility	Release: DL_E rate due to all dose formation pathways		Discharge: DL_E rate due to a critical water use type		Total DL_E rate due to air and water dose pathways	
	%	µSv	%	µSv	%	µSv
NPP, NHPP, NHP	4	40	1	10	8	80

Limit values of radionuclide intake through the respiratory system (PI^{inhal}) and digestive system (PI^{ingest}), as well as limit air radionuclide concentrations (PC^{inhal}) and drinking water (PC^{ingest}) are determined for population (Category C). Numeric values of permissible levels in case of impact of a single radiation type, single radionuclide and single radiation pathway under relevant reference radiation conditions are given in Table 3.9.

Table 3.9. Permissible levels of radionuclide intake through the respiratory and digestive systems, air and water concentrations for Category C.

Radionuclide	PI^{inhal}, Bq/year	PI^{ingest}, Bq/year	PI^{inhal}, Bq/m^3	PI^{ingest}, Bq/m^3
^{54}Mn	4×10^4	2×10^5	20	8×10^5
^{58}Co	3×10^4	3×10^4	10	6×10^5
^{60}Co	3×10^3	1×10^5	1	8×10^4
^{90}Sr	6×10^2	4×10^3	0.2	1×10^4
^{110}Ag	5×10^3	4×10^4	2	2×10^5
^{131}I	8×10^3	6×10^3	4	2×10^4
^{134}Cs	3×10^3	4×10^4	1	7×10^4
^{137}Cs	2×10^3	5×10^4	0.8	1×10^5
^{3}H	2×10^5	8×10^6	100	3×10^7

Within the period under survey (2004-2017), permissible release and discharge at Rivne NPP were regulated in accordance with documents that specify limits for release and discharge (PR_i and PD_i) of key dose forming radionuclides during normal operation. Permissible release and discharge rates at Rivne NPP were reviewed twice over the period under consideration.

Limit release values (PR_i) for key dose forming radionuclides during normal operation are currently established at SS Rivne NPP and agreed upon with the MoH of Ukraine (23 February 2012) (see Table 3.6).

Permissible release/discharge values meet the requirements for NPP operation from the viewpoint of radiation safety of the population within the local natural ecological system. PR_i and PD_i values are not affected by the number of power units in operation. Permissible release/discharge values may not be exceeded during normal operation of the NPP.

In accordance with the document "Permissible water discharge of radioactive substances from SS Rivne NPP" (group 1 radiation and hygienic regulation) 132-2011-КУ-ЦРБ, limit discharge PD_i values (limit permissible amount of radioactive substances, which may discharged into the environment with water from SS Rivne NPP) for key dose forming radionuclides during normal operation are currently established at SS Rivne NPP and agreed upon with the MoH of Ukraine (23 February 2012) (see Table 3.6). Permissible discharge values meet the requirements for NPP operation from the viewpoint of radiation safety of the population within the local natural ecological system. PD_i values are not affected by the number of power units in operation.

Permissible discharge values may not be exceeded during normal operation of the NPP.

In accordance with requirements of [11], reference levels of gas-aerosol release and liquid discharge of radioactive substances were established for SS Rivne NPP.

See Table 3.10 and Table 3.11 for the reference levels of gas-aerosol release and liquid discharge from SS Rivne NPP, as approved by Deputy Minister of Health of Ukraine on 13 May 2013.

Table 3.10. Reference levels of gas-aerosol release.

Radionuclide group	Reference level, MBq/day
Long-lived radionuclides (LLR) mix	9.0
Inert radioactive gases (IRG)	$8{,}7\times10^5$
Iodine radionuclides	40
Radionuclides	Reference level, MBq/month
^{60}Co	35
^{134}Cs	48
^{137}Cs	42
^{3}H	$5{,}2\times10^5$

Table 3.11 Reference levels of liquid discharge of radioactive substances.

Radionuclides	Reference level, MBq/year
^{60}Co	18
^{90}Sr	64
^{134}Cs	20
^{137}Cs	240
^{144}Ce	110
^{3}H	$5{,}6\times10^6$

ATL compliance facilitates the optimization of technological processes, the development of organizational and technical measures aimed at reducing the level of aerosol discharges and water discharges of the NPP into the environment, as well as preventing the company from achieving the established reference levels of emissions and discharges of radioactive substances. The number of chemical (non-radioactive) emissions of pollutants into the atmosphere from sources at SS Rivne NPP is regulated by the "Permits for the Emission of Pollutants into the Atmosphere by Stationary Sources" (Annex A).

Planned activity is the operation of power units of SS Rivne NPP. Due to the fact that the development of the industrial complex of SS Rivne NPP is foreseen through the reconstruction and revamping of existing production units, which functionally fit into the existing NPP infrastructure exclusively within its territory, no urban planning restrictions are considered. Fire safety is ensured by compliance with requirements of legislative acts and regulations of [32-38] during the period of operation and reconstruction of the industrial complex of SS Rivne NPP, namely due to the existing regulatory gap between the distances between buildings and structures through fire extinguishing systems, road arrangements, and more.

Fire safety aspects reflect all aspects of fire safety:

- the purpose and functions of the fire safety system;
- fire prevention solutions from the master plan;
- classification of buildings and structures in terms of fire safety;
- three-dimensional planning solutions, fire barriers, fire protection of buildings and structures, and basic provisions for the selection of fire-extinguishing materials;
- evacuation routes and exits, access routes, and safety of engineering departments;
- fire protection measures for technological processes;
- fire protection measures for electrical installations;
- fire protection measures for ventilation systems;
- fire protection systems: firefighting water supply, fire alarm, fire extinguishing, anti-dust protection, fire notification and evacuation management, lightning protection, and grounding;
- primary means of fire extinguishing.

4 SS RIVNE NPP PRODUCTION WASTE

In the process of NPP operation, formation of solid, liquid, and gaseous waste is inevitable.

Radioactive waste (RAW) - physical objects and substances having radionuclide activity or radioactive contamination which exceeds the limits set by current regulations, provided that the use of these objects and substances is not planned. RAW is a special type of radioactive material (in any aggregate state), for which:

- it is established that it cannot be used neither now nor later in the future, or

- no final decision yet exists about the ways these materials can be used in modern or future industrial processes [11]. RAW classification is established by the State Sanitary Rules DSP 6.177-2005-09-02 “Main Sanitary Rules of Radiation Safety of Ukraine” [11].

Electric power generation at NPPs is accompanied by the formation of RAW directly during the course of the main technological process, as well as in the course of implementation of by-the-book and repair procedures. Safe state of RAW management at all stages of its formation and existence is indisputable for sustainable development of nuclear power industry. The RAW management system is an important component of the overall safety system for the use of nuclear energy.

The main principles of RAW management at NPPs are minimization of its formation and interconnection between all stages (from formation to disposal) [39].

The Strategy of Radioactive Waste Management in Ukraine approved by the Cabinet of Ministers of Ukraine, as well as the National Target Environmental Program on Radioactive Waste Management approved by the Law of Ukraine, provides for the extraction and processing of RAW accumulated at NPPs during their operation by creating an infrastructure for characterization, conditioning, and packaging of RAW in a way suitable for its subsequent transportation for storage and/or final disposal.

Releasing volumes in RAW storages at NPPs for recycling/conditioning is a prerequisite for extending the life of an NPP.

RAW management at SS Rivne NPP is carried out according to:

- the Law of Ukraine “On the Management of Radioactive Waste” dated 30 June 1995 No. 256/95 -VR [40];

- the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” dated 8 February 1995 No. 40/95 -VR [5];

- the Law of Ukraine “On the National Target Environmental Program on Radioactive Waste Management” dated 17 September 2008 No. 516-VI [41];

- Strategies for Radioactive Waste Management in Ukraine approved by the Resolution of the Cabinet of Ministers of Ukraine dated 19 August 2009 No. 516- VI [42];

- The “Integrated Program of Radioactive Waste Management at SE NNEGC Energoatom” PM-D.0.18.174-16, which was put into effect by the order dated 10 December 2016 No. 927-r. [43]

State regulatory bodies for the management of RAW are the State Nuclear Regulatory Inspection of Ukraine and the Ministry of Health of Ukraine; the Ministry of Energy and Coal of Ukraine is the state governance body.

Specialized Enterprise SSE “TsPPVV” (storage operator) within the State Agency for Exclusion Zone Management is responsible for receipt and disposal (if necessary, long-term storage) of conditioned RAW. At present, NPP RAW is not transferred to storages for long-term storage or disposal; however, work on preparation for transfer to the special enterprise has begun.

Planning of RAW management activities at SS Rivne NPP is carried out in accordance with the "Integrated Program for Radioactive Waste Management at SE NNEGC Energoatom" PM-D.0.18.174-16 [43]. It defines the main directions of activity and a list of activities on RAW management at SE NNEGC Energoatom, in particular, the minimization of the formation of RAW, the improvement of existing RAW management systems at NPP sites, the building of integrated RAW processing lines for the preparation of NPP RAW to transfer to the state property, the provision of NPPs with RAW storage facilities, the harmonization and improvement of the regulatory and methodological framework in the field of RAW management by NPPs etc.

The main principles of SE NNEGC Energoatom when planning activities in the field of RAW management are the following:

- ensuring an adequate level of safety in the field of RAW management;
- minimization of RAW formation volumes from NPP operation;
- selection of optimal technologies for RAW processing, taking into account such factors as:
  - ✓ individual and collective exposure doses of personnel;
  - ✓ costs of RAW processing;
  - ✓ amount of RAW generated;
  - ✓ duration and costs of temporary storage of RAW;
  - ✓ requirements for the final product acceptable for disposal;
  - ✓ possibility of using the selected RAW processing methods both at the operation stage and at the stage of decommissioning of the nuclear installation;
- ensuring the possibility of processing, immobilization, and temporary storage of RAW to be created during prolongation of the NPP's lifetime;
- use of modern technologies for processing and immobilization of RAW to ensure its safe transportation and disposal;
- ensuring the quality of all processes and work on the management of RAW at NPPs.

The main measure to improve the RAW management system at SS Rivne NPP is the construction of a RAW processing complex (RAW CT). The PM-D.0.18.174-16 program foresees the commissioning of the RAW management facility in 2018. A Separate Permit of the State Nuclear Regulatory Inspectorate of Ukraine on the commissioning of a new infrastructure facility (a RAW processing complex) was received.

The State Nuclear Regulatory Inspectorate of Ukraine provided regulatory support to the work, consideration and approval of integrated testing programs and related technical decisions regarding the experimental commissioning of the RAW CT of SS Rivne NPP composed of technological installations:

- extraction of SRAW from SRAW storage compartments;
- SRAW sorting and fragmentation;
- SRAW super-compression;
- SRAW cementing;
- measurement of SRAW activity;
- deactivation of metal;
- recycling of spent lubricant.

Commissioning of the complex will allow:

- reducing the amount of accumulated SRAW and SRAW generated during the operation;

- conditioning solid RAW (SRAW) to ensure its safe long-term storage or disposal;
- receiving additional free volumes in existing storages for the temporary storage of containers with conditioned SRAWs in state ownership.

Handling of RAW at SS Rivne NPP is carried out as at any operational SS of the NPP in accordance with the basic scheme shown in Fig. 4.1.

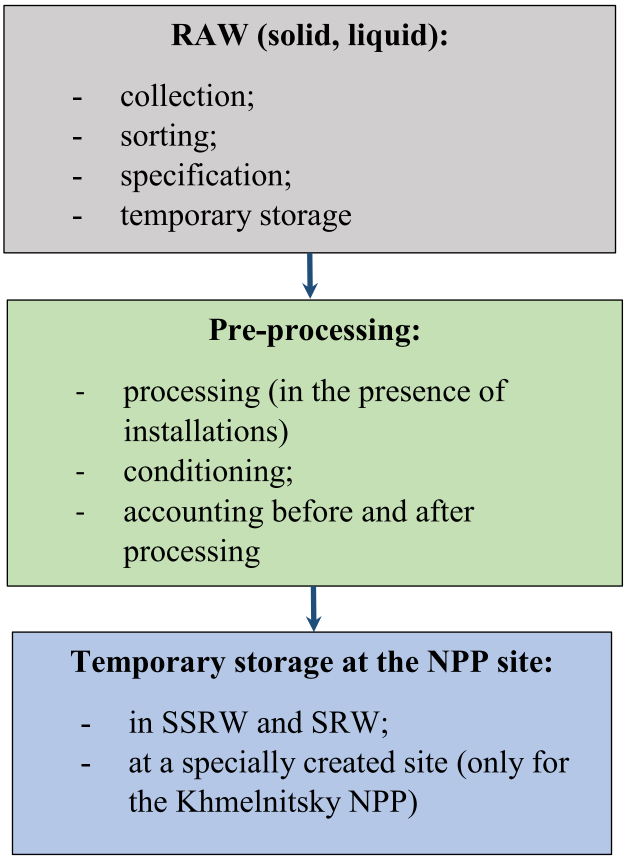


Fig. 4.1. Principal scheme of RAW management at NPPs

The state of RAW management at the Ukrainian NPP is characterized by the absence of a complete technological cycle from processing to obtaining the final product acceptable for further long-term storage or disposal.

At present, due to the unpreparedness of the Operator of Storages of SSE "TsPPVV," which is subordinated to the State Agency of Ukraine for Exclusion Zone Management, to the reception of RAW at the NPP for long-term storage and disposal, no RAW is delivered to this specialized enterprise.

4.1 Management of solid RAWs at operation of power units

Solid RAWs are generated during the normal operation of the NPP, during repairs, and in case of accidents [44].

Main sources of solid RAW formation are maintenance and repair of power units, including:

- operation of equipment, buildings, and structures of the NPP;
- reconstruction and revamping of equipment;

- decommissioning of equipment, including replacement of steam generators;
- decontamination of equipment, premises, buildings, and structures of the NPP;
- maintenance and repair of equipment;
- installation, disassembly, and replacement of thermal insulation;
- construction and reconstruction;
- replacement of worn and worn items of equipment and consumables;
- replacement of worn outwear and PPE of the personnel;
- implementation of sanitary-hygienic measures in the zone of strict regime.

Solid RAW, as a rule, is:

- metal formed during the replacement of equipment and as a result of repair work;
- wood products (stairs, linings, forests etc.);
- use of personal protective equipment;
- rubber products, cable products;
- filters of ventilation systems of RV and LC;
- thermal insulation materials;
- waste of construction origin (concrete crumb, plaster etc.);
- rubbing material, rags;
- ash after RAW treatment at combustion plant;
- internal reactor units and elements of RV systems.

Transportation of containers from SRAW to the SRAW storage facility in a special building on the site of SS Rivne NPP is carried out using a special motor transport (SMT).

SRAW distribution according to the types of processing is shown in Fig. 4.2.

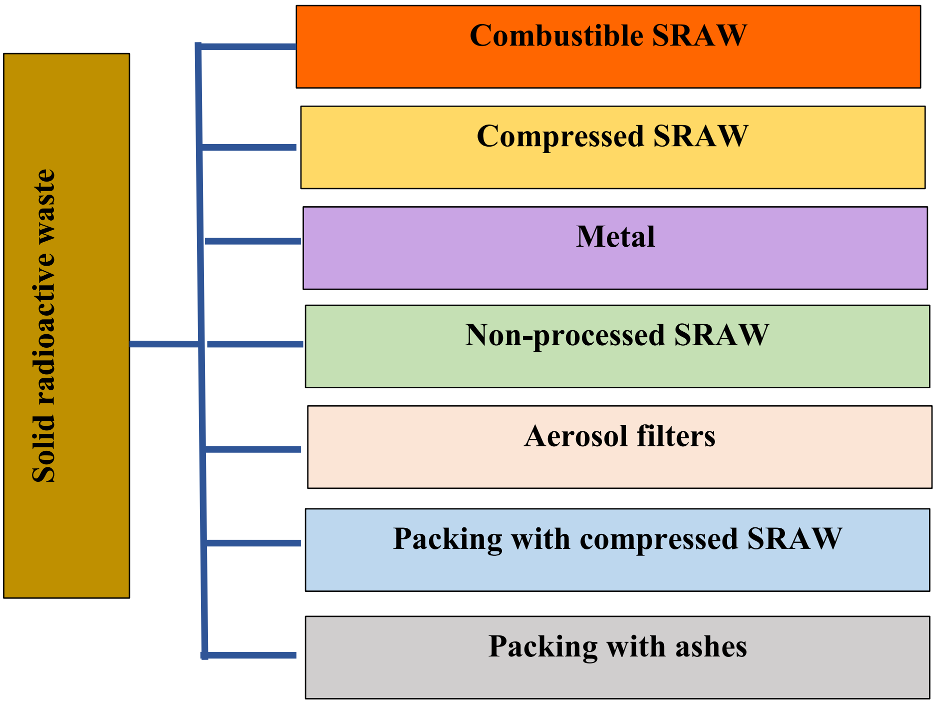


Fig.4.2. SRAW distribution by types of processing

Solid RAW is classified by type:

- Short-term ($T_{1/2}$: up to 10 years);
- Medium-term ($T_{1/2}$: up to 100 years);
- Long-term ($T_{1/2}$: over 100 years).

SRAW management at the SS RNPP includes:

- collection of waste into polyethylene bags in places of their generation;
- primary sorting of waste with fragmentation (if necessary);
- transportation of waste from temporary collection sites;
- sorting of wastewater based on the activity of NAV, SAV and VAV;
- transportation of SRAW by special vehicle OT-20 from temporary collection sites to LC No. 2 (for power units Nos. 3, 4);
- acceptance of SRAW by personnel of TsD and RAW for temporary storage;
- loading of SRAW by the personnel of the TsD and RAW into the cell of the SSRW of LC No. 1 (for power units Nos. 1, No. 2) and SSRW of LC No. 2 (for power units Nos. 3, 4).

In accordance with SP AS-88 [45], all SRAW sorted by type and classified by activity are placed for temporary storage in the SRAW storage facility in the special building at the site of SS Rivne NPP.

The scheme of treatment of SRAW at SS Rivne NPP is shown in Fig. 4.3.

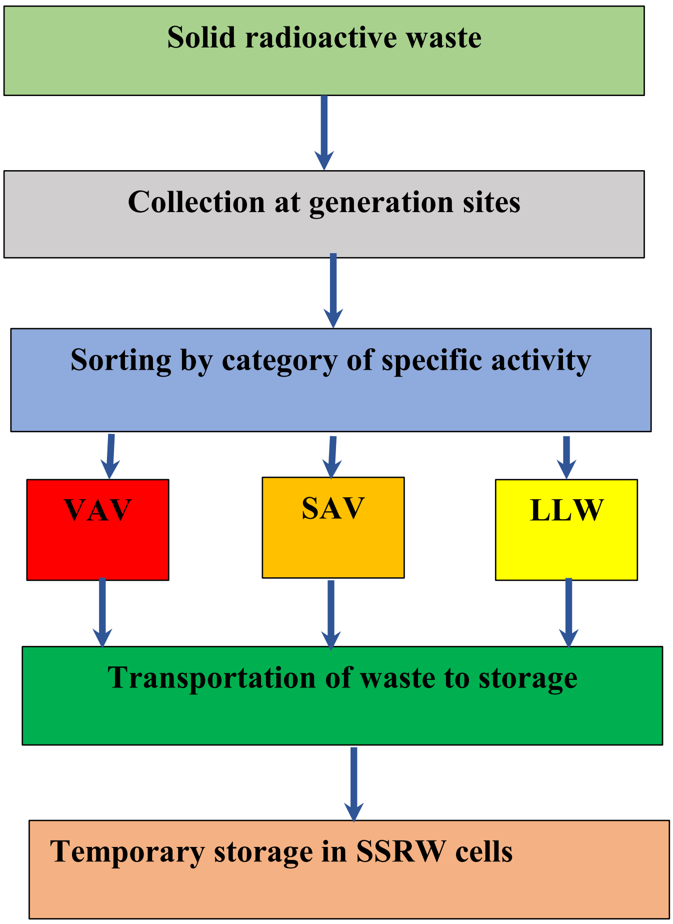


Fig. 4.3. SRW management scheme at SS Rivne NPP

In accordance with [45], all SRAW sorted by type and classified by activity is placed to SRAW storages in a special building at the site of SS Rivne NPP for temporary storage.

SRAW classification by groups, which is determined depending on the level of sequestration set for a particular group of radionuclides in the RAW, is given in Table 4.1.

Table 4.1. Classification of RAW by groups [11].

RAW group	Solid RAW	Removal rate kBq×kg^{-1}
1	Transuranium alpha emitting radionuclides	0.1
2	Alpha emitting radionuclides (with the exception of transuranic)	1
3	Beta and gamma emitting radionuclides (except those included in group 4)	10
4	H-3 C-14 Cl-36 Ca-45 Mn-53 Fe-55 Ni-59 Ni-63 Nb- 93m Tc-99 Cd-109 Cs-135 Pm-147 Sm-151 Tm-171 Tl-204	100

Table 4.2 presents the classification of SRAW categories by criterion of specific activity

Table 4.2. Classification of SRAW categories by specific activity [11].

SRW category	Interval of values of specific activity of SRAW, kBq/kg			
	Group 1	Group 2	Group 3	Group 4
Low-active	$>10^{-1}<10^{1}$	$>10^{0}<10^{2}$	$>10^{1}<10^{3}$	$>10^{2}<10^{4}$
Medium-active	$\geq 0^{1}<10^{5}$	$\geq 10^{2}<10^{6}$	$\geq 10^{3}<10^{7}$	$\geq 10^{4}<10^{8}$
High-active	$\geq 10^{5}$	$\geq 10^{6}$	$\geq 10^{7}$	$\geq 10^{8}$

Classification of RAW with an unknown radionuclide composition (URC) and an unknown specific activity by the criterion of power absorbed in the air at a dose of 0.1 m from the surface of the object (container) is given in Table 4.3.

Table 4.3. Classification of RAW by the criterion of power of doses absorbed in air [11].

SRW category		Power of doses absorbed in air, μGy/hour
1	Low-active URC	1+100
2	Medium-active URC	100+10,000
3	High-active URC	10000

The first stage of complex tests was completed at RAW CT at SS Rivne NPP, which was constructed in conjunction with the European Commission, as part of the TACIS International Technical Assistance Project. The second stage, the so-called "hot" tests on real RAW, the successful completion of which will be the start of operation of the first complex at existing nuclear power plants in Ukraine, is underway.

In February of this year, the first stage of complex ("cold") tests of auxiliary systems and all seven plants of the RAW CT, which included experts of the power plant and representatives of the State Nuclear Regulatory Inspectorate of Ukraine at SS Rivne NPP, came to the end. As a result of the first stage, reporting documentation sent to the State Nuclear Regulatory Inspectorate of Ukraine was prepared and a separate permission for the second stage ("hot") tests was received.

Modern technological equipment meets the high European standards. The activity of the complex at SS Rivne NPP will not only reduce the amount of waste generated during the operation but will also increase the safety and environmental friendliness of the domestic nuclear power industry as a whole and preserve the environment.

The permit was issued on 1 June 2018, with the term of validity of the completion of the life cycle “Operation of the Nuclear Installation of the Power Unit No. 4 of Rivne NPP.” Decision on its issuance was made by the State Nuclear Regulatory Inspectorate of Ukraine on the basis of the positive results of the state examination of documents substantiating the safety of the implementation of the declared type of activity and the inspection survey conducted by the committee of the State Nuclear Regulatory Inspectorate of Ukraine with the aim of studying the capacity of the operating organization (SE NNEGC Energoatom) to carry out commissioning of the RAW Processing Complex of Rivne NPP. More detailed information can be obtained from Annex C “Development and Implementation of the Wastewater Treatment System at SS Rivne NPP” of Volume 2 “Report on the Environmental Impact Assessment of the Site of SS Rivne NPP. General Description of SS Rivne NPP. Production Waste.”

4.2 Management of liquid RAWs at operation of power units

During the operation of the NPP, liquid RAW is generated in the technological systems of the reactor compartment and the special building, as a result of water contact with nuclear fuel elements and contamination of lubricants, as well as during the operation of water cooling system plants.

LRAW is mainly represented as:

- unorganized flows of circuit I coolant;
- radiation of contaminated lubricant;
- spent ion-exchange resins of SWP;
- water resulting from decontamination;
- sewage waters of sanatoria and special washing room;
- water from hydraulic filters;
- cubic remnants;
- spent filtering materials of SWP;
- slurry of SWP.

SS Rivne NPP operates a transport overpass, which allows to carry out the transfer of drainage water and decantate of the CB from the special building No. 1 to the special building No. 2. The spent filter materials (SFM) are transported to SRW tanks, where they are stored under a water layer, with the help of a hydrotransport system.

The scheme of treatment of LRAW at SS Rivne NPP is shown in Fig. 4.4.

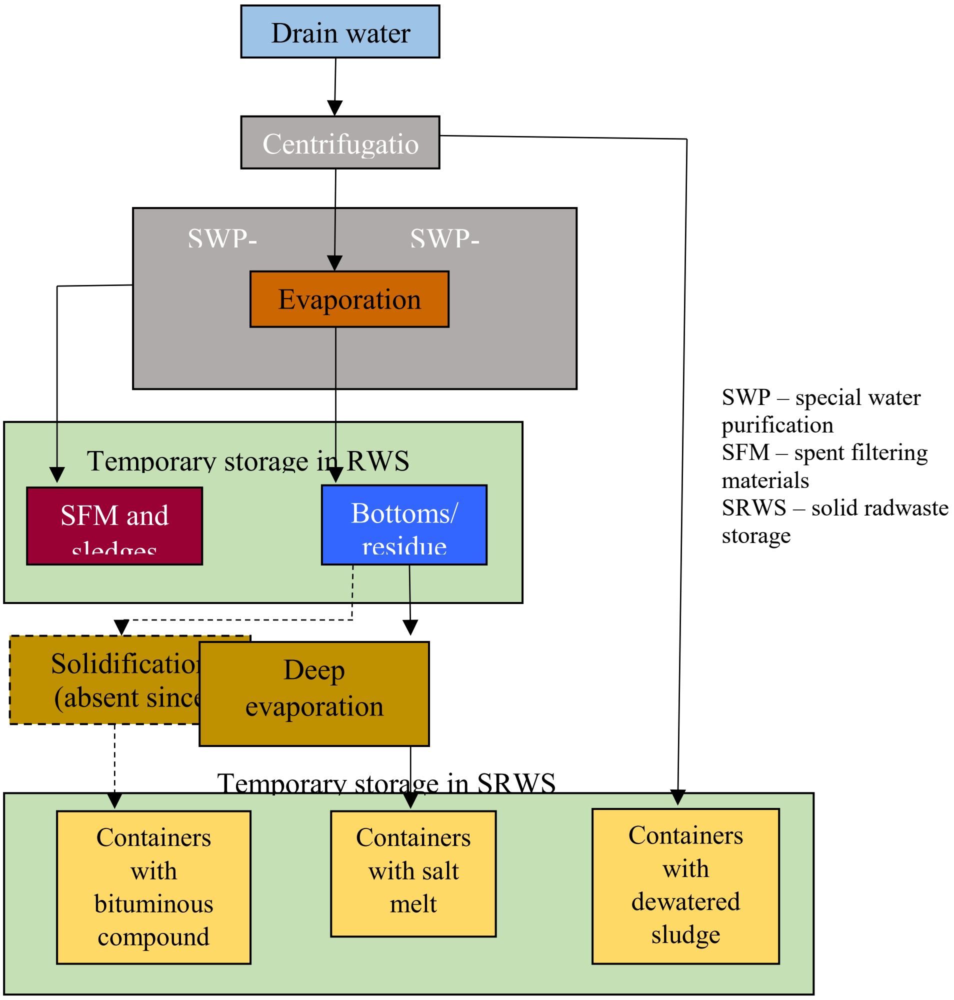


Fig. 4.4. Scheme of treatment of LRAW at SS Rivne NPP

According to the results of the analysis of the sources and the amount of drainage formation, relations between the sources of formation of LRAW for each of the power units, the special building, SS Rivne NPP as a whole determined and implements "Measures Aimed at Minimizing the Formation of Liquid RAWs at SS Rivne NPP" [46], as a result of which a significant reduction in the annual flow of drainage water occurs.

According to DSP 6.177-2005-09-02, liquid RAW includes:

- solutions of inorganic substances;
- pulp of filter materials;
- saline melt;
- organic liquids (oils, solvents etc.) with the following radiation characteristics:
  - ✓ the content of individual radionuclides exceeds the permissible concentration established for water used by the population for food and drinking purposes;
  - ✓ the composition of the mixture of radionuclides is such that the sum of the ratio of the specific activity of each individual radionuclide to its corresponding value exceeds one.

In the process of normal operation of the equipment of SS Rivne NPP, radioactive contaminated environments (drains, or drainage water) are formed and collected in special tanks. Radioactive environments and effluents are supplied from the reactor facilities, generated as a result of the operation of special water purification (SWP) systems, decontamination of equipment and work clothes, sanitary - domestic mergers, mergers of laboratories etc.

After the processing and evaporation of drainage water using SWP evaporative machinery, a liquid concentrate of salts (the cubic balance, CB) is generated. CB is stored in special liquid RAW storage (SLRW) in metal sealed containers made of corrosion-resistant steel equipped with an automated system for determining the level of LRAW and a leakage alarm. To exclude the emergency leakage of LRAW into the environment, all the tanks are located in reinforced concrete units faced with sheets of corrosion-resistant steel to the height of emergency filling of containers.

The SLRW is sent to a deep evaporation unit (DEU) for processing, where an even more concentrated product is generated, which is fed into a container (capacity: 200 dm^3) and freezes to the solid phase in the process of cooling. Containers with saline melt (the product of the cuvette remover at the deep evaporation unit) is transported to solid RAW storages (SSRW) for temporary storage.

According to the results of the analysis of the sources and the amount of drainage formation, relations between the sources of formation of LRAW for each of the power units, the special building, SS Rivne NPP as a whole determined and implements “Measures Aimed at Minimizing the Formation of Liquid RAWs at SS Rivne NPP,” as a result of which a significant reduction in the annual flow of drainage water occurs.

During LRAW treatment SS Rivne NPP uses and operates the following:

- centrifugation plant (CP) designed for preliminary purification of drainage water from mechanical impurities by centrifugation in the cycle of SWP-3 system, as well as cleaning tanks designed to collect and protect drainage water from accumulated slurry.

- deep evaporation unit. Two lines of the unit УУУ-1-500М in 2015 were in operation for 2,508 hours. The result of deep evaporation installations at SS Rivne NPP in 2015 is the processing of 1,084 m^3 of cubic remnants and the receipt of 480 containers (96.0 m^3) with saline floatation. In 2015, the total volume of CB of LC Nos. 1, 2 in the SLRW amounted to 3,217 m^3.

- water purification systems (WPS). In order to clean technological environments from corrosion products and chemical mixtures, provision is made for WPS installations, which include ion-exchange filters. In the course of operation of SWP filters, SFM (ion exchange resins) are generated. SFM are collected and stored in SRAW containers under a water layer.

- asphalt-based solidification installation. Until 2002, the asphalt-based solidification installation (UB) was used, which was removed from operation due to the installation of the DEU. At UB, the CB was evaporated in asphalt-based solidification installations with the subsequent incorporation of bitumen heated to a certain temperature. Obtained product of processing(salt-bitumen compound (SBC)) was sent to a container with subsequent transportation to the SSRW for storage. The asphalt-based solidification installation is intended for processing of the cubic balance. Design capacity of the installation is 150 dm^3/hour. The principle of operation of the installation is to evaporate the cubic balance to 5% humidity with the simultaneous incorporation of salts into the bitumen matrix. Installation was removed from operation on 31 December 2002 and has not been used since then.

As of today, a complex of works on the preparation of the SBC for the transfer to SSE “TsPPRV.”

The general scheme for handling drainage waters and LRAWs is shown on Fig. 4.5.

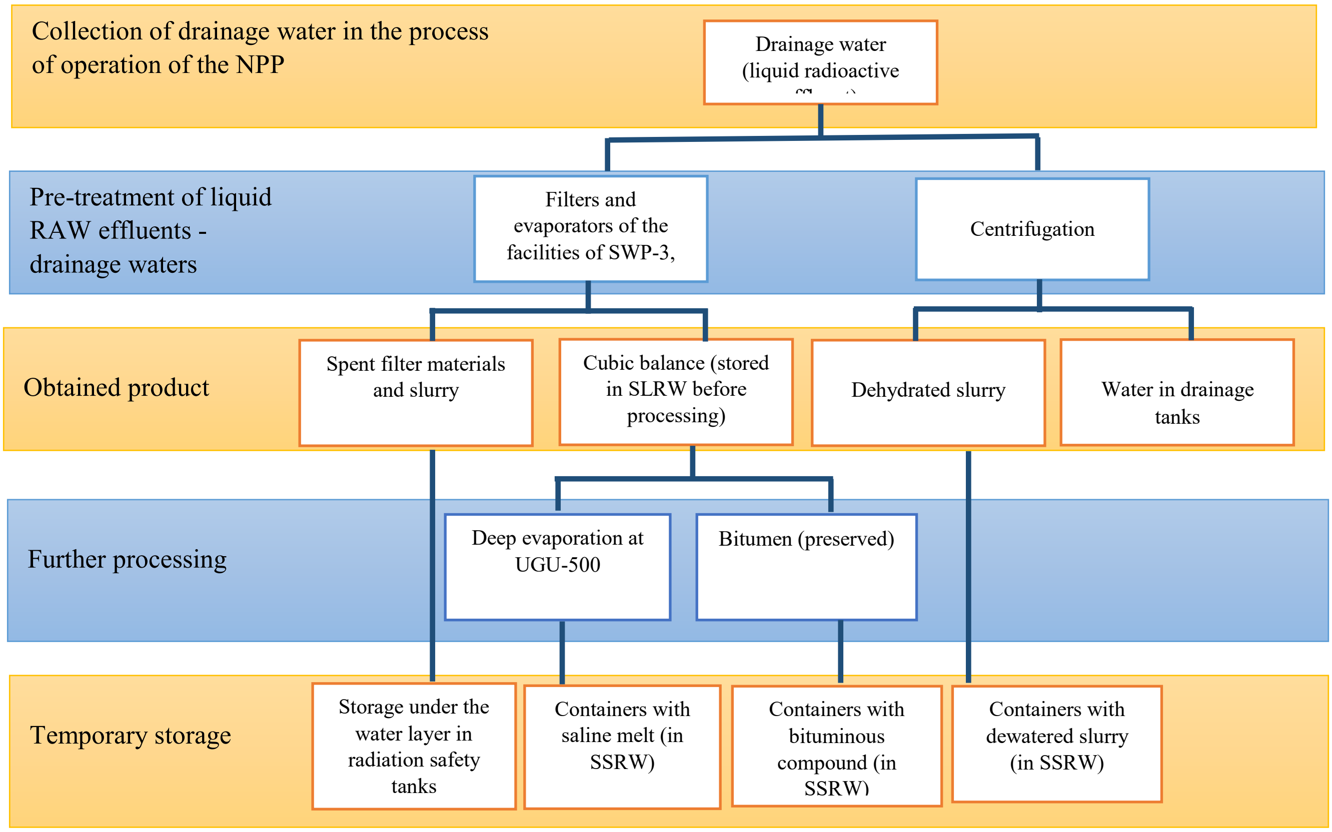


Fig. 4.5. Scheme of treatment of drain water and LRAW at SS Rivne NPP

Accumulation of liquid RAW in the repositories of SS Rivne NPP as of 31 December 2017 is depicted in Fig. 4.6.

During 2017, SS Rivne NPP established:

- 380 m^3 of cubic balance;
- 3.6 m^3 of spent filter materials;
- 5.0 m^3 of dehydrated slurry (25 containers);
- 77.6 m^3 of salt floating (388 containers).

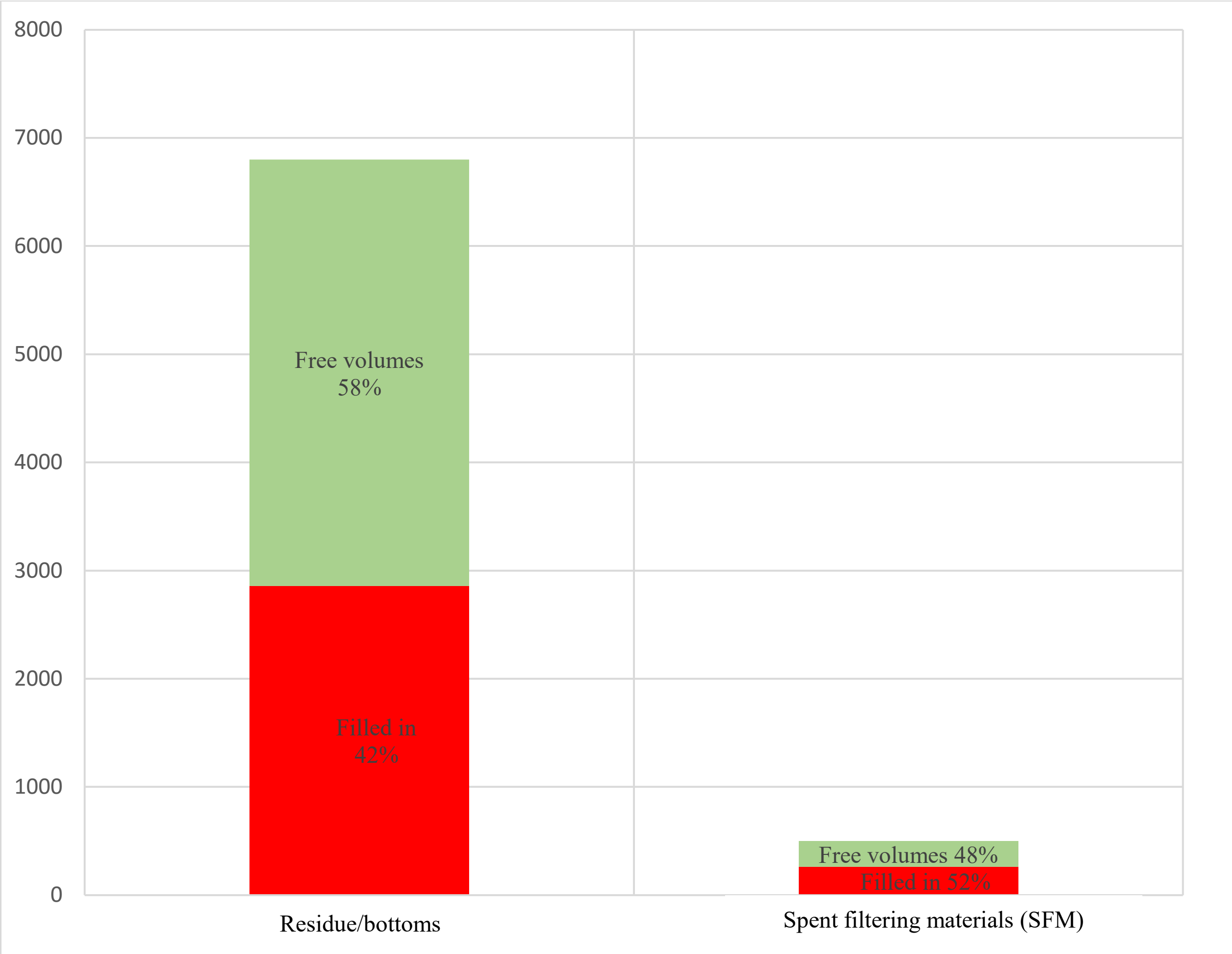


Fig.4.6. Accumulation of LRAW in the SLRW of Rivne NPP

The treatment of LRAW at Ukrainian NPPs is characterized by the absence of a complete technological cycle from processing to obtaining the final product suitable for further long-term storage or disposal; therefore, an interagency working group (RAW IWG) was set up to address the issues of optimization of the RAW management strategy of Ukrainian NPPs. Representatives of SE NNEGC Energoatom, SS NPP, VP STC, State Nuclear Regulatory Inspectorate of Ukraine, the Ministry of Energy and Coal Industry, PJSC KIEP, the Ministry of Health of Ukraine, DAC, and ChNPP are involved in the group (order of SE NNEGC Energoatom dated 21 January 2015 No. 60-r). It was agreed that at the first stage of the work of the RAW IWG it would be advisable to concentrate efforts on improving the RAW management system of the NPP. For solving problem issues, on 9 March 2016, "Advanced Plan of Priority Measures for Optimization of the Radioactive Waste Management System at SE NNEGC Energoatom" was developed and approved. The issues of further processing of SMF, saline melt, dehydrated slurry are solved within the framework of the work of this group.

In case of constant work of deep evaporation units and implementation of measures planned in the "Integrated Program of Radioactive Waste Management at SE NNEGC Energoatom" PM-D.0.18.174-16 [47], free volumes of capacities of SLRW will be sufficient to ensure the safe operation of power units of SS Rivne NPP, both during the period of project operation and during the period of prolonged operation of power units.

4.3 Design data on the generation and processing of non-RAWs

Summarized data on the generation and placement of non-RAW at SS Rivne NPP for 2017 are given in Table 4.6 [16]. Ingeneration from all units on volumes and types of non-RAW from SS Rivne NPP, which are to be transferred to a specialized economic entity for utilization (removal) in 2016, was provided to SS "Warehousing" of SE NNEGC Energoatom for the formulation of plans. The transfer of secondary raw materials to RV VP SG in the reporting period was carried out on the basis of "Regulations on the Organization of Work with Secondary Raw Materials" PL- D.045.541- 15.

In 2017, the environmental and chemical laboratory of the Environmental Protection Service of SS Rivne NPP (according to the certificate of registration No. R-4/12-59-4 dated 11 May 2015) monitored the status of groundwater and soils at waste disposal sites. Monitoring was carried out in accordance with the approved schedule of analytical control of the environment around the slurry tank and industrial and construction waste landfill.

The enterprise developed the "Instruction on Processing Non-RAW at SS RNPP" 083-1-I-SONS. Order No. 436 dated 31 05 2017 appointed officials responsible for waste management.

Annually, according to item 15 of "Procedure for Maintenance of the Register of Objects of Generation, Management, and Utilization of Waste" approved by the Resolution of the Cabinet of Ministers of Ukraine No. 1360 dated 31 August 1998, amendments to the registration card and changes to the passports of waste disposal sites are submitted to the Department of Ecology and Natural Resources of the Rivne Regional State Administration: construction and industrial waste landfill and slurry tank.

In accordance with item 19 of the "Procedure for Maintenance of the Register of Waste Disposal Sites" approved by the Resolution of the Cabinet of Ministers of Ukraine No. 1216 dated 3 August 1998, the results of observations and control measurements of the landfill and slurry passport are reviewed annually. In order to control the waste disposal sites (WDS) at SS Rivne NPP in Q3 of 2017, the State Agency "Rivne Regional Laboratory Center" of the Ministry of Health of Ukraine conducted instrumental and laboratory measurements of atmospheric air pollution at waste disposal sites. Analysis of qualitative indicators of water, soil, and atmospheric air shows that the operation of the WDS is carried out in accordance with requirements of environmental legislation and does not harm the natural environment.

Changes in passports are approved by the Department of Ecology and Natural Resources of the Rivne Regional State Administration, which is recorded through relevant records.

Waste management at the enterprise is carried out in accordance with requirements of regulatory documents and production instructions.

During the reporting period, solid household waste was transferred to the landfill of the municipal enterprise of the city. During the year, in accordance with the "Regulations on the Relationship between SS 'Warehousing' and SS NPP, SS "Atom Komplekt," SS "Atomprojectengineering," and DOVK SE NNEGC Energoatom" PL-D.0.45.551-13, spent fluorescent lamps, monitors, batteries, and spent and worn tires were transferred to other specialized enterprises through RV VP SG for further utilization (removal) of waste.

Exhausted oils and lubricants (motor, turbine, industrial, transformer), spent batteries, glass scrap, metal scrap, and scrap paper (except for technical documentation, accounting and other documents to be destroyed) were transferred to the Rivne Department of SS "Warehousing" as secondary raw materials. The transfer of waste as a secondary raw material was carried out on the basis of the "Regulation on the Organization of Work with Secondary Raw Materials" PL-D.0.45.541-15.

In connection with the entry into force of the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Concerning the Reduction of the Number of Permitting Permit Documents" dated 9 April 2014 No. 1193-VII the granting of permits for operations in the field of waste management will be carried out in accordance with requirements of the relevant Procedures (resolutions) after their approval by the Cabinet of Ministers of Ukraine. At present, the relevant Procedure has not been approved (the letter of explanation from the Department of Ecology and Natural Resources of the Rivne Regional State Administration No. 2560/02/2-07/15 dated 9 December 2015).

Table 4.6. Generation and placement of non-RAW at SS Rivne NPP.

Hazard class	Name and physical state of waste	Storage location	Presence of waste as of 1 January 2017	Limit of waste generation	Movement of waste in the reporting quarter (since the beginning of the year)				
					Waste generated, pcs/ton; (from the beginning of the	Waste used	Waste removed to the disposal site: WDS	Waste transferred to the side, pcs/ton; (from the	Waste balance as of 1 December 2017
I	Other damaged or used luminescent lamps and waste containing mercury (spent materials)	Separate premises in the enterprise, metal containers	0 pcs / 0 ton	40000 12.0 tons	16789 5.037	-	-	16789 5.037	0
I	Damaged or used lead-acid batteries (spent materials)	Separate premises in the territory of the enterprise	0.641	5т	9.080	-	-	9.188	0.533
Total for class 1:			**0.641**	**17.0**	**14.0**	**-**	**-**	**14.104**	**0.533**
II	Used transformer oils (oils)	Metal tanks	0	100	0	-	-	0	0
II	Used turbine, industrial, synthetic oils (oils)	Metal tanks	18.780	400	20.730	-	-	22.980	16.530
II	Used engine oils and lubricants (oils)	Metal tanks	34.177	40	5.526	0.362	-	-	39.341
Total for class 2:			**52.957**	**540**	**26.256**	**0.362**	-	**22.980**	**55.871**
III	Oil slurries (slurry)	Slurry tank	12.664	20	4.324	-	4.374	0	16.988
III	Damaged, used, or contaminated filtration materials (spent materials)	Landfill of SS RNPP	20.941	8	0.530	-	0.430	0.100	21.371
III	Damaged, used, or contaminated rubbing materials (solid)	Landfill of SS RNPP	15.256	7	1.134	-	1.080	0.054	16.336
III	Used absorbents (solid)	Landfill of SS RNPP	7.090	2	0.400	-	0.400	0	7.490
III	Damaged, used batteries	Separate premises in the	0		0.255	-	-	0.255	0

Hazard class	Name and physical state of waste	Storage location	Presence of waste as of 1 January 2017	Limit of waste generation	Movement of waste in the reporting quarter (since the beginning of the year)				Waste balance as of 1 December 2017
					Waste generated, pcs/ton; (from the beginning of the	Waste used	Waste removed to the disposal site: WDS	Waste transferred to the side, pcs/ton; (from the	
		territory of the enterprise							
Total for class 3:			**55.951**	**37**	**6.643**	**-**	**6.284**	**0.409**	**62.185**
IV	Sludge generated from water cleaning (slurry)	Slurry tank	116979	40000	22516.85	-	22516.85	5866.0	133629.770
IV	Used ion exchange resins (solid)	Landfill of SS RNPP	197.73	120	8.000	-	8.000	-	205.730
IV	Construction waste (solid)	Landfill of SS RNPP	25667.7	5000	4190.2	-	4190.2	-	29857.972
IV	Used filtration means (solid)	Landfill of SS RNPP	116.60	55	0	-	0	-	116.600
IV	Incompletely burned lime (solid)	Landfill of SS RNPP	10284.6	6000	1136.340	-	1136.340	-	11421.000
IV	Waste from wastewater treatment (sediment from slurry sites)	Landfill of SS RNPP	178.0	40	50.0	-	50.0	-	228.000
IV	Residue obtained in the process of extracting sand (solid)	Landfill of SS RNPP	19.18	30	20.5	-	20.5	-	39.680
IV	Tank sediment (solid)	Landfill of SS RNPP	11.271	-	0	-	0	-	11.271
IV	Wood cuttings (solid)	Landfill of SS RNPP	5.53	50	10.58	10.580		-	5.530
IV	Used wooden packaging (pallets, drums)	Landfill of SS RNPP	2.0	5	0.7	-	0.700	-	2.700
IV	Damaged, used, or contaminated mixed packing materials, including wood or metal (solid)	Landfill of SS RNPP		-	0	-	0	-	0
	Total at the landfill of SS RNPP (hazard class 4)								
IV	Small plastic packaging (PET bottle)	Specially allocated places at subdivisions			0.129			0.129	0
IV	A mixture of wastes, materials, and plastic products that are not subject to special treatment (waste plastics, helmets etc.)	Specially allocated places at subdivisions	0.122		0.782			0.782	0

Hazard class	Name and physical state of waste	Storage location	Presence of waste as of 1 January 2017	Limit of waste generation	Movement of waste in the reporting quarter (since the beginning of the year)				
					Waste generated, pcs/ton; (from the beginning of the	Waste used	Waste removed to the disposal site: WDS	Waste transferred to the side, pcs/ton; (from the	Waste balance as of 1 December 2017
IV	Packing materials from plastic (plastic barrels, boxes)	Specially allocated places at subdivisions			0.165			0.165	0
IV	Scrap paper and paperboard (solid)	Specially allocated places at subdivisions	0	20	11.620			11.620	
IV	Spoiled or used wood and wood products (lumber waste)	Specially allocated places at subdivisions	0	300	16.277			11.219	5.058
IV	Fuel slag (solid)	Specially allocated places at subdivisions	6.316	5	0.232	0.232			6.316
IV	Other destroyed, used, or not repairable equipment (including for scientific research, typography, office)	Specially allocated places at subdivisions	0	-	0.052			0.052	0
IV	Damaged, used, contaminated tires (solid)	Warehouse hangar TrC	0.015	30	5.849			5.854	0.010
IV	Broken glass (solid)	SG metal containers	0	35	9.800			9.701	0.099
IV	Communal waste (mixed) incl. waste from rubbish bins (solid)	Municipal waste landfill	0	1000	529.460			529.46 0	0
Total for class 4:			**153468**	**52699**	**28502.8**	**10.8**	**25996.0**	**6428**	**175532**

As a result of the production activity in SS Rivne NPP, non-RAW of class 1 to 4 are generated:

- Hazard class I: used spent fluorescent lamps, used normal elements, used thermometers containing mercury etc.

- Hazard class II: waste from technological processes of production and distribution of energy of electric, gas, steam, and hot water not indicated in any other way (packaging from hazardous chemicals); damaged or used batteries and other batteries; damaged or used nickel-cadmium batteries (including lanterns); waste of auxiliary materials and substances used in energy (delayed chemical reagents).

- Hazard class III: used petrochemicals (slurry and paste), used oil, used lubricants (paste), oiled sand, used lubricated automobile filters, waste from technological processes of production and distribution of energy, electricity, gas, steam, and hot water not indicated in any other way (packaging from diisopropylamine).

- Hazard class IV: a solution for the manifestation and substandard water-based solutions of substances that accelerate the process of manifestation, substandard photographic film and paper containing silver or silver compounds (spent radiographic film), spent waste fabric, packaging for paint (solid: drums and cans), oils from tanks (solid: barrels and jars), used tire with metal cord (solid), ferrous metal scrap, non-ferrous metal scrap, waste paper, pharmaceuticals (including veterinary ones), medical equipment and goods (including aerosols), damaged, expired, or not identified remaining medical equipment and goods (expired potassium iodide pills), damaged or used protection against chemical or bacterial aerosols (gas masks etc.), damaged, used, or contaminated protective clothing (used wetsuits), broken glass, used damaged shoes (special footwear), used or damaged clothes (overalls), used filtration material "Sipron," used silicone organic matter, remains of other film (film from the printer), used thaw wire with lubricants, medical waste (needles, syringes, ampoules), damaged or used paints, enamels, varnishes, inks, gluing materials and their remains that cannot be used for their purpose, substandard office machines and computers, waste plastic, non-standard solutions for fixing (fixers), building waste (solid), slurry formed from water lighting, waste washings, earthenware solutions, sawdust or planed timber, broken porcelain insulators (solid), waste communal (solid), used ion exchange resins (solid), waste after quenching of lime (solid) etc., waste heat-insulating material, sand-like abrasive material, used carbon sorbent, used filter materials, dust abrasive metal, abrasive non-standard products, sludge after washing of vehicles, waste sludge, sulfide sludge, used paraffin, mineral wax, greasy waste formed after cleaning sewage pipes.

Characteristics of the slurry reservoir are given in Table 4.8.

Table 4.8. Slurry reservoir characteristics.

Slurry reservoir area	0.6 ha
Number of sections	6
Capacity (design)	226 thous. t
Volume of waste deposited as of 1 January 2018	133.636 thous. t
Number of observation wells	4

The waste, which can be disposed and recycled with the use of appropriate technology and industrial-technological and/or economic conditions available in Ukraine, is partly used by other subdivisions of the NPP and are mainly taxed as secondary raw materials and sold through separate subdivision “Skladske gospodarstvo” (warehousing) of SE NNEGC Energoatom to other organizations and individuals. Such waste includes slurry formed during water settling process, ferrous and non-ferrous scrap, waste oil, paper and cardboard, plastics, glass, wood, textiles, rubber (worn tires), photo materials that contain silver compounds, equipment components that contain precious metals and rich stones etc.

Hazardous waste is collected separately by type and transferred to specialized enterprises for disposal and removal via separate subdivision “Skladske gospodarstvo” in accordance with agreements, which are cost-demanding for the Company. Such waste includes, e. g., fluorescent lamps and devices containing mercury, lead-acid batteries, oil sludge from treatment plants for waste water contaminated by petroleum products, monitors, waste batteries, unsuitable medicines etc. SS Rivne NPP has a copy of a license for collection, transportation, storage, and disposal of the following: spent petroleum products, including oils and mixtures thereof; spent fluorescent lamps and spent batteries of lead-acid accumulators. Furthermore, solid household waste containing easily degradable organic component is transferred (under cost-demanding agreement) to the municipal communal enterprise for landfilling at Varash landfill.

Construction and industrial waste from SS Rivne NPP is removed to own landfill located 3 km away from Varash town at the location of a depleted sand quarry. The access road is hard-surfaced; the landfill perimeter is fenced with reinforced-concrete slabs. The first plot was operated since commencement of operations of SS Rivne NPP and is currently recultivated; the second plot has been closed since 2008. Starting from the beginning of 2009, waste is landfilled at the third plot of the landfill commissioned in December 2007 by a certificate of the working committee. The site for the fourth landfilled plot is a back up one. Hazardous waste of Class 3, which is contaminated with petroleum products (spent absorbents, spent filtering materials, and spent wiping materials) are removed to the landfill packed in polyethylene bags. Construction and industrial wastes are compacted and spread at the landfill of SS Rivne NPP using T-170-mounted bulldozer. The landfill is secured by day watching. Characteristics of the industrial waste landfill of SS Rivne NPP are given in Table 4.9.

Table 4.9. Characteristics of the industrial waste landfill of SS Rivne NPP.

Landfill area	5 ha
Number of plots	4
Capacity (design)	204.6 thous. t
Volume of waste deposited as of 1 January 2018	42.193 thous. t
Number of observation wells	2

Non-radioactive waste management is carried out in accordance with environmental legislative requirements specified in “SS RNPP Non-Radioactive Waste Management Instructions” [48] and in the order on appointment of responsible persons. Accounting is carried out in accordance with the standard primary accounting form No. 1-VT “Accounting for Waste and Packaging Materials and Containers”; reporting is conducted in accordance with the state statistical observation form No.1 - waste (annual) “Waste Generation and Management”.

The results of laboratory studies obtained from certified laboratories show no impact of waste disposal sites (slurry reservoir and landfill for construction and industrial waste) on condition of the atmospheric air, soils, and groundwater.

4.4 Spent Nuclear Fuel Management Facilities

One of their important components in the technological cycle of an NPP is spent nuclear fuel (SNF), which is formed in the process of energy generation in nuclear reactors.

Life cycle of nuclear fuel in reactors is determined by the permissible burnup depth of fission isotopes. After reaching the planned burnup depth, nuclear fuel is unloaded from reactor and is considered to be spent fuel, since it cannot directly be used for energy production [39].

After unloading from the reactor core, the SNF is transferred to the spent fuel storage pools (SFSP). Spent fuel is stored in these storage pools for the time necessary to reduce energy release due to radioactive decay of separation products to allowable levels. After storage of spent fuel in SFSP for a limited time, spent fuel assemblies (SFA) shall be removed from the NPP power unit and transferred for storage (disposal) or recycling. This is due to the fact that the capacity of storage pools of NPP units is limited, and free volume for unloading nuclear fuel from the reactor core or periodic revisions of the reactor shell and in-vessel components of the VVER reactors must be available.

At the same time, factors that are determined by the specifics of this material must be taken into account when handling spent nuclear fuel: high radioactivity level and presence of high-value components (uranium, plutonium, germanium, erbium, palladium, zirconium etc.) that could potentially be used in other nuclear fuel cycles (nuclear fuel for fast reactors, MOX-fuel for light-water reactors). Taking into account the above, spent nuclear fuel is not classified as radioactive waste.

Current state of the global nuclear power industry shows that given the current level of technology, it is not possible to come to final conclusions on economic feasibility of recycling or disposal of spent fuel (i.e., the final stage of nuclear fuel cycle (NFC)). In this regard, Ukraine, like most of the countries that develop the nuclear power sector, has adopted a so-called “delayed solution” that envisages organization of long-term storage of spent nuclear fuel. The above “delayed solution” allows taking decision as to the final stage of the Nuclear Power Cycle later on, taking into account global technological development and economic benefits for the state.

Currently, two storage facilities are used in Ukraine for temporary storage of spent nuclear fuel (SNF): wet-type SNF storage facility (SNFF-1 at Chernobyl Nuclear Power Plant) and dry-type SNF storage facility (DSNFF at Zaporizhzhya NPP). Besides, two additional storage facilities in Ukraine are under construction: dry-type SNF storage facility (SNFF-2 at Chernobyl Nuclear Power Plant) and Centralized Storage for SNF from VVER-type reactors of Ukrainian NPPs (SNF CS).

5 COMPREHENSIVE ASSESSMENT OF SS RIVNE NPP SITE IMPACT ON THE ENVIRONMENT UNDER NORMAL OPERATING CONDITIONS

Main types of possible environmental impacts during operation of the power units and the impacts of facilities and structures included in the technological complex located at the industrial site of SS Rivne NPP, as well as other facilities of the energy complex in the area of the station (sanitary protection zone and observation zone) based on the production technology are as follows:

- radiation exposure;
- chemical exposure;
- physical exposure.

Measures adopted by SE NNEGC Energoatom at SS Rivne NPP to minimize environmental pollution are as follows:

- delivery of spent fluorescent lamps, spent lead batteries, lubricants, and other secondary raw materials for demercurization in accordance with the established procedure;

- maintenance of the validity terms of permits for storage and use of toxic substances in the technological process of the nuclear power plant;

- annual acquisition of limits and permits for generation and placement of non-radioactive waste and for emission of pollutants into the atmosphere by stationary sources;

- primary accounting of emissions, water use, and waste, as well as the monitoring of environmental impact of radiation and non-radiation factors.

Adversely affected environmental components include: air environment, geological and aquatic environments, soils, animal and plant world, and social and anthropogenic environment.

5.1 Atmospheric air

Rivne Nuclear Power Plant is an enterprise with a large number of necessary auxiliary production units. The enterprise is registered in the field of air pollution protection by the state. There are 290 motor vehicles, including 142 diesel and 148 gasoline ones, as well as 7 units of rail transport. 2 certified testing and control stations for diagnostics of motor vehicles and measurement of toxicity and smoke of the exhaust gases are in operation.

240 stationary air emission sources that release 40 polluting non-radioactive substances are registered. The most probable emission source is the start-up and standby boiler house designed to burn sulphuric fuel oil. Since 1994 there has been no need for operation of this boiler house; thus its boilers are started at the minimum capacity one unit per year only for personnel training and equipment testing. Stationary sources of atmospheric air emissions at Rivne NPP are concentrated on 7 production sites. Air pollutant emissions from stationary sources at each site are regulated based on separate permits, namely:

- - № 5620881201-1 from 28.11.11 (permit validity is unlimited);
- - № 5610700000-8 from 30.05.2018 (valid for 10 years);
- - № 5610700000-11 from 27.12.13 (valid for 5 years);
- - № 5610700000-12 from 24.10.2014 (permit validity is unlimited);
- - № 5610700000-13 from 24.10.2014 (permit validity is unlimited);
- - № 5610700000-14 from 24.10.2014 (valid for 10 years);
- - № 5610700000- 16 from 24.10.2014 (permit validity is unlimited).

To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for air emissions from stationary sources has been developed, approved by the Department of Ecology and Natural Resources of the Rivne Regional State Administration.

14 sources of air emissions are equipped with gas treatment units (GTU). Certificates were provided for each GTU. Gas treatment equipment is operated in accordance with the Regulations on Technical Operation of Gas Treatment Units. Persons responsible for the technical operation of GTUs were appointed by order of the Director General of the Rivne NPP. In accordance with the design documents and working conditions, operating manuals for each GTU were developed and approved. Daily time records are kept for each GTU.

Annual reports are submitted to the Main Statistics Department and the Department of Ecology and Natural Resources of the Rivne Regional State Administration according to the form 2-TP (air). Reports are developed using a calculation method based on the data on the use of raw materials, fuel, materials, and equipment operating time. During the year, stationary sources of the Rivne NPP release 33 to 37 tons of pollutants into the air, including:

- non-methane volatile organic compounds - 18-25 t;
- nitrogen compounds - 5-9 t;
- substances in the form of suspended solid particles (microparticles and fibres) - 1.4-2.7 t;
- sulphur compounds - 1.4-2.7 t, etc.

Air pollutant emissions from the NPP are 2-3 thousand times less than that from a coal-fired TPP with a similar installed capacity.

Sampling and monitoring of the radionuclides content in the surface air are carried out in accordance with the radiation control regulations in force at Rivne NPP once every 10 days at 16 control stations. The volumetric activity of anthropogenic radionuclides in atmospheric air over 37 years of observations did not exceed the standard values as per NRBU-97. The volumetric activity for ^{90}Sr and ^{137}Cs is within the “zero background”.

Gas-aerosol emissions of radioactive substances released to the atmosphere through ventilation pipes are dissipated in the atmosphere and form a so-called “cloud of emissions”. Aerosol particles fall out of the cloud and settle on the ground, migrating into elements of ecological systems adjacent to NPPs.

Laboratory of external radiation control (LERC) uses stainless steel pans with an area of 0.25 m^2 to collect atmospheric precipitations. The tray bottom is lined with a filter paper in accordance with DST 12026-76.

The pans are located at 22 monitoring points in accordance with the history of long-term pre-launch meteorological observations at the construction site of SS Rivne NPP (according to the windrose diagram), mainly in settlements within the OZ. In accordance with the Regulation, atmospheric precipitation sampling frequency is 1 time per month.

Long-term observation results indicate that the total β-activity of precipitations and content of ^{90}Sr and ^{137}Cs during the observation period are within the “zero background” and do not depend on the distance from an observation point to SS Rivne NPP.

The assessments have shown that the major share of gas-aerosol release within the dose during operation of power units of SS Rivne NPP will be by inert gases through irradiation from the cloud. The maximum annual average concentrations of these radionuclides in the air were obtained in the east direction at a distance of about 1.5 km from the plant. They made: 1.351×10^{-11} Ci/m^3 (0.5 Bq/m^3) for 133Xe; 2.703×10^{-13} Ci/m^3 (0.01 Bq/m^3) for ^{85}Kr; 5.406×10^{-14} Ci/m^3 (0.002 Bq/m^3) for ^{41}Ar.

Non-exceedance of the effective dose of 100 mrem/year (1 mSv/year) per population (Category B) is possible when maximum air concentrations of these radionuclides are as follows: 26.489×10^{-8} Ci/m^3 (9.8 kBq/m^3) for ^{133}Xe; 54.06×10^{-8} Ci/m^3 (20 kBq/m^3) for ^{85}Kr; 0.973×10^{-8} Ci/m^3 (0.36 kBq/m^3) for ^{41}Ar, which is 10^3-10^6 times higher than the maximum design concentrations of radioactive noble gases (RNG) during normal operation of the power units.

Preservation of the anthropogenic environment is provided by a number of special measures. They include:

- layout and design measures;
- safety systems are provided in accordance with the staged protection principle;
- system for possible discharge and release monitoring;
- organization of operation in accordance with the regulations and instructions that prohibit work in case of violation of safe operation limits;
- emergency planning system.

The radiation impact of the NPP on the environment, including anthropogenic environment, is assessed by radiation monitoring of both sources of possible radiation contamination (discharges and releases by the NPP) and the radiation situation affected, for which purpose systems for observation of underground and surface water, soil condition and geological processes were also developed and are in operation.

A public alert system is in place within the 30 km zone.

5.2 Climate and microclimate

The Rivne Oblast is located in the northwest of Ukraine. The area of the Oblast is 20051 km^2, which is 3.1% of the total territory of Ukraine.

There are 16 administrative districts and four cities of regional subordination: Rivne, Dubno, Varash, Ostroh. In total there are 1027 urban settlements, including 11 towns, 16 urban-type settlements and 1000 rural settlements. As of 01.01.2017 the population of the region is 1162,7 thousand people.

The climate is moderately continental: a mild winter with frequent thaw periods, a warm summer, an average annual precipitation is 600-700 mm. The winter comes at the end of November and a steady snow cover is formed in the last days of December - the first decade of January. The summer is coming in late May and lasts until September. This is the period of the maximum air and soil temperatures, precipitation, and crop maturation. The rainless, cool early autumn weather is set in early September.

The Rivne Oblast is geomorphologically divided into three parts: Polissya, Volyn Forest Plateau and Male (Small) Polissya, located in the south, between the towns of Radyvyliv and Ostroh, including the spurs of the Podolian Upland with its altitudes of more than 300 meters above the sea.

The review of the meteorological and aeroclimatic parameters of the climate allows us to determine the climatic conditions of the NPP zone including the conditions that favour or slow down the process of self-purification of atmospheric air in the area of the Rivne NPP.

According to the map of climatic zonation for construction, the area of the Rivne NPP and its 30-kilometer zone are located in the second climatic region (subarea II-B), in the zone of moderate-continental climate with a positive water balance, a mild and wet winter, a relatively cool and rainy summer, a long-lasting wet autumn and an unstable weather in the transitional seasons.

The climate of the area is formed under the influence of both maritime and continental air masses. The nature and intensity of the main climatogenic factors significantly differ depending on the seasons of the year.

The climate main characteristics in the 30-kilometer zone of the Rivne NPP presented in this section are based on the records from the meteorological stations (Hydrometerological Committee of Ukraine) the nearest to the NPP and located in the perimeter of the zone at various distances from the site of the Rivne NPP :

- Lyubeshiv meteorological station - 54 km to the northwest;
- Manevichi meteorological station - 26 km to the west;
- Sarny meteorological station - 50 km to the east;
- Rivne meteorological station - 80 km to the south-southeast;
- Lutsk meteorological station - 78 km to the southwest.

The Manevichi meteorological station is the nearest station to the Rivne NPP. This meteorological station is located in a 30-kilometer zone of the NPP and it is determined as the reference station for evaluation of the principal climatic characteristics for construction and technological design of the NPP. Its representative function was established during the site screening based on the synchronic inspections performed in 1968-1970 at the temporary meteorological station located in the village of Stara Rafalivka, 9 km north of the construction site.

The aerological climate characteristics are based on the data of Shepetivka meteorological station [12], which is a reference station for the north-western territory of Ukraine. All above listed meteorological stations have long-term observation periods that ensure the reliability of the multi-year climate parameters.

The metrological conditions of the northern part of the NPP zone are recorded by Lyubeshiv meteorological station, the central and western (including the industrial area of the Rivne NPP) - Manevichi meteorological station, the eastern - Sarny meteorological station, the south-eastern and southern - Rivne meteorological station and the southwest – Lutsk meteorological station. This conditional zonation of the territory of the 30-kilometer zone helped to identify the influence of local factors of individual parts of the territory on the distribution of meteorological characteristics in the NPP zone.

The analysis of the temperature regime in the zone of the Rivne NPP shows that the temperature conditions of the eastern and southern parts of the monitoring area are somewhat different from the rest of the territory, there is some continentality here.

The air humidity parameters within the monitoring area are nearly identical:

- average annual relative humidity is 78-79%;
- average annual partial water vapour pressure - 8,7-8,9 hPa;
- saturation deficit - 3,2-3,5 hPa.

The soil temperature at a depth in the northern part of the zone is slightly lower than in the rest of the territory (0.4-0.5˚C at all levels of standard depths). In general, the average annual soil temperature at the depth of 0,4 m is 8.3-8.7˚C, at the depth of 1,6 m - 8.5-8.9˚C, at the depth of 2,4 -3,2 m - about 9˚C which was recorded on the territory of the 30-kilometer zone of the Rivne NPP.

In the cold season, the negative soil temperature remains at the depth of 0,4 m and equals to minus 0.3-1.6˚C. The soil temperature remains positive in the deep layers, but continues to decrease until March-April.

The maximum index of soil temperature at the depth of 2,4-3,2 m is observed in August-September (12.3-13.8°C), while the maximum temperature of the surface layer is recorded in July-August.

The highest index of solar radiation is observed in June-July, the lowest – in November-December. The annual amount of normal beam solar radiation in the area of the Rivne NPP is 1650 MJ/m^2, the scattered - 1870 MJ/m_2.

In the context of the year, the maximum cloudiness is observed during the cold period (8,0 – 8,1 points in general cloudiness). The lower cloudiness is mostly observed in November-December (6,0-6,8 points). The minimum cloudiness, both general and lower, is observed in August (5,0-5,2 general and 2,9-3,2 lower points). The diurnal variation of cloudiness is feebly marked in the cold period of the year; in the warm period – the maximum cloudiness is observed in the middle of the day under influence of the convection processes and less at the night.

The review of atmospheric precipitation data of the monitoring area of the Rivne NPP showed the following:

- the maximum annual amount of precipitation falls in the western, central and eastern part of the area (64-627 mm);
- to the north and south of the central part the precipitation decreases to 588 mm in the north and 579 mm in the south;
- the maximum daily precipitation is 103-119 mm;
- the prevailing wind direction during precipitation – the western and the northwest;
- the maximum long-term daily amount of precipitation in the territory of the 30-kilometer zone was not exceeded during the years of the NPP operation,
- the intensity of precipitation at different time intervals is identical for the entire zone.

The density of the snow cover depends on the weather conditions. According to the Sarny, Lutsk and Rivne meteorological stations (snow measuring records), the average density of snow cover in the first decade of January, when the fresh snow is not yet settled, equals to 98 kg/m^3 on the east and 143-150 g/m^3 on the north. By the end of January, the density of snow cover reaches its maximum (133 kg/m^3 on the east and 159-165 kg/m^3 on the south), remaining at this level almost to the loss of snow. At the maximum ten-day depth, the average density is 216 kg/m^3 on the east and 238-240 kg/m^3 on the south of the 30-kilometer zone.

The average annual amount of evaporation from the water surface in the ice-free period is 602 mm, the maximum is 946 mm and the minimum is 419 mm. During the ice-free period, the maximum average monthly amount of evaporation occurs in the summer months (110-120 mm in June-July). In the dry rain-free years, the evaporation in the summer months can increase to 198-213 mm.

The wind is a horizontal movement of air relative to the surface of the earth. The principal wind characteristics are wind speed and wind direction. Both of these characteristics are determined by the preassure (baric) area, which in our case is specific for entire Ukraine and for the irregular surface of the monitoring area.

The wind regime is the main factor determining the distribution of impurities. The wind causes the horizontal dispersion of pollutants, removes them from the source of emissions and transfer outside of the 30-kilometer zone limits.

According to the performed observations, we can estimate that the maximum wind speeds, in the mentioned gradients, in the territory of the 30-kilometer zone of the Rivne NPP, are mostly frequent in the western and north-western directions and rarely in the southwest direction (with wind speed ≥ 25 m/s). The extreme wind speeds were recorded in the southern part of the zone and reached 38 m/s (Rivne meteorological station) and 40 m/s (Lutsk meteorological station) in the north-western direction. The maximum wind speeds are usually observed during cyclone activity.

The probability of potentially dangerous tornado risk phenomenon in the limited area, which is the 30-kilometer zone of the Rivne NPP, according to [8], is estimated on the basis of the annual probability of tornado and its intensity rate. These characteristics are as follows:

- an annual probability of tornado passing through any point of the 30-kilometer zone of the Rivne NPP NP is 9.25 x 10^{-7} reactor/per year;
- an estimated intensity rate of the potential tornado is 1,92. The probability that the intensity rate of tornado will exceed is equal to 0.90 (in 90 of 100 cases the estimated intensity rate will not be exceeded).

The probability of intensive spontaneous dust storms in the northern and western regions of Ukraine (where the Rivne NPP is located) is about 5%, it means that they can occur one time in 20 years.

The fogs with visibility ≤ 100 m are observed in 7% cases in the western part of Ukraine, whereas the heavy fogs were not observed on the territory of Rivne and Khmelnytsky Oblasts.

It should be noted that the meteorological disasters have a multiple effect on the nuclear power plant - from surcharge load on the plant's facilities (strong wind, tornadoes, ice, snowfall) to creating the favourable conditions for both distribution of impurities and pollutants transfer at large distances (heavy rainfall and flood, strong wind, dust storms).

During the operation of the station, the meteorological disasters did not cause any emergency situations at the Rivne NPP.

In total, the annual capacity of the mixed layer in this area is only 540 m (the average of 800-900 m on the territory of Ukraine) which reduces the mechanism of natural self-purification of the atmospheric air in the area of the Rivne NPP.

The height frequency of the mixed layer ≤ 500 m is maximum in winter (85-92%). In this period, the mechanism of air mixing is the most complicated. In the warm period, the frequency of thin mixed layers is reduced to 32-42%, which characterizes a more intense mixing in the lower layers of the atmosphere.

In the cold period of the year, the cloud cover is observed more often (due to the cyclonic nature of the weather). In November-February, in 51-60% of cases, the cloud base is observed in the layer of up to 1.0 km and in the upper layers above1 km and equals to 40-49%. In the cold period of the year, the cloud base has the maximum frequency in the layer of 0.2-0.4 km (from 17-18% in January-February to 20-26% in November-December).

In summer, the maximum frequency of cloud base is observed in the layers of above 1 km. In the layer up to 1 km, the cloud base is extremely rare. From May to September, the cloud base at a height of 0.4-1.0 km was not observed.

The stratification of the atmosphere basically determines the height of the mixed layer. Under neutral atmospheric stability, the height of the mixed layer with an edge of less than 500 m is most frequent. The interdependency between the height of the mixed layer and the atmospheric stability can be proximately estimated by the data on the seasonal frequency of the categories (classes) of the atmospheric stability and the data on the frequency of the height of the mixed layer ≤ 500 m.

The prevalence of the stable classes of atmospheric stability and the low-strength mixed layers in the area of the Rivne NPP determines the less intense mechanisms of natural self-purification of the atmosphere in the monitoring area.

Based on the results of numerical modelling of impurities transfer and the mathematical models recommended by the IAEA, we can estimate that the industrial emission sources located outside the monitoring zone of the Rivne NPP (in the cities of Rivne and Lutsk) have a slight effect on the environmental pollution of the 30-kilometer zone of the Rivne NPP. The quality of atmospheric air is determined by emissions from enterprises that provide environmentally safe operation of the Rivne NPP.

From all above said, we can conclude that the environmental characteristics of the atmosphere within the 30-kilometer zone around the Rivne NPP have not been deteriorated during the period of the Rivne NPP operation.

The microclimate in the area of the Rivne NPP is formed under influence of the regional climate characterized by a relatively long cold period (~210 days), relatively cooler summer (average July temperature is 18.1°C), low winter temperatures and high humidity during the winter period. In summer, at the high temperatures and low humidity, the impact of the cooling units on the microclimate is much lower than in the autumn-winter period with low temperatures and high air humidity.

The steam-condensate plumes have a strong impact on the microclimatic conditions and affect the atmospheric precipitation, meteorological visibility, insolation, fog, ice glazing in the area of the Rivne NPP.

In the cold period of the year, the zone of perturbation of humidity field in the boundary layer of the atmosphere in the area of cooling towers location of the Rivne NPP is characterized by the following parameters:

- specific humidity of air emitted by the cooling towers is 5,0-5,2 g/kg (relative is close to 100%);
- maximum perturbation of a humidity field is observed at an altitude of 200 m and extends 1.5 km from the cooling towers. In total, the zone of perturbation of the humidity field is observed up to a height of 500 m and at a distance of 4,0 – 4,5 km from the centre of the cooling tower system.

The zone of maximum warming in the cold period of the year is formed at an altitude of 150-300 m and extends 2,5-3,0 km from the cooling tower system. The air temperature in the zone of temperature perturbation is in the range from minus 2,0˚C to 2,8-3,0˚C.

In the warm period, the zone of perturbation of humidity field in the boundary layer of the atmosphere is characterized by the following parameters:

- specific humidity of air emitted from the cooling tower is 8,3 – 11,2 g/kg;
- maximum perturbation of the humidity field is observed at an altitude of 150-250 m (11,2 g/kg) and extends to a distance of 1,5 km from the cooling towers. In total, the zone of perturbation of humidity field in summer is observed up to a height of 350 m and at a distance of 3.0 - 4.0 km from the centre of the cooling tower system.

According to the calculation data, the "perturbation zones" of air temperature and humidity fields near the land surface during the cold period (winter) extends from the source of emissions in the wind direction (Figures 3.5 and 3.6). The maximum surface air temperature in this case at the level of 800 to 1500 m from the cooling towers is around 1˚C above the background (ΔT = 0,89˚C), that is equal to minus 3,4˚C. At the altitude of 2,5-3,0 km from the cooling towers, the air surface temperature decreases by 0,1°C (ΔT = 0,08˚C) and can be minus 4,3˚C, that is nearly equal to the background temperature.

After dispersion in the air flow, the plume particles are modified: they enlarge in the process of coalescence, settle down and intensively evaporate. The interrelation processes, which contribute to humidity accumulation and dispersion, determine the macrophysical characteristics of the plumes, their structure, the precipitation intensity and eventually the environmental impact.

The performed calculations of visibility which are based on estimation of homogeneity and isotropy of the plume, showed that with the observed parameters of the microstructure of visibility zone in the plumes (at a distance of 500 - 1000 m), the visibility is 300 - 600 m. The measurements were taken from a helicopter and are as follows:

- 100-200 m in the nearest zone of the thick plume;
- more than 500 - 1000 m in the remote zone of the thick plume;
- formation of short and medium length plume did not significantly deteriorate the visibility.

The potential number of days when fog can cause the absolute shading is approximately 3 days during the warm period and 5 days in the cold period. The partial shading from plumes will always exist, but there are no quantitative characteristics about the duration of this phenomenon in the area of the Rivne NPP.

In the area of the Rivne NPP, in the cold period of the year, which is characterized by a small number of clear days, the factor of insolation reduction during few sunny days is quite important for estimation of the sanitary and hygienic quality of air.

The increase of air temperature and humidity due to the steam-condensate emissions of the cooling towers occurs mainly in the boundary layer of the atmosphere, at an altitude of 200 - 500 m. In the surface layer, the heat and humidity impact of the cooling towers is observed only in the immediate proximity. The increase of air temperature by about 0,5-1,0˚C in winter against the background temperature of January at a distance of up to 1 km from the cooling towers and the increase of annual amount of precipitation by 2-3% are inconsiderable. Actually, the impact of the cooling towers on the microclimate and environment outside the sanitary-protective zone is not expressed. As an exception, there can be observed some occasional ice glaze and frost.

Annually, the stationary sources of the Rivne NPP eject from 33 to 37 tons of pollutants into the atmosphere: non-metallic volatile inorganic compounds - from 18 to 25 tons, nitrogen compounds - from 5 to 9 tons, suspended solids (micro particles and fibers) - from 1.4 to 2.7 tons, sulphur compounds - from 1.4 to 2.7 tons, etc. The emissions of air pollutants of the nuclear power plant are 2-3 thousand times less than that of the coal-steam power station with a similar installed power capacity.

The SS “Rivne NPP” releases the air pollutant emissions in accordance with the emission permit conditions. The amount of raw materials and other materials used in 2017 does not exceed the values stipulated in the provided documents.

Taking into account the small values of chemical pollutants released in the atmosphere, it is inappropriate to provide any additional measures for emissions reduction, except for existing gas treatment units.

The estimated annual gross emissions in total by all substances equal to 9,044 ÷ 10,335 tons/per year, which is 0,7% of the currently approved values. In the absolute values these emissions are estimated in some grams (compound of manganese, fluoride hydrogen) and 120 ÷ 150 kg (gasoline, wood dust). Consequently, the above-mentioned values do not have a significant impact on environment. This conclusion is confirmed by estimation of maximum surface concentration of these substances in the atmosphere.

Therefore, the estimation justified in this section allows us to conclude that the future operation of all 4 power units of the Rivne NPP and introduction of new sources of chemical emissions will not impact the ecological situation of the 30-kilometer zone and will not exceed the normative values of chemical (non-radioactive) pollution for residential areas.

According to the performed estimation, the dispersion of pollutants in the atmospheric air within the sanitary protection zone does not exceed the maximal permissible concentration and the emitted volumes do not exceed the permissible values, consequently, there is no need to provide additional measures aim to reduce the air pollutant emissions.

The results of Environmental Impact Assessment of the power units and the industrial site of the Rivne NPP indicate that the environmental impact of the Rivne NPP will continue to be at the same level and there are no prerequisites for the deterioration of ecological environment around the Rivne NPP.

5.3 Geological environment

The reliability of the operation of NPP buildings and structures depends on the stability of geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability - once in 100 years): magnitude 5, maximum estimated earthquake (probability - once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;
- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of geological environment and is the key factor for ensuring safe operation of SS Rivne NPP.

In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:

- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;
- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuously cooperates with leading scientific organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013-2016.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

The analysis of control characteristics shows that the work of the Rivne NPP does not significantly change the quality of underground water. Radiation state of groundwater is satisfactory, content of ^{226}Ra, ^{137}Cs, ^{90}Sr is much lower than the values that are standardized in the Radiation Safety Standards of Ukraine.

5.4 Water environment

A part of water from the cooling system is continuously returned to the river through a single discharge point from the industrial storm sewer, which is located 30 m downstream of the river (additional) water intake point. The industrial storm sewer system continuously receives purge from circulation systems and, from time to time, other residual water from the power units site — after making sure that the allowed standard pollutants concentrations are not exceeded. Permit for the special use of water includes discharge of up to 18,409.0 thous. m^3 of water per year (0.7 m^3/s).

Chemical composition of the return water, river water upstream of the SS Rivne NPP water intake, as well as downstream of the discharge is monitored by the certified laboratory stations. Laboratory of the Heating and Underground Utilities workshop takes and analyses wastewater samples at least 6 times a day (for petroleum products and pH).

The environment protection and chemical laboratory of the environmental protection service (EPS) conducts laboratory testing of surface and reverse (sewage) water for 25 indicators three times a week. The analysis results for the parameters being monitored indicate that the allowable discharge limits (in tonnes) were not exceeded, quality (purity) of the discharged water complies with the regulatory limits, discharged water contains the same natural impurities as the river water, and operation of SS Rivne NPP does not significantly change quality of the surface water.

As to hydrogeological conditions, the industrial site of SS Rivne NPP is located on a levelled ridge at elevation of 188.5 m. Absolute elevation values of natural relief prior to construction in the central part of the industrial site were 185.00 to 189.00 m and up to 190.00 to

193.00 m in certain areas. Elevation of the levelled site for the main structures is 188.50 m. Here the following water-bearing beds and complexes encounter (listed from top to bottom):

- bulk soils (on separate sites) and natural Quaternary sediments: sands, sandy loams (below), in many cases - loamy soils. Base of layer is at an average depth of 15.00-25.00 m from the levelling elevation; the approximate absolute elevations are mostly 166.00-168.00 m. The water-table aquifer (ground water) is fed by atmospheric precipitation and, partly, due to inflows from other horizons. The groundwater depth is 1.00-2.00 m. The main discharge of the aquifer system is to the south from the industrial site, i.e., in the valley of the Styr River. The aquifer is controlled by three wells of the stationary observation hydrogeological network for temporary perched layer and by 123 wells for other groundwater;
- the aquifer of the upper Cretaceous deposits. Fissured chalk predominates in the section, in which karst-suffosion processes develop (hollow spaces, large cracks filled with suspension of chalk particles or “recovered” by particles of rocks that lie above (sand, loamy sand, sometimes even clay, more often in weighed condition)). The total thickness of sediments is 15.00 m; the base of layer is at absolute elevation of 148.00-151.00 m. A zone of waterproof clay mass with inclusions of malmrock remnants is located in the upper part of the loamy-chalk layer. The depth of occurrence of this pressure groundwater level within the industrial site is 25.00-40.00 m. The aquifer is controlled by 54 wells of the stationary observation hydrogeological network;
- the aquifer in the deposits of the Berestovets Formation of the upper Proterozoic complex is widespread and balanced in terms of extent and thickness. Water-bearing rocks: fissured basalts and various grainy fissured tuffs. The waterproof layer is the dense tuff, which lies in the upper part of the section. The separating layer between the Upper Proterozoic and the Upper Cretaceous aquifers is massive chalk; however the aquifers are hydraulically connected due to low abundance of this rock. Therefore, elevations of the piezometric level of both aquifers do not differ significantly. Recharge occurs due to infiltration of water from higher aquifers through the fault system; partial recharge - from lower aquifers. Confined aquifer. The aquifer within the industrial site is at a depth of 40.00-45.00 m. The aquifer is controlled by 13 wells of the stationary observation hydrogeological network.

Hydrogeological observations include:

- measurement of water level and temperature in wells;
- measurement of water temperature along the entire length of the barrel in wells (temperature well logging);
- pumping water out of the wells;
- well water sampling for determination of the chemical composition of the groundwater;
- inspection of the condition of hydrogeological monitoring wells.

Sanitary protection zones of the first belt of artesian wells in Ostriv village are isolated and fenced. Analysis at the sites of slurry reservoir and landfill for construction and industrial waste of SS Rivne NPP is carried out by ecological and chemical laboratory, which is authorized to perform measurements of the chemical composition of underground water (wells). The analysis of monitored parameters confirms that operation of SS Rivne NPP does not introduce significant changes into the groundwater quality.

As to radiation impact on surface and ground waters, the impact of liquid discharges of SS Rivne NPP on the objects of the Styr River is monitored at three locations:

- Village of Mayunichi (10 km upstream);

- downstream of the discharge point of the stormwater drainage;
- Village of Sopachiv (10 km downstream).

Sampling is carried out once a decade, and the specific activity of natural and technogenic radionuclides is determined with the use semiconductor-based γ-spectrometers. Tritium activity is determined with the use of a Tri-Carb 3170 TR/SL liquid scintillation radiometer.

Concentration of radionuclides in the Styr River water is thousands of times below the permissible concentration of radionuclides in drinking water. Maximum values of the specific activity of tritium are hundreds of times below the permissible concentration of this radionuclide in drinking water.

Benthal deposits, waterweed, and fish of the Styr River are sampled annually in August. The samples undergo γ-spectrometric analysis. The objects of the Styr River contain no man-made radionuclides, with the exception of ^{137}Cs of "the Chernobyl origin". Specific activity of ^{137}Cs in fresh fish is hundreds of times below the established permissible level.

In order to control the non-propagation of radioactive substances in groundwater, radiation monitoring of groundwater is carried out on the territory of the industrial site of SS Rivne NPP. Underground water supply sources are monitored by measurement of radionuclide content in artesian wells.

Samples of water from the first aquifer, which lies at a depth of 10-14 m from the surface, are collected from 35 monitoring wells. Sampling frequency for the monitoring and artesian wells is once per quarter. Each sample undergoes measurement of Σβ-activity using MRS-9604 α/β radiometer and specific activity of tritium using Tri-Carb 3170 TR/Sl scintillation radiometer. Samples from the monitoring wells are combined by objects and undergo γ-spectrometric analysis. Activity of man-made isotopes in groundwater is thousands of times below the levels of permissible concentration in drinking water. The network of artesian wells consists of 9 wells drilled in the territory of the Ostriv water intake. Water samples are taken from the common collector and undergo γ-spectrometric analysis and tritium measurements. The artesian well water contains no man-made isotopes.

5.5 Soil

Analysis at the sites of slurry reservoir and landfill for construction and industrial waste of SS Rivne NPP is carried out by ecological and chemical laboratory, which is authorized to perform measurements of the chemical composition of soils. The analysis of monitored parameters confirms that operation of SS Rivne NPP does not introduce significant changes into the quality of soils.

Both soil samples and samples of grassy vegetation were taken simultaneously at the points of constant observation. Samples are taken from 22 control locations from the layer of 0-5 cm in April-May and are measured by γ-spectrometers. Content of radionuclides in soil and vegetation was determined mainly by natural radionuclides and ^{137}Cs of the "Chornobyl" origin.

5.6 Plant and animal world and objects of the natural reserve fund

The territory of the Rivne NPP OZ lies within the Volyn Polissya, which occupies the western part of the Ukrainian Polissya. Geographic location of this territory contributed to the formation of typical Polissya nature (predominance of moraine-fluvioglagic sedimentary deposits, domination of sod-podzolic soils, high bogginess and forest coverage). Specific features of this territory are geological structure (domination of chalk and marls of the upper Cretaceous in the base rock, and occurrence of basaltic rocks in the southern part).

Natural vegetation was mainly preserved; the share of plowed land at the most part of the territory is insufficient and varies from 10% in the northern and eastern parts to 20-25% in the western part. Only in the central part it rises to 43.5%. Forests are the dominant vegetation; the average forest coverage is 49.6%. There are a lot swamps on the territory being studied, and these swamps differ both by origin and area.

The animal world of the Rivne NPP OZ is represented by animal complexes typical for Polissya. More than 60 mammals species and about 200 birds species live there. Rodents are the dominant mammalians; however, predators (common fox, wolf, the raccoon dog, least weasel (Mustela nivalis, stoat (Mustela erminea)) are also found. Birds are predominantly of the tree-shrub species. Song-birds (black grouses, hazel grouses, and wood grouses) are also found in the Volyn Polissya region. The following reptile spices should be mentioned: the adder, the grass snake, the smooth snake, the anguine lizard, the viviparous lizard, fresh-water turtle.

Years of researches have shown that radionuclide emissions do not increase the activity of man-made isotopes (^{137}Cs, ^{90}Sr etc.). Accumulated radionuclides in plants during normal operation of the power plant will not exceed the permissible norms; and the current contamination by ^{137}Cs of “the Chornobyl origin” has been studied in detail within the monitoring zone. As to accumulation of radionuclides in plants, the highest contamination is currently found in marsh plants with highest concentration in mosses and mushrooms and lower concentration levels — in cranberries and blueberries.

Care must be taken as to consumption of forest and swamp products, and particularly, mushrooms. Taking into account wider ecological amplitude of blueberries, its radionuclide contamination can vary greatly depending on local conditions. Blueberries, which are currently collected and procured quite intensively, must be carefully monitored for content of radionuclides.

On the whole, based on the analysis of changes in the background concentration of radionuclides with increase of distance from the power units of SS Rivne NPP, it can be concluded that the radiation regime of the plant during its normal operation does not affect the vegetation and does not cause any changes in the radiation level of individual plant species.

Technical design solution on cooling of process water in cooling towers and spray pools (instead of a cooling pond) allowed minimizing adverse impact of the plant on the ecosystem and preserving the valuable floodplain of the Styr River with its meadow, shrub, and forest animal complexes.

5.7 Social environment

Rivne NPP is located in a mixed forest zone in western Volyn Polissia - in the northwestern part of the Rivne Region, 120 km away from the regional centre, in the Volodymyretskyi District on the Styr River. This Ukrainian NPP is nearest to the neighbouring states [30].

SS Rivne NPP site choice was due to low fertility of sandy land and great distance from densely populated areas. Rivne NPP and its satellite town, Varash (former Kuznetsovsk) are located in the most stable seismic zone of Ukraine. The recurrence of magnitude 6 earthquakes according to the MSK-64 seismic scale is once in 5000 years [49].

The 30 km observation zone of SS Rivne NPP is within the boundaries of two regions: Rivne and Volyn. The size of population in 90 settlements over the territory of about 3000 km^2 is about 130 thous. people. Fig. 2.1. shows the location of SS Rivne NPP and the 30 km zone around it that covers parts of Rivne and Volyn regions.

SS Rivne NPP is located in the moderate continental climate zone. West winds are predominant. Air quality is generally good due to limited industrial activities. The Styr River is the main source of surface water. Forests cover 50 % of SS Rivne NPP territory and are of a considerable economic and environmental value. Agricultural land use accounts for 27 %. 48 territories within the OZ of SS Rivne NPP are classified as nature reserve fund.

The OZ of SS Rivne NPP, which covers 2826 km^2, includes a total of 109 settlements with 143 thous. residents, with the population density of 58.82 people/km^2 in the Region of Rivne and 37.19 people/km^2 in the Region of Volyn.

Satellite town of SS Rivne NPP, Varash, is 3 km away from the power plant and is the largest town in the observation zone. The town’s population is about 42,000 people [50]. The density of population within this territory made 55 people/km^2 back in 1973, while currently it makes 3,684 people/km^2. Other relatively large nearby settlements include the urban type settlements of Manevychi (Volyn Region), Volodymyrets and Rafalivka (Rivne Region).

Demography as of 2017 is characterized by 46.7 % of urban population and 53.3 % of rural population. Development of electricity production capacities promoted urbanization process. The highest increase in population was observed in the NPP satellite town due to labour migration. Urban population growth in the region was accompanied with decrease in rural population (due to migration).

The estimated size of actual urban population as of 1 January 2017 made 42.2 thous. people. In 2016, the population decreased by 311 people, which made 7.4 people per 1,000 people of the actual population [50].

The size of population increased due to natural (264 people) and migration (47 people) growth.

Natural population growth level in 2016 made 6.3 people per 1,000 people of the actual population.

The birth rate made 11.9 live-born infants per 1,000 people of the actual population, and the death rate made 5.6 dead per 1,000 people of the actual population.

Population residing near SS Rivne NPP benefits from the environment being used by a very small number of industrial facilities, therefore it is marginally affected by industrial pollution. SS Rivne NPP is the major industrial facility in the region.

During normal operation of SS Rivne NPP, the radiation conditions and population doses in the region are defined by the existing natural background radiation. SS Rivne NPP radiation impact on the population and the environment does not exceed 0.05 % of the dose level produced by natural radiation sources, and does not change the natural radiation level in the area around the NPP.

Hazardous radiation levels exist only for personnel performing radiation hazardous works, however these risks are brought to a minimum if radiation safety rules are followed. No hazardous radiation risks are present for other works and beyond working hours during normal operation of SS Rivne NPP.

Observed contribution of SS Rivne NPP in air, water and soil pollution does not exceed the permissible levels and is insignificant compared with other pollution sources. The results of long-term radiation monitoring indicate the absence of a substantial radiation impact of the NPP on the environment and, consequently, on the population health in the OZ.

The major contribution in human body radiation exposure within the OZ during normal operation of the NPP is due to natural radionuclides and their decay products. The impact of artificial radionuclides from long-range fallout, Chornobyl radionuclides and, much less, radionuclides from SS Rivne NPP releases on the radiation amount is significantly lower. The hourly dose formed from natural radionuclides exceeds the dose from annual SS Rivne NPP releases.

The decisions on acceptability of certain release amounts were taken based on the level of unconditional justifiability for urgent countermeasures as per NRBU-97 [24].

In this case, the countermeasure with the lowest justifiability level - reduced stay outside for children - was chosen. The radiation levels make 10 mSv, 100 mGy and 300 mGy for the entire body, thyroid gland and skin, respectively.

Table 5.1. Maximum estimated population radiation doses during design basis accidents at power units No. 1 and No. 2 with VVER-440 reactors [30].

Design basis accident	Effective dose for the entire body, mSv	Dose for thyroid gland, mGy	Dose for skin, mGy
MDBA (double-ended rupture of the main coolant pipeline)	9.11	9.53	2.05×10^{-2}
Steam generator header cover lift-up	3.84	35.1	3.34×10^{-2}
Planned cool down line rupture (during PEP)	2.76×10^{-1}	2.20×10^{-1}	6.47×10^{-5}
Accidents caused by spent fuel pool leaks	2.87×10^{-4}	9.63×10^{-3}	1.93×10^{-7}
Accidents caused by fuel assembly drop in the spent fuel pool	2.19×10^{-1}	3.27	5.93×10^{-3}
Accidents caused by hydraulic lock drop in the spent fuel pool	4.39×10^{-1}	6.55	1.19×10^{-2}

Table 5.2. Maximum estimated population radiation doses during design basis accidents at power units No. 3 and No. 4 with VVER-1000 reactors [30].

Design basis accident	Effective dose for the entire body, mSv	Dose for thyroid gland, mGy	Dose for skin, mGy
MDBA (double-ended rupture of the main coolant pipeline)	6.51	1.43	0.0329
Coolant leakage from the first loop into the second loop (steam generator header cover lift-up)	5.63	85.9	0.361

Design basis accident	Effective dose for the entire body, mSv	Dose for thyroid gland, mGy	Dose for skin, mGy
Accidents caused by spent fuel pool leaks	0.26	0.74	0.01
Accidents caused by fuel assembly drop in the spent fuel pool	6.87	5.7	0.027
Accidents caused by hydraulic lock drop in the spent fuel pool	6.88	18.5	133

As can be seen from Tables 5.1 and 5.2, even during the MDBA maximum estimated radiation doses are well below the justifiability limit for population evacuation as per the current regulations (50 mSv for the entire body).

5.8 Anthropogenic Environment

The major part of the 30 km zone around SS Rivne NPP is occupied by territories of two districts: Manevytskyi (Volyn Region) and Volodymyretskyi (Rivne Region). Agriculture in the regions specializes in grain crop production and meat and dairy cattle breeding. Agricultural lands in both districts are located mainly on soddy-podzolic soils.

Manevytskyi District is situated in the northern part of the Polissia lowland, which is particularly marshy. 25,000 hectares of marshy areas in the district have been drained, which currently represents about one third of the agricultural lands. 17 communal households of different ownership forms in Manevytskyi District are within the observation zone, and, due to the change of the land ownership, there is an ongoing restructuring of communal households. The area of arable lands tends to reduce due to the acute shortage of resources. The agricultural soils are poor; several-fold increase in their yields is possible trough fertilizing, but the households lack funds for the necessary agrotechnical measures.

There are 53,000 hectares of agricultural land in the district, of which 31,500 hectares are for arable land, while the crop area, for the above reason, made only 18,500 hectares in 1999. The number of meat and dairy cattle at communal households has reduced more than four times, and a decrease in the average milk yield per cow is observed. The reason for these negative trends is the lack of feeds and feed additives, as well as the use of low productivity cattle breeds.

In the Volodymyretskyi District, 23 communal households are within the observation area around SS Rivne NPP, with 51,500 hectares of agricultural land, of which about 30,000 hectares are of arable land and about 18,000 hectares - of crop area. The livestock population was 27,700 heads in 1995 and 5,700 heads in 1999, and the average milk yield per cow has also decreased.

Analysis of the existing situation in the agricultural production in the 30 km zone around SS Rivne NPP suggests that there is a need for significant investments to improve soil fertility, feed supplies and breeding activities in livestock production. Therefore, the situation in the agricultural sector depends on the general state of the national economy.

Industry on the territory under consideration is represented by food industry enterprises (bakery plants, dairy plants), construction material enterprises, quarries and a peat plant, motor transport enterprises, and a road construction management office.

Industry within the 30 km zone around the Rivne NPP is represented by food industry enterprises (bakery plants, dairy plants), construction material enterprises, quarries and a peat plant, motor transport enterprises, and a road construction management office. A section of the Kyiv-Kovel railway line passes 150 m south of the industrial site of the NPP. The nearest railway station Rafalivka is 5 km east of the NPP. Kyiv-Kovel state motor road passes about 20 km south of the industrial site of the NPP. There are also several gas stations, Rafalivskyi Karier PubJSC (a quarry) for the extraction of sand, gravel, clay and kaolin, Polytskyi basalt quarry, etc. within the OZ around SS Rivne NPP. In total, there are 28 industrial facilities within the OZ around SS Rivne NPP: 13 in the Volyn Region and 15 in the Rivne Region.

Public institutions are concentrated in the Town of Varash. Housing fund within the 30 km zone (except for Varash) is represented by one-story buildings with a significant degree of wear. Residential construction is not provided with district water supply, sewage and heat supply networks, even in district centres (Manevychi and Volodymyrets). Public institutions located within the zone (except for Varash) also have no utility support.

Operation of SS Rivne NPP has no adverse impact on the existing agricultural, industrial and civil buildings and structures.

Public institutions located within the zone (except for Varash) have no utility support.

The total area of residential buildings and the main civilian facilities in Varash and in the Volodymyrets and Manevychi district centres are presented in Table 5.3.

Table 5.3. Main civilian facilities in settlements within the 30 km zone around the SS Rivne NPP.

Name of settlement	Total housing area, m^2	Hospitals	Community centres, clubs	Schools	Kindergartens
Town of Varash	598719	1	3	7	12
sett. Volodymyrets	126669	1	6	6	3
sett. Manevychi	129540	2	2	2	-

In Manevychi, A network of pharmacies, veterinary pharmacies and medical centres is being actively developed in Volodymyrets and the region in general. The town has an optical store, a paediatrician’s office, dental offices, “Rodolad” private family medical centre, health insurance companies, etc. District department of Professional Disinfection Communal Enterprise operates in Volodymyrets.

Within the 30 km zone around SS Rivne NPP in the Volodymyretskyi District, medical facilities operate in Rafalivka, the villages of Kidra, Ozero, Velyki Tseptsevychi, and there are MOS in the villages of Sobishchytsi, Krasnosillia, Lypne, and Kanonychi.

In Manevychi, The following educational facilities operate in Volodymyrets: inter-town vocational training centre; Volodymyrets District College, and an experimental education institution of the all-Ukrainian level.

In Manevychi, only 2 medical facilities operate: Manevychi Central District Hospital and Manevychi District Primary Healthcare Centre. The settlement has the Manevychi Children’s and Youth Sports School, a general education school levels I through III and a gymnasium. There also is a District Community Centre and a Department of Culture at Manevychi District State Administration.

During normal operation, the impact of SS Rivne NPP on the anthropogenic environment is limited by the following factors:

- activities and infrastructure that may develop in adjacent territories of the NPP are restricted for security reasons: such restrictions include, in particular, potentially hazardous activities, recreational activities, flying objects, transportation of hazardous substances;
- the presence of the NPP promotes local economy, small and medium-sized businesses, providing direct or indirect services related to operations of the NPP;
- SS Rivne NPP satellite town benefits from certain infrastructure investments by the NPP.

Harmful air releases and water discharges, thermal releases and discharges, as well as water consumption by the NPP do not significantly affect the anthropogenic environment.

In the case of design basis accidents at SS Rivne NPP, including the MDBA, their negative impact on the man-made objects will not exceed the permissible limits and will not require any special measures.

In the case of an analysed beyond design basis accident, temporary restrictions on the use of food produced within a restricted area along the accidental radioactive trail may be necessary.

So, during normal operation, SS Rivne NPP does not produce an adverse impact on the anthropogenic environment.

According to the Code of Civil Protection of Ukraine, anthropogenic security characterizes the state of protection of population and territories from anthropogenic emergencies.

The reliability of the operation of NPP buildings and structures depends on the stability of the geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability - once in 100 years): magnitude 5, maximum estimated earthquake (probability - once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

The construction site of SS Rivne NPP was selected in 1965 by the government commission as the most favourable site in the Rivne Region of the Ukrainian SSR based on the entire set of all factors, in particular geotechnical. The site was selected in compliance with all regulatory requirements then in force, and agreed upon with the ministries and departments concerned. Over 1800 wells were drilled during the design process. No caverns were found during the survey of the territory.

However, in April 1982, a crater with a diameter of 3 m and a depth of 2.5 m was formed in the excavation for workshop in the special building of unit No. 3, which was under construction. The results of additional geotechnical surveys demonstrated that karst-suffosion processes in the geological section of SS Rivne NPP site in chalk rocks (depth of occurrence of 25-40 m) are possible. In connection with the individual manifestations of this process that occurred at SS Rivne NPP site, the commission formed by the Council of Ministers of the USSR in 1983 and the Ministry of Energy of the USSR determined the appropriate measures to ensure reliable and safe operation of operating power units No. 1 and No. 2, unit No. 3 (which was under construction), and unit No. 4 (which was on the design stage).

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;
- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Essential structures of power unit No. 4 were built on piles, which are based on basalts and, consequently, completely cut through the layer that is exposed to karst processes, which ensures the reliability of their operation. Soil cementation was carried out under the rest of buildings and structures of power unit No. 4.

On 20 April 2002, a meeting of an independent expert group chaired by V. M. Shestopalov, Member of the National Academy of Sciences of Ukraine, was held at SS Rivne NPP to discuss the geotechnical state of the industrial site and base soils of structures at Rivne NPP. The following was established by the expert group:

- the structures were operated in a stable mode, levels of soil subsidence and core samples from the buildings over the entire period of operation were well below the design values;
- the efficiency of the anti-karst measures under buildings of power units No. 1-3 (in particular, cement grouting of the chalk layer) is confirmed with time;
- continuous attention at SS Rivne NPP was paid to the geological and anthropogenic state of the environment and to the reliability of operation of the buildings;
- the possibility of building power unit No. 4 on piles based on basalts, which will cut through the chalk layer, raises no doubts.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of the geological environment and is key to the safe operation of SS Rivne NPP.

In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:

- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;

- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuous cooperation with leading scientific organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Annual reports are drawn up based on the works performed.

Within the frame of extension of operational lifetime of power units No. 1 and No. 2, SE Kyiv Institute of Engineering Surveys and Research “ENERGOPROEKT” carried out a set of geotechnical surveys and geophysical soil studies in 2008. According to the results of the studies, Scientific and Technical Report on Geotechnical Survey (a comprehensive analysis of the soil conditions at the bases of buildings and structures) 14-349/07-08, 10-439.1 was issued with a positive conclusion on further safe operation of buildings and structures [52].

Within the frame of extension of operational lifetime of power unit No. 3, SE Kyiv Institute of Engineering Surveys and Research “ENERGOPROEKT” developed a Scientific and Technical Report on Complex Geotechnical and Geophysical Survey 14-126-08, 10-726-1» [53]. The results of the studies suggested that the engineering and geological situation within the structures of power units No. 1-3 are in line with the operational lifetime extension, namely:

- karst monitoring did not record any active karst processes;
- the observation data on subsidence of buildings did not exceed the permissible values;
- according to hydrogeological monitoring data, the hydrogeological situation is characterized as stable and controlled by all indicators;
- soil condition ensures reliable operation of structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013-2016.

According to the results of the surveys, specialists of Prydniprovska State Academy of Civil Engineering and Architecture issued positive opinion on further extension of operation of power unit buildings and structures. Decisions on further operation of power unit buildings and structures were agreed upon by the State Nuclear Regulatory Inspectorate of Ukraine.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

6 POTENTIAL ACCIDENTS DURING THE OPERATION OF SS RIVNE NPP POWER UNITS

6.1 List of potential accidents during the operation of SS Rivne NPP power units

The criterion of acceptability of ecological consequences of accidents is determined by NRBU-97 [24]. For the analysis of the radiation consequences of accidents, the following design basis accidents were studied at SS Rivne NPP:

- Maximum design basis accident.
- Steam generator header cover lift-up - Emergency spike.
- Steam generator header cover lift-up - Pre-emergency spike.
- Hydraulic lock drop in the spent fuel pool.
- Fuel assembly drop on the reactor core and FA top nozzles in the spent fuel pool.
- Spent fuel container drop from a height of more than 9 meters.
- Fuel assembly drop on the reactor core in the rector.
- Impulse tube rupture beyond the containment.
- Planned cool down line rupture.
- Rupture of the process blow off pipeline for cleaning in the process blow off system of the reactor building.

In addition, the impact in case of a design basis accident was considered.

The main factor of the environmental impact is the emergency release into the atmosphere.

“Steam generator header cover lift-up - Emergency spike” is the most dangerous accident (from among the design basis accidents) for humans during the period of 2 days and 2 weeks, with radiation doses of 0.19 mSv and 0.32 mSv, respectively, at the border of the SPZ [54]. For the period of 1 year, the most dangerous accident for humans is the design basis accident “Fuel assembly drop on the reactor core in the reactor”, the maximum design basis accident and the design basis accident “Hydraulic lock drop in the spent fuel pool”: 1.44 mSv, 1.28 mSv, and 1.17 mSv, respectively [54].

Total emissions of radioactive substances for the specified accidents may make:

- “Steam generator header cover lift-up — Emergency spike”: 4.35×10^{15} Bq;
- “Fuel assembly drop on the reactor core in the reactor”: 1.21×10^{14} Bq;
- maximum design basis accident: 7.17×10^{15} Bq;
- “Hydraulic lock drop in the spent fuel pool”: 5.34×10^{14} Bq.

The maximum total volumetric activity in the surface layer of atmospheric air will be 1.35×10^{6} Bq/m^3 and the maximum loss soil fallout density will be 3.57×10^{7} Bq/m^2 for the accident “Steam generator header cover lift-up - Emergency spike”.

In case of design basis accidents [54], the levels of unconditionally justified emergency intervention in case of acute exposure are not exceeded, the levels of prevented doses do not exceed the levels of unconditional justification, there is no need for planning of basic urgent countermeasures, support countermeasures at such a level of prevented doses are not appropriate; equivalent individual doses for 1 year for the thyroid gland in children by inhalation and for the entire body due to external exposure at the most adverse conditions at the border and beyond the sanitary protection zone do not exceed the threshold values of 0.3 Sv/year and 0.1 Sv/year, accordingly [45].

In case of beyond design basis accidents, the maximum activity of radionuclides in the surface air and density of fallout to earth surface is expected within the CPZ. The maximum air volumetric activities at the border of the SPZ are expected to make up to 10.3 MBq/m^3 for ^{95}Zr. The maximum soil fallout densities at the border of the SPZ are expected to make up to 9.58 GBq/m^2 for ^{95}Zr. Effective doses of radiation for 2 days, for 2 weeks and for 1 year will be 0.43 Sv, 1.79 Sv, and 9.46 Sv, respectively. Levels of unconditional justification for the use of countermeasures are exceeded, and application of all types of countermeasures, including evacuation, will be required [54].

6.2 SS Rivne NPP emergency plan

In accordance with the requirements of the document "General Safety Regulations for Nuclear Power Plants. NP 306.2.141 - 2008” [55], item 10.13, SS Rivne NPP developed “the SS Rivne NPP Emergency Plan” [56]. The plan was approved by the Director General of SS Rivne NPP on 26 December 2017 and put into effect by an order of the enterprise.

The emergency plan defines the emergency organizational structure of SS Rivne NPP, the distribution of responsibilities and liabilities for emergency response, the composition of emergency response equipment, and the composition of external organizations involved in the emergency response, and determines the emergency response composition and procedure for the site of SS Rivne NPP and in the SPZ. Provisions of the emergency plan are mandatory for officials and structural subdivisions of SS Rivne NPP, external organizations involved in the emergency response at the site of SS Rivne NPP and the SPZ.

The emergency plan is interdependent and coordinated with the plans of the emergency response of the level of the Company's management.

7 RISK ASSESSMENT

External events

Based on the analysis of the reassessment of the safety of NPP units to the list of events with insignificant impact on the safety of power units (frequency of occurrence less than 10^{-6}), flooding, the effect of extreme temperatures, heavy snowfalls, ice, hail, lightning, explosion, and fire effects, toxic gases.

Quantitative indicators of the impact on the safety of such dangerous events as tornadoes, earthquakes are characterized by the values of the criteria of the ChPAZ and ChGAV.

The estimated value of the integral frequency of damage to the active zone is for 1.69E-05 1/year for the power block No. 1 and 8.44E-06 1/year for the power block No. 2.

The estimated value of the integral frequency of boundary emergency discharge for the RU is 7.84E-06 1/year for the power block No. 1 and 7.10E-06 1/year for the power block No. 2. Щbtained values fully satisfy the probabilistic safety criteria according to NP 306.2.141-2008 [56] and safety criteria of the IAEA for operating NPP power units (1E-04).

Based on results of the analysis of the impact of external extreme events, it turns out that the project of power units, technical means and administrative measures for the protection of structures, systems, and elements provide reliable protection of power units from the effects of extreme external events of natural and man-made origin.

Risk of exposure to radiation

SPZ dimensions shall be determined to ensure that the limit dose rate for the population outside its borders is not exceeded during normal operation, violation of normal operation, and decommissioning of NPPs, as set out in cl. 5.5.4. NRBU-97 [24]: 80 uSv/year: 40 μSv/year due to atmospheric emissions and 40 μSv/year due to liquid discharges. The value of the limit dose rate is approximately 10 times below the dose received by the population from natural sources.

Under normal operation conditions, the maximum doses at the boundary of the SPZ of SS Rivne NPP are up to 0.47 μSv/year, which does not exceed the dose limit quota of 40 μSv/year according to NRBU-97 for emissions of nuclear power plants.

In case of a design basis accident, the maximum allowable values of the radiation criteria of equivalent and absorbed doses in the organs and for the whole body at the border and outside the sanitary protection zone comply with the regulatory requirements (NRBU-97 and SP AES-88) [24, 25]. Of all design basis accidents, “Steam generator header cover lift-up - Emergency spike” is the most hazardous DBA for human within 2 days and 2 weeks, with radiation doses of 0.19 μSv i 0.32 μSv, respectively, at the border of the SPZ. For the period of 1 year, the most dangerous for a person is the design basis accident "Fuel assembly drop on the reactor core in the rector," the maximum design basis accident and the design basis accident "Hydraulic lock drop in the spent fuel pool" is 1.44 mSv, 1.28 mSv, and 1.17 mSv, respectively.

In accordance with calculations of doses of emergency exposure of the population at the MDBA, which was performed by the IAE named after Kurchatov for power units Nos. 1-3 and VNIIAES for power unit No. 4 in 1989 confirmed the size of the SPZ at 2.5 km.

According to these calculations, the radiation dose for the thyroid gland of children with MDBA at a distance of 2.5 km did not exceed 6.5 baires for WWER-440 and 1 bar for WWER-1000 units at the permissible level of 30 baires.

Of all design basis accidents, “Steam generator header cover lift-up - Emergency spike” is the most hazardous DBA for human within 2 days and 2 weeks, with radiation doses of 86.7 μSv i 155 μSv, respectively, at the border of the SPZ. The maximum DBA with the dose of 316 μSv is the most hazardous DBA for human within 1 year. DBA “Fuel assembly drop on the reactor core in the rector” with the dose of 3.18 μSv is the most hazardous DBA for human within 50 years.

Based on the above-mentioned calculation data, within 2 weeks of a BDBA at the border of the SPZ (2.5 km) lower justifiability limits are exceeded, and shelter, iodine prophylaxis in children and limited stay outside for both children and adults shall be needed, while at the border of the OZ (30 km), shelter and limited stay outside are required.

Risk of non-radiation effects.

In the part of non-radiation impact on the environment during the production and economic activities, SS Rivne NPP carries out emissions of pollutants and atmospheres, discharges of reverse water into water facilities, storage, disposal, and burial of waste, and uses land plots.

Emergency situations caused by the leakage of working environments are localized by closing the appropriate shut-off or sectioning fittings and do not go beyond the premises.

Back-up diesel power plants operate in the event of accidents involving the cut-off of the main supply's supply. In case of a complete cut-off of power supply, all 20 diesel generators with full load, which causes emissions of pollutants into the atmosphere, must simultaneously operate. In accordance with the calculations provided in the “Document Justifying Emission Volumes...” [57], the pollution of the atmosphere during the period of operation of the RDEC lies within normal limits. Effects of the chemical factors of SS Rivne NPP on the environment under normal operating conditions are insignificant. Outside SPZ, the risk of chemical factors is absent.

During the period under study and in 2017, there were no exceedances of estimated and projected volumes of waste generation and disposal.

Development of infrastructure and new enterprises in the area of the location of SS Rivne NPP (new man-made facilities) is limited due to the safe operation of the plant. Such restrictions include, in particular, potentially hazardous activities, recreational activities, flying objects, transportation of hazardous substances.

In general, during the period under study (from 2013 to 2017), the production activity of SS Rivne NPP did not lead to any changes in the environment that would indicate a deterioration in its condition.

Thus, the degree of environmental risk during operation of SS Rivne NPP and its impact on the living conditions of the population do not exceed acceptable levels and can be characterized as insignificant.

8 ASSESSMENT OF THE COMPLEX OF IMPLEMENTED TECHNICAL SOLUTIONS VIABILITY

Proceeding from requirements of environmental and sanitary legislation of Ukraine, as well as regulatory documents on the provision of technogenic safety, the implemented environmental measures and technical solutions are estimated as optimal on the basis of a comprehensive assessment of the impact on the natural, social, and man-made environment and taking into account the natural, social, and man-made factors and conditions in the vicinity of SS Rivne NPP.

9 LIST AND CHARACTERISTICS OF THE FINAL IMPACT

No excessive negative residual impacts of the operation of SS Rivne NPP on the environment have been recorded and are expected in the future in the conditions of implementation of the full complex of measures implemented at the NPP.

Residual negative impacts of SS Rivne NPP operation include radiation, chemical, and acoustic atmospheric air pollution that does not exceed the regulatory values, as well as the impact on surface water through the discharge of reverse water into the Styr River.

All industrial waste is expected to be stored and disposed of in accordance with the sanitary regulations under the established procedure.

Operation of SS Rivne NPP is characterized by positive factors:

- the presence of the NPP promotes local economy, small and medium-sized businesses, providing direct or indirect services related to the SS Rivne NPP operations;
- - the Varash satellite city benefits from investments made into the city's infrastructure by SS Rivne NPP.

CONCLUSIONS

In the part of non-radiation impact on the environment during the production and economic activities, SS Rivne NPP carries out emissions of pollutants and atmospheres, discharges of reverse water into water objects, storage, disposal, and burial of waste, and uses land plots.

Emissions of pollutants into the air are carried out in accordance with permits and do not exceed the permissible values.

The amount of raw materials and other resources used in 2017 does not exceed the values established by regulatory documents.

Water use in the enterprise is carried out in accordance with the established limits and regulations of the GDS established by the permit for special water use. The analysis of qualitative indicators of water, which is controlled by the ecological-chemical laboratory SONS, shows that the operation of SS Rivne NPP does not make significant changes in the quality of surface water of the Styr River. There were no exceedances of discharges limits in water facilities during the reporting period.

Waste management at the enterprise is carried out in accordance with requirements of regulatory documents and production instructions. During the year, other enterprises were transferred to other enterprises for the further utilization or disposal of waste from spent fluorescent lamps, accumulator batteries, motor oils, turbine, transformer oil, oil slurry, household waste etc.

In 2017, there were no excess of estimated and projected volumes of waste generation and disposal.

The ecological tax for 2017 amounted to UAH 890,737.22.

Planned environment protection measures are carried out in due time with an established system of continuous monitoring operating. In general, the production activity of SS Rivne NPP in 2016 did not lead to any changes in the surrounding natural environment that would indicate a deterioration in its condition. The list of permitting documents in the field of environmental protection on the basis of which SS Rivne NPP implemented its production activity in the reporting period is given in the Annex.

LIST OF REFERENCES

1. Закон України «Про оцінку впливу на довкілля», Відомості Верховної Ради (ВВР), 2017, № 29, ст.315.
2. ДБН А.2.2-1-2003 «Склад і зміст матеріалів оцінки впливів на навколишнє середовище (ОВНС)».
3. ДБН А.2.2-1-2003 «Посібник до розроблення матеріалів оцінки впливів на навколишнє середовище».
4. Закон України «Про захист людини від впливу іонізуючого випромінювання», Відомості Верховної Ради України (ВВР), 1995, № 12, ст.81.
5. Закон України «Про використання ядерної енергії та радіаційну безпеку», Відомості Верховної Ради України (ВВР). 1995, № 12, ст.81.
6. СНиП П-7-81 «Строительство в сейсмических районах».
7. код доступу: https://ru.wikipedia.org/wiki/Шкала_Медведева_-_Шпонхойера_-_Карника
8. «Рішення про розміри та межі санітарно – захисної зони та зони спостереження Рівненської АЕС», № 132-1-Р-11-ЦРБ.
9. Енергетична стратегія України на період до 2030 року.
10. Режим доступу: https://www.rnpp.rv.ua/assets/DocSite/czentr/Raes_1_23.pdf.
11. ДСП 6.177-2005-09-02. Основні санітарні правила забезпечення радіаційної безпеки України (ОСПУ-2005), Наказ МОЗ України від 02.02.2005 р. №54.
12. «Регламент радіаційного контролю Рівненської АЕС» 132-1-Р-ЦРБ.
13. НП 306.2.141-2008 Загальні положення безпеки атомних станцій, затверджені наказом Державного комітету ядерного регулювання України від 19.11.2007 № 162.
14. Закон України «Про електроенергетику», Відомості Верховної Ради України (ВВР)
15. «Інтегрована система менеджменту ВП «Рівненська АЕС». Екологічна програма» 083-1-25-QA-02/2017.
16. Звіт про оцінку впливу нерадіаційних факторів ВП «Рівненська АЕС» ДП «НАЕК «Енергоатом» на оточуюче природне середовище за 2017 рік./Міністерство енергетики та вугільної промисловості України. ДП «Національна атомна енергогенеруюча компанія «Енергоатом». ВП «Рівненська атомна електростанція», 2018 р. -25 с.
17. «Комплексные программы мониторинга геологической среды и природо-техногенной системы РАЭС – геологическая среда. Киев 2011г. 14-7011-08,10-584».
18. «Наставления гидрометеорологическим станциям и постам. Выпуск 2. Часть 2.Ленинград 1975 г.; Выпуск 6. Часть 1.Ленинград 1978 г.».
19. «Положення про виконання спостережень за гідрологічним режимом р. Стир на гідрологічному посту ГТЦ 172-2-П-ГТЦ».
20. Закон України «Про охорону навколишнього природного середовища», від 25.07.1991 р. № 1264-XII.
21. Постанова КМУ «Про затвердження Положення про державну систему моніторингу довкілля» від 30 березня 1998 р. № 391, Київ (зі змінами і доповненнями від 27 травня 2015 року № 379).
22. ПМ-Д.0.08.428-10. Програма реконструкції системи радіаційного контролю АЕС України. ДП НАЕК «Енергоатом».

23. КсПБ АЕС України № 14401 «Модернізація системи радіаційного контроля (СРК) АЕС».
24. ДГН 6.6.1-6.5.001-98 Норми радіаційної безпеки України. Державні гігієнічні нормативи (НРБУ-97).
25. Закон України «Про землі енергетики та правовий режим спеціальних зон енергетичних об'єктів», Відомості Верховної Ради України (ВВР), 2011, № 1, ст.1.
26. Наказ від 25.11.11 р № 1830 Про введення в дію «Рішення про розміри та межі санітарно-захисної зони та зони спостереження Рівненської АЕС № 132-1-Р-ЦРБ».
27. Регламент радіаційного контроля Рівненської АЕС 132-1-Р-ЦРБ, 2016 р.
28. ДСТУ 95.1.01.03.024-97 Автоматизовані системи контролю радіаційної обстановки для атомних станцій. Основні положення.
29. 132-6-Э-ЦРБ. Техническое описание и инструкция по эксплуатации. Автоматизированная система контроля радиационной обстановки.
30. Нетехнічне резюме. Матеріали з обґрунтування безпеки подовження терміну експлуатації енергоблоку № 3 ВП «Рівненська АЕС» у понадпроектний термін/ Міністерство енергетики та вугільної промисловості України. ДП «Національна атомна енергогенеруюча компанія «Енергоатом». ВП «Рівненська АЕС», Вараш, 2018 р. – 58 с.
31. ДНАО П.0.03-1.73-87 (СП АС-88). Санитарные правила проектирования и эксплуатации АЭС.
32. НАПБ А.01.001-2004 Правила пожежної безпеки в Україні.
33. ВБН В.1.1-034.03.307-2003 Противопожарные нормы проектирования атомных электростанций с водо-водяными энергетическими реакторами.
34. НАПБ 06.015-2006 Перелік приміщень і будівель енергетичних підприємств Міненерго України з визначенням категорії і класифікації зон вибухопожежної і пожежної небезпеки.
35. НАПБ Б.03.002-2007 Нормы определений категорий помещений, зданий и внешних установок по взрывопожарной и пожарной безопасности.
36. НАПБ 05.028-2004 Противопожарная защита энергетических предприятий, отдельных объектов и энергоагрегатов. Инструкция по проектированию эксплуатации.
37. НАПБ В.01.034-2005/111 Правила пожарной безопасности в компаниях, на предприятиях и в организациях энергетической отрасли Украины.
38. Закон України "Про пожежну безпеку" від 17.12.1993 р № 3745-XII.
39. Доповідь про стан ядерної та радіаційної безпеки України у 2017 році. Держатомрегулювання України, 2018. -81 с.
40. Закону України «Про поводження з радіоактивними відходами», від 30.06.1995 р. № 256/95 –ВР.
41. Закон України «Про Загальнодержавну цільову екологічну програму поводження з радіоактивними відходами» від 17.09.2008 р. № 516-VI.
42. Стратегія поводження з радіоактивним відходами в Україні, схваленої розпорядженням Кабінету Міністрів України від 19.08.2009 р. № 516- VI.
43. Комплексна програми поводження з РАВ у ДП «НАЕК «Енергоатом» ПМ-Д.0.18.174-16, що введена в дію розпорядженням від 12.10.2016 р. № 927-р.

44. Поводження з радіоактивними відходами при експлуатації АЕС ДП «НАЕК «Енергоатом» станом на 31.12.2015, Міністерство енергетики та вугільної промисловості України ДП «НАЕК «Енергоатом», 2016. -104 с.
45. Санитарные правила проектирования и эксплуатации атомных станций (СП АС-88/93) (рекомендаційний характер документу).
46. «Заходи з мінімізації рідких радіоактивних відходів у ВП РАЕС».
47. Комплексна програми поводження з РАВ у ДП «НАЕК «Енергоатом» ПМ-Д.0.18.174-16, що введена в дію розпорядженням від 12.10.2016 р. № 927-р.
48. «Інструкції з поводження із нерадіоактивними відходами у ВП РАЕС».
49. Шкала MSK-64.
50. Головне управління статистки у Рівненській області, ресурс доступу:https://www.kuznetsovsk-rada.gov.ua/ofitsijna-informatsiya/1161-sotsialno-ekonomichne-stanovishche-m-varash-u-sichni-2017-roku.
51. Кодекс цивільного захисту України.
52. «Науково-технічний звіт про інженерно-геологічні вишукування (комплексний аналіз стану ґрунтів основ будівель та споруд) 14-349/07-08, 10-439.1».
53. «Науково-технічний звіт з комплексних інженерно-геологічних та геофізичних досліджень. 14-126-08, 10-726-1», 2014 р.
54. Заключний звіт «Проведення оцінки впливу на довкілля ВП «Рівненська АЕС», Книга 3. Частина 2 «Повітряне середовище. Вплив радіаційного фактору на атмосферне повітря». ТОВ «НТ-І», 2018 р.
55. НП 306.2.141-2008 Загальні положення безпеки атомних станцій, затверджені наказом Державного комітету ядерного регулювання України від 19.11.2007 № 162.
56. Аварійний план ВП «Рівненська АЕС»: частина І 006-1.1-АП-УПАГР; частина ІІ Картки дій 006-1.2-АП-УПАГР; частина ІІІ Додатки 006-1.3-АП-УПАГР, 2017 р.
57. Документи, у яких обґрунтовується обсяги викидів, для отримання дозволів на викиди забруднюючих речовин в атмосферне повітря стаціонарними джерелами для про майданчиків ВП «Рівненська АЕС «ДП «НАЕК «Енергоатом».

Annex A

List of Licenses, Permits of SS Rivne NPP in the Field of Environmental Protection (Non-Radiation Umpact)

No.	Document title	Date of issue	Term of validity	Issuer of the permit, license
Protection of atmospheric air				
1	Permit No. 5610700000-8 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (TrTs RNPP)	23/09/2013	23/09/2018	DENR* of the Rivne Regional State Administration DENR Letter No. 2754/04/1-09/16 06/12/2016
2	Permit No. 5610700000-11 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (the industrial zone)	27/12/2013	27/12/2018	
3	Permit No. 5610700000-12 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (vocational school No. 12, Sports Complex, Community Center)	24/10/2014	unlimited	
4	Permit No. 5610700000-13 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (URP, ASKRO, TsGO)	24/10/2014	unlimited	
5	Permit No. 5610700000-14 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (asphalt-bitumen plant, TsSR)	24/10/2014	24/10/2024	
6	Permit No. 5610700000-16 for emissions of pollutants into the atmosphere by stationary sources of SS Rivne NPP in Kuznetsovsk (sewage treatment facilities for household faecal waste from the industrial site of SS RNPP)	24/10/2014	unlimited	
7	Permit No. 5620881201-1 for emissions of pollutants into the atmosphere by stationary sources of ROK “Bile Ozero” of SS Rivne NPP	28/11/2011	unlimited	
Protection of water resources				
8	Permit Ukr No. 1/RVN for special water use by SS Rivne NPP	06/08/2015	06/08/2020	DENR of the Rivne Regional State Administration
9	Permit Ukr No. 454/RVN for special water use by ROK “Bile Ozero” of SS Rivne NPP (continued)	15/01/2014	Continued perpetual	
10	License No. 458 on the management of hazardous waste as determined by the Cabinet of Ministers of Ukraine	02/12/2015	perpetual	The Ministry of Ecology and Natural Resources of Ukraine
Protection of land and subsoil				
11	Special permit for the use of subsoil No. 2263 (Rafalivske-1 deposit)	09/10/2000	20 years	The Ministry of Ecology and Natural Resources of Ukraine

Annex B

Determination of the degree of environmental risk in case of accidents

Introduction

As part of the environmental risk analysis for BDBA, two characteristics are considered:

- "medical risk" is the risk of medical consequences (deterministic and stochastic) from accidental exposure;
- "situation risk" is the risk from the commissioning of the power unit No. 4 of the RNPP that takes into account both the probabilistic characteristics of the reactor accident and the risk of the medical consequences of such an accident.

"Medical risk" is a characteristic of the consequences of an accident but provided that the accident has occurred. This characteristic has a medical meaning and "interprets" a hypothetical emergency radioecological situation in medical terms.

"Situation risk," as opposed to 'medical risk," is a characteristic for making engineering decisions in terms of risk, which formalizes the risk of negative consequences for the population from commissioning an engineering object, in the same way as in other scientific and technical areas.

The following aspects of the risk of medical consequences from a hypothetical accidental exposure are assessed:

- the maximum (corresponding to the axis of the passing radioactive cloud) and the average (averaged over space) risk characteristics of stochastic effects as a function of distance from a nuclear power plant;
- full risk (from whole-body exposure) and the risk from exposure of individual organs;
- the number of lethal and non-lethal cases due to exposure.

The "medical risk" (the medical consequences) and the situation risk in the emergency scenario of 10% core meltdown (this is the main scenario of the BNP at Unit 4 of SS Rivne NPP) is assessed, and the sensitivity of the values of medical risk is analyzed by examining the total risk of stochastic medical effects in an accidental release of 10 and 100 times greater than the reference release. The isotopic composition of the release is given in Table A.1.

The risk of stochastic consequences ("medical risk") is assessed for the 100% core flashing scenario (the second scenario of the BDBA at block 4 of SS Rivne NPP). The isotopic composition of the release is given in Table A.2.

The situation risk is assessed at 10% and 100% fusion of the core.

Risk assessments are carried out for two strategies:

- with the introduction of countermeasures, and
- without the introduction of countermeasures.

The theoretical basis for assessing "medical risk" is currently the ICRP Publication No. 60 [18], and the "risk situation" that combines the probability of an accident and the likelihood of consequences in an accident is the ICRP Publication No. 46 [19], which specifies the method of risk assessment from a radiation hazardous event.

Table A.1 - **Emission of the most dangerous isotopes at 10% core melt in 10 hours**

Isotope	Physico-chemical form	Total access to the contents Ku	Total output from the shell, Ku	Total output from the shell, Bq	Total amount of radioiodine, Bq
J-131*)	Mollecular	2.13E+07	2.18E+02	7.11E+12	J-131=2.58E+13
J-131*)	Organic	3.66E+05	4.86E+02	1.0E+13	

J-132	Mollecular	4.86E+07	1.0E+02	5.14E+12	J-132=1.62E+13
J-132	Organic	4.18E+05	3.5E+02	1.0E+13	
J-133	Mollecular	5.80E+07	4.86E+02	1.0E+13	
J-133	Organic	5.14E+05	9.76E+02	3.5E+13	J-133=5.06E+13
J-134	Mollecular	7.11E+07	4.86E+01	1.0E+12	
J-134	Organic	7.11E+05	3.5E+01	1.0E+12	J-134=3.17E+12
J-135	Mollecular	5.80E+07	2.18E+01	8.21E+12	
J-135	Organic	5.14E+05	5.14E+02	1.0E+13	J-135=2.79E+13
Cs-134	Aerosol	4.13E+06	6.59E+01	2.18E+12	
Cs-137	Aerosol	3.5E+06	3.5E+01	1.0E+12	
Sr-90	Aerosol	2.65E+05	2.18E+01	1.0E+10	
Xe-133	Gas	5.80E+07	7.66E+04	2.18E+15	
Xe-135	Gas	1.63E+07	1.66E+04	4.86E+14	
Kr-85m	Gas	5.14E+06	8.21E+03	2.18E+14	
Kr-87	Gas	8.35E+06	1.0E+03	5.14E+13	
Kr-88	Gas	1.63E+07	2.18E+03	1.0E+14	

* Isotopes under the containment envelope are distributed as follows:

- molecular: 99%;
- organic: 1%

Table A.2 - Emission of the most dangerous isotopes at 100% core melt in 24 hours

Radionuclide	Physical form	Activity, Ku	Activity, Bq
J-131	Mollecular	5.00E+02	1.0E+13
J-132	Mollecular	1.30E+02	4.86E+12
J-133	Mollecular	9.00E+02	3.5E+13
J-134	Mollecular	3.50E+01	1.0E+12
J-135	Mollecular	6.00E+02	2.18E+13
J-131	Organic	6.00E+02	2.18E+13
J-132	Organic	6.00E+01	2.18E+12
J-133	Organic	8.00E+02	2.18E+13
J-134	Organic	1.00E+01	4.86E+11
J-135	Organic	3.50E+02	1.0E+13
J-131	Aerosol	8.00E+03	2.18E+14
J-132	Aerosol	2.18E+03	8.21E+13
J-133	Aerosol	1.66E+04	5.14E+14
J-134	Aerosol	6.00E+02	2.18E+13
J-135	Aerosol	1.00E+04	3.5E+14
Cs-134	Aerosol	1.00E+03	5.14E+13
Cs-137	Aerosol	9.00E+02	3.5E+14
Sr-90	Aerosol	7.00E+02	2.18E+13
Xe-133	Gas	9.00E+06	3.5E+17
Xe-135	Gas	1.00E+06	4.86E+16
Kr-85m	Gas	5.00E+05	1.0E+16
Kr-87	Gas	2.00E+05	7.11E+15
Kr-88	Gas	1.00 E+06	4.86E+16

Risk assessments of medical consequences from exposure are based on the following sections of the EIA (Volume 5):

- 5.2 "Analysis of the sources of radionuclides in agroecosystems in case of beyond design basis accidents";
- 5.4 "Forecast of the content of biologically significant radionuclides in the components of agroecosystems and agricultural products in case of beyond design basis accidents";
- 5.6 "Estimation of dose loads on critical components of agroecosystems and possible effects in case of beyond design basis accidents."

The basis for assessing the risk of non-stochastic (deterministic) effects is doses of the acute period of the accident for the whole body and for individual organs.

The basis for assessing the risk of stochastic effects is life-long doses for the whole body and for individual organs.

All aspects of risk (maximum, medium, full, for organs, and with and without the introduction of countermeasures) are assessed as a function of distance from RNPP.

A.1 Risk of deterministic effects

Model

As is well known, dose-effect threshold dependencies are used to evaluate deterministic effects on radiation.

The method of assessing the risk of deterministic consequences is described in full in the publications [20, 21]. This methodology boils down to the following.

The risk of deterministic effects of radiation r is determined by the exponential "harm function."

$$r = 1 - \exp(-H)$$
$$H = 1n2 * (D / D_{50})^{s}, \quad (1)$$

where D - dose received during the period under review;

D_{50} - dose at which effects appear in 50% of the irradiated population;

S - parameter that characterizes the slope of the dose-risk function.

$$D_{50} = D_{\infty} + D_{0} / DR \quad (2)$$

Where D_{∞} - alue D_{50} at high dose rate;

DR - average dose rate during the irradiation period;

D_{0} - parameter.

The function r, which models the threshold function, is rapidly growing in nature.

Parameters for various organs in this function are determined by a large amount of experimental data and can be considered as known.

It is assumed that the risk value is zero if this value does not exceed the assigned threshold (for example, 1%).

BDBA accident analysis was carried out using formulas and parameters specified in the work [21] (Table 2) using the package PC Cosyma (Version 2), EUR 16240 EN (NRPB-SR280).

Result of risk assessments of deterministic consequences

The risk of deterministic effects turned out to be zero, i.e., the doses in BDBA were lower than the threshold at which deterministic effects appear.

Calculations were carried out at an accident scale of 100 times larger than those indicated in Table A.1.

It turned out that in this case the risk of deterministic effects is zero.

A.2 Risk of stochastic medical effects at core melt

A.2.1 Risk at 10% core melt in 10 hours

The following aspects of the risk of stochastic effects from exposure at BDBA at RNPP were analyzed:

- maximum (along the axis of the radioactive cloud) full (due to whole-body radiation) risk of stochastic effects;
- maximum (along the axis of the radioactive cloud) risk of stochastic effects from exposure of individual organs;
- the spatial structure of risk of stochastic effects in the contaminated sector;
- average values of the full (from whole-body exposure) risk of stochastic effects and the risk of stochastic effects from exposure of individual organs;
- amount of medical effects.

Maximum (along the axis of the radioactive cloud) full stochastic risk and maximum stochastic risk from exposure of individual organs were evaluated for two options for accidental exposure: with the introduction of countermeasures and without the introduction of countermeasures.

Maximum (along the axis of the radioactive cloud) risk of stochastic effects from exposure of the whole body and individual organs during BDBA at RNPP

Table A.3 and Figures A.1-A.12 give the maximum values of the risk of stochastic effects from whole-body exposure (full risk) and individual organs during accidental exposure.

Assuming that the population turned out to be on the axis of the passed radioactive cloud and then lived for the next 50 years at the point of passage of the cloud, while consuming agricultural products produced in the region, the pollution conditions of which correspond to the axis of the cloud.

The risk of exposure to the following organs was considered:

- skin (fig. A.2);
- bone marrow (fig. A.3);
- bone surface (fig. A.4);
- mammary glands (fig. A.5);
- lungs (fig. A.6);
- ventricle (fig. A.7);
- large intestine (fig. A.8);
- liver (fig. A.9);
- pancreatic gland (fig. A.10);
- thyroid gland (fig. A.11);
- genital glands (fig. A.12).

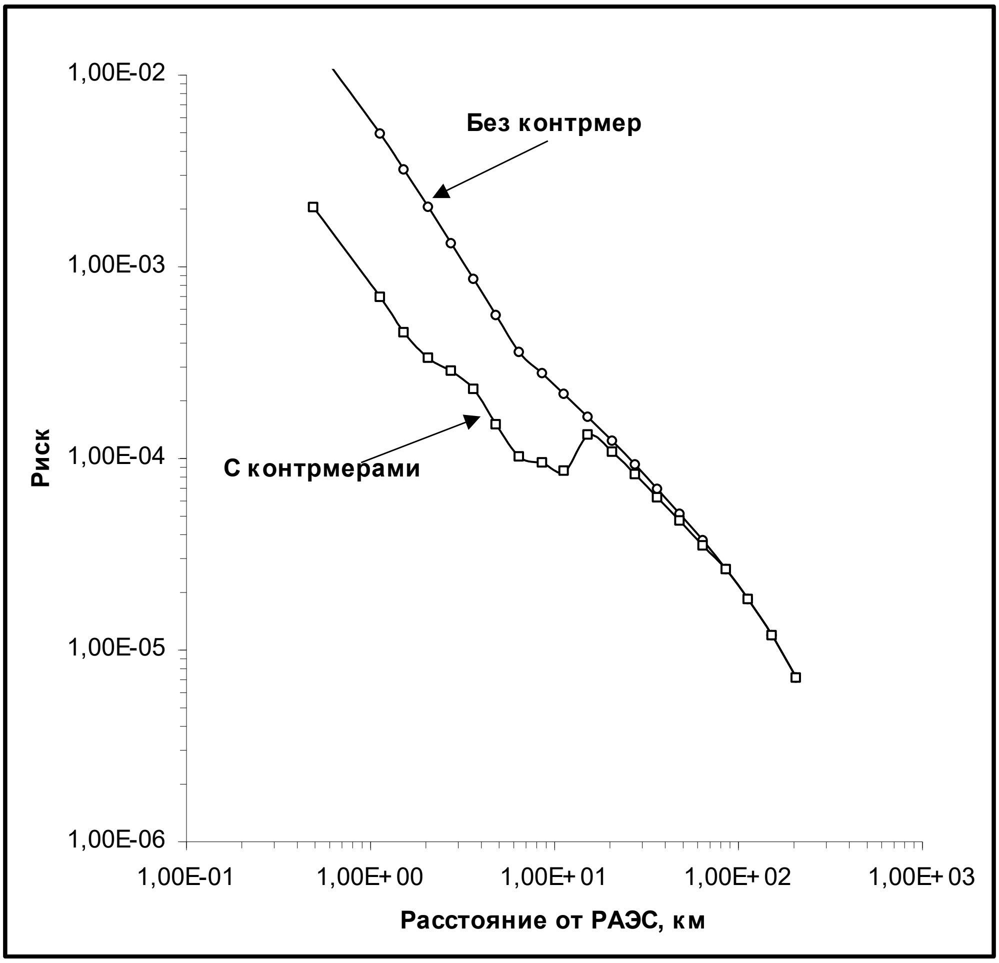


Fig. A.1 - Maximum full risk of occurrence of fatal cancer as a function of distance from RNPP with and without the introduction of countermeasures.

Table A.3 - Maximum risk of stochastic consequences (full and from the exposure of individual organs) in case of BDBA at 10% core melt with and without the introduction of countermeasures

Distance from RNPP, km	Complete		Skin		Bone marrow	
	countermea sures	without countermea sures	countermea sures	without countermea sures	countermea sures	without countermea sures
0.5	2.127E+03	1.355E+04	6.79E-03	8.10E-06	2.127E+03	1.355E+04
1.15	6.79E-03	4.753E+03	2.127E+03	2.127E+03	6.79E-03	3.908E+03
1.55	4.75E+03	3.908E+03	1.355E+04	1.355E+04	4.753E+03	2.127E+03
2.1	3.908E+03	2.127E+03	8.16E-08	1.355E+04	2.127E+03	1.355E+04
2.8	2.127E+03	1.355E+04	5.59E-03	7.13E-03	2.127E+03	1.355E+04
3.7	2.127E+03	8.45E-04	3.908E+03	4.753E+03	2.127E+03	6.79E-03
4.9	1.355E+04	5.59E-03	1.355E+04	3.908E+03	1.355E+04	4.753E+03

6.55	1.355E+04	3.908E+03	1.355E+04	1.355E+04	9.38E-03	2.127E+03
8.75	9.38E-03	2.127E+03	1.355E+04	1.355E+04	8.86E-06	2.127E+03
11.5	8.45E-05	2.127E+03	1.355E+04	1.355E+04	8.3E-06	1.355E+04
15.5	1.355E+04	1.355E+04	8.77E-08	8.77E-08	1.355E+04	1.355E+04
21	1.355E+04	1.355E+04	6.79E-03	6.79E-03	1.355E+04	1.355E+04
28	8 10E-05	9.38E-03	4.753E+03	4.753E+03	7.13E-03	8.28E-06
37	6.79E-03	6.79E-03	3.908E+03	3.908E+03	6.79E-03	6.79E-03
49	4.753E+03	5.59E-03	2.127E+03	2.127e+03	4.753E+03	4.753E+03
65.5	3.908E+03	3.908E+03	1.355E+04	1.355E+04	3.908E+03	3.908E+03
87.5	2.127E+03	2.127E+03	1.355E+04	1.355E+04	2.127E+03	2.127E+03
115	1.355E+04	1.355E+04	9.38E-03	9.38E-03	1.355E+04	1.355E+04
155	1.355E+04	1.355E+04	6.79E-03	6.79E-03	1.355E+04	1.355E+04
210	7.13E-03	7.13E-03	4.753E+03	4.753E+03	6.79E-03	6.79E-03

Continuation of Table A.3

Distance from RNPP, km	**Bone surface**		**Mammary glands**		**Lungs**	
	countermeasures	**without countermeasures**	**countermeasures**	**without countermeasures**	**countermeasures**	**without countermeasures**
0.5	5.59E-03	3.908E+03	5.59E-03	2.127E+03	3.908E+03	1.355E+04
1.15	1.355E+04	1.355E+04	1.355E+04	9.38E-03	1.355E+04	6.79E-03
1.55	1.355E+04	6.79E-03	1.355E+04	6.79E-03	7.13E-03	4.753E+03
2.1	8.37E-07	4.753E+03	7.13E-03	3.908E+03	4.753E+03	2.127E+03
2.8	7.13E-03	2.127E+03	6.79E-03	2.127E+03	4.753E+03	1.355E+04
3.7	5.59E-03	1.355E+04	5.59E-03	1.355E+04	3.908E+03	1.355E+04
4.9	3.908E+03	1.355E+04	3.908E+03	1.355E+04	2.127E+03	7.13E-03
6.55	2.127E+03	8.09E-07	2.127E+03	7.13E-03	1.355E+04	4.753E+03
8.75	2.127E+03	6.79E-03	2.127E+03	5.59E-03	1.355E+04	3.908e+03
11.5	2.127E+03	5.59E-03	2.127E+03	4.753E+03	1.355E+04	3.908E+03
15.5	3.908E+03	3.908E+03	3.908E+03	3.908E+03	2.127E+03	2.127E+03
21	2.127E+03	2.127E+03	2.127E+03	2.127E+03	1.355E+04	1.355e+04
28	2.127E+03	2.127E+03	1.355E+04	2.127E+03	1.355E+04	1.355E+04
37	1.355e+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04
49	1.355e+04	1.355E+04	1.355E+04	1.355E+04	7.13E-03	7.13E-03
65.5	9.38E-03	9.38E-03	8.41E-06	8.67E-06	5.59E-03	5.59E-03
87.5	6.79E-03	6.79E-03	6.79E-03	6.79E-03	4.753E+03	4.753E+03
115	4.753E+03	4.753E+03	4.753E+03	4.753E+03	2.127E+03	2.127e+03
155	3.908E+03	3.908E+03	2.127E+03	2.127E+03	1.355E+04	1.355E+04
210	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355e+04

Continuation of Table A.3

Distance from RNPP, km	**Ventricle**		**Large intestine**		**Liver**	
	countermeasures	**without countermeasures**	**countermeasures**	**without countermeasures**	**countermeasures**	**without countermeasures**
0.5	3.908E+03	1.355e+04	3.908E+03	1.355E+04	1.355E+04	1.355E+04
1.15	1.355e+04	6.79E-03	1.355E+04	6.79E-03	6.79E-03	3.908E+03
1.55	7.13E-03	4.753E+03	7.13E-03	4.753E+03	4.753E+03	2.127e+03
2.1	5.59E-03	2.127e+03	5.59E-03	2.127E+03	2.127E+03	1.355e+04
2.8	4.753E+03	1.355E+04	4.753E+03	1.355E+04	2.127e+03	9.38E-03

3.7	3.908e+03	1.355E+04	3.908E+03	1.355E+04	1.355E+04	6.79E-03
4.9	2.127E+03	7.13E-03	2.127E+03	7.13E-03	1.355E+04	4.753E+03
6.55	1.355E+04	5.59E-03	1.355E+04	5.59E-03	8.64E-06	2.127E+03
8.75	1.355E+04	4.753e+03	1.355e+04	4.753E+03	8.20E-06	2.127E+03
11.5	1.355E+04	3.908e+03	1.355e+04	3.908E+03	7.13E-03	1.355E+04
15.5	2.127E+03	2.127e+03	2.127E+03	2.127E+03	1.355E+04	1.355E+04
21	1.355E+04	1.355e+04	1.355E+04	1.355E+04	9.38E-03	1.355E+04
28	1.355E+04	1.355E+04	1.355E+04	1.355E+04	7.13E-03	7.13E-03
37	1.355E+04	1.355E+04	1.355E+04	1.355e+04	5.59E-03	5.59E-03
49	8.10E-06	8.39E-06	8.10E-06	8.39E-06	4.753E+03	4.753eE+03
65.5	5.59E-03	6.79E-03	5.59E-03	6.79E-03	3.908E+03	3.908E+03
87.5	4.753E+03	4.753E+03	4.753E+03	4.753E+03	2.127E+03	2.127E+03
115	3.908E+03	3.908E+03	3.908E+03	3.908E+03	1.355E+04	1.355E+04
155	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04
210	1.355E+04	1.355E+04	1.355E+04	1.355E+04	6.79E-03	6.79E-03

Continuation of Table A.3

Distance from RNPP, km	**Pancreatic gland**		**Thyroid gland**		**Genital glands**	
	countermeasures	**without countermeasures**	**countermeasures**	**without countermeasures**	**countermeasures**	**without countermeasures**
0.5	2.127E+03	1.355E+04	1.355E+04	4.753E+03	3.908E+03	2.127E+03
1.15	7.13E-03	4.753E+03	4.753E+03	1.355E+04	1.355E+04	7.13E-03
1.55	4.753E+03	2.127E+03	2.127E+03	8 10E-04	8 76E-05	4.753E+03
2.1	3.908E+03	1.355E+04	5.59E-03	5.59E-03	5.59E-03	3.908E+03
2.8	2.127E+03	1.355E+04	4.753E+03	3.908E+03	5.59E-03	2.127E+03
3.7	2.127E+03	7.13E-03	2.127E+03	1.355E+04	4.753E+03	1.355e+04
4.9	1.355E+04	5.59E-03	1.355E+04	1.355E+04	2.127E+03	8 97E-05
6.55	1.355E+04	3.908E+03	1.355E+04	7.13E-03	1.355E+04	5.59E-03
8.75	9.38E-03	2.127E+03	1.355E+04	5.59E-03	1.355E+04	4.753e+03
11.5	9.38E-03	2.127E+03	8 42E-06	4.753E+03	1.355E+04	3.908E+03
15.5	1.355E+04	1.355E+04	8 64E-06	2.127E+03	2.127E+03	2.127E+03
21	1.355E+04	1.355E+04	8 28E-06	1.355E+04	2.127E+03	2.127E+03
28	9.38E-03	9.38E-03	6.79E-03	1.355E+04	1.355E+04	1.355e+04
37	6.79E-03	7.13E-03	4.753E+03	8 60E-06	1.355E+04	1.355e+04
49	5.59E-03	5.59E-03	3.908E+03	5.59E-03	9.38E-03	9.38E-03
65.5	3.908E+03	4.753E+03	2.127E+03	3.908E+03	6.79E-03	6.79E-03
87.5	2.127E+03	2.127E+03	2.127E+03	2.127E+03	4.753E+03	4.753E+03
115	1.355E+04	1.355E+04	1.355E+04	1.355E+04	3.908E+03	3.908E+03
155	1.355E+04	1.355E+04	1.355E+04	1.355E+04	2.127E+03	2.127E+03
210	7.13E-03	7.13E-03	7.13E-03	7.13E-03	1.355E+04	1.355E+04

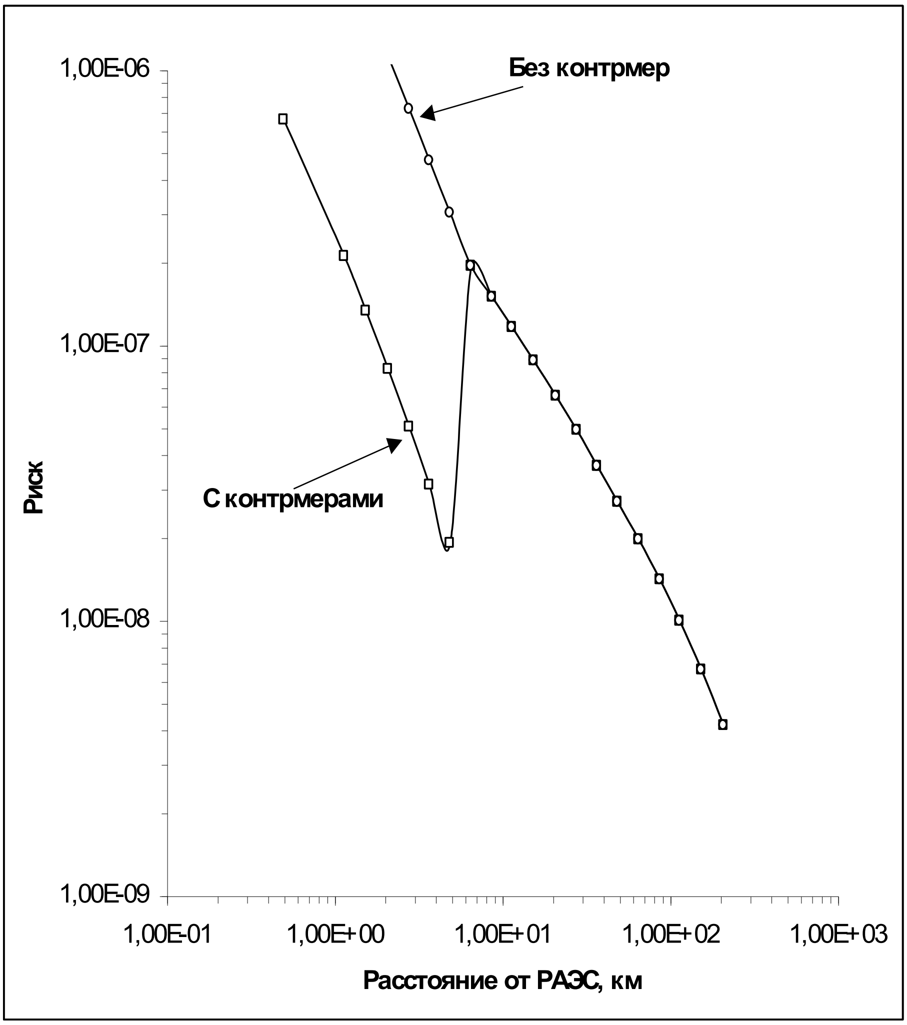


Fig. A.2 - **Maximum fatal cancer risk from skin exposure as a function of distance from RNPP with and without the introduction of countermeasures.**

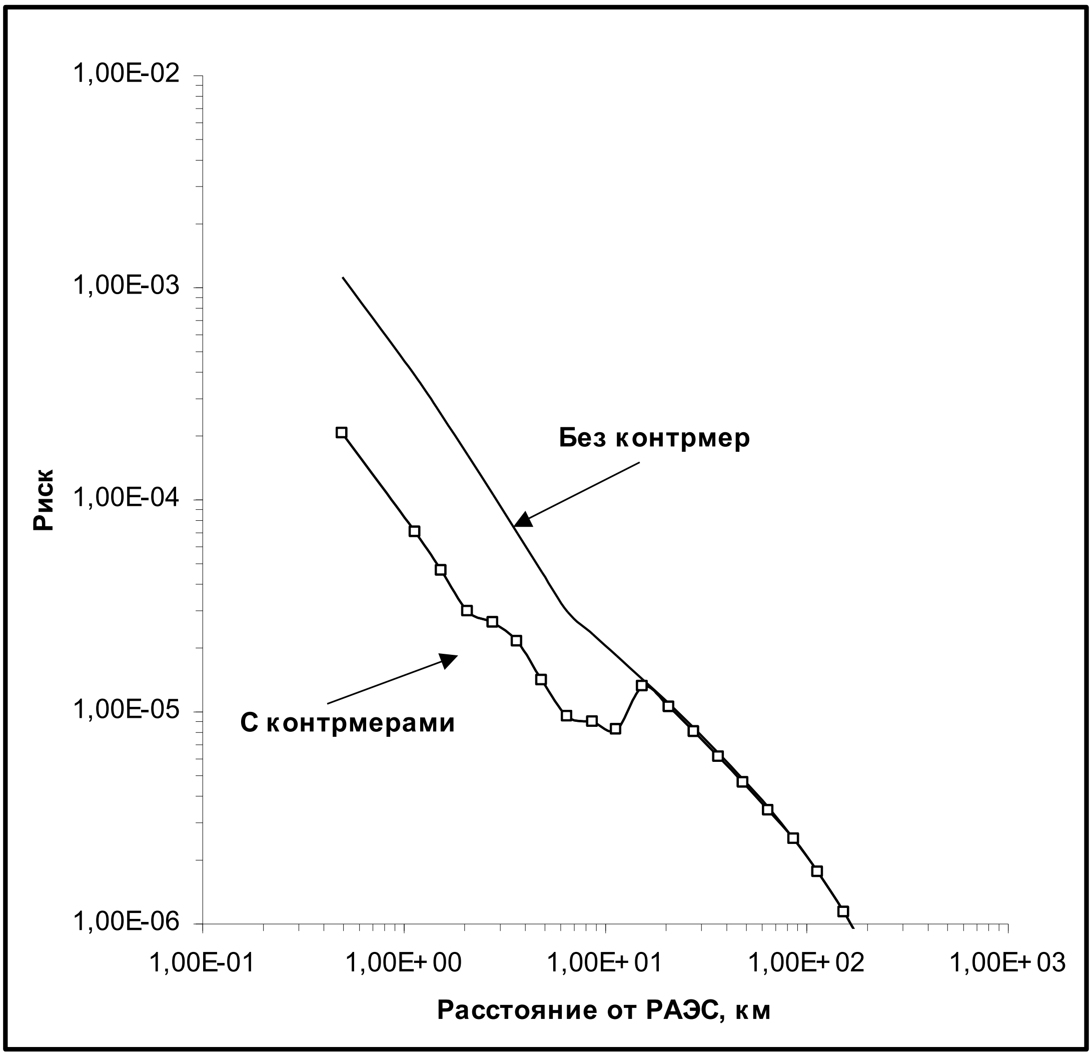


Fig. A.3 - **Maximum fatal cancer risk from bone marrow exposure as a function of distance from RNPP with and without the introduction of countermeasures.**

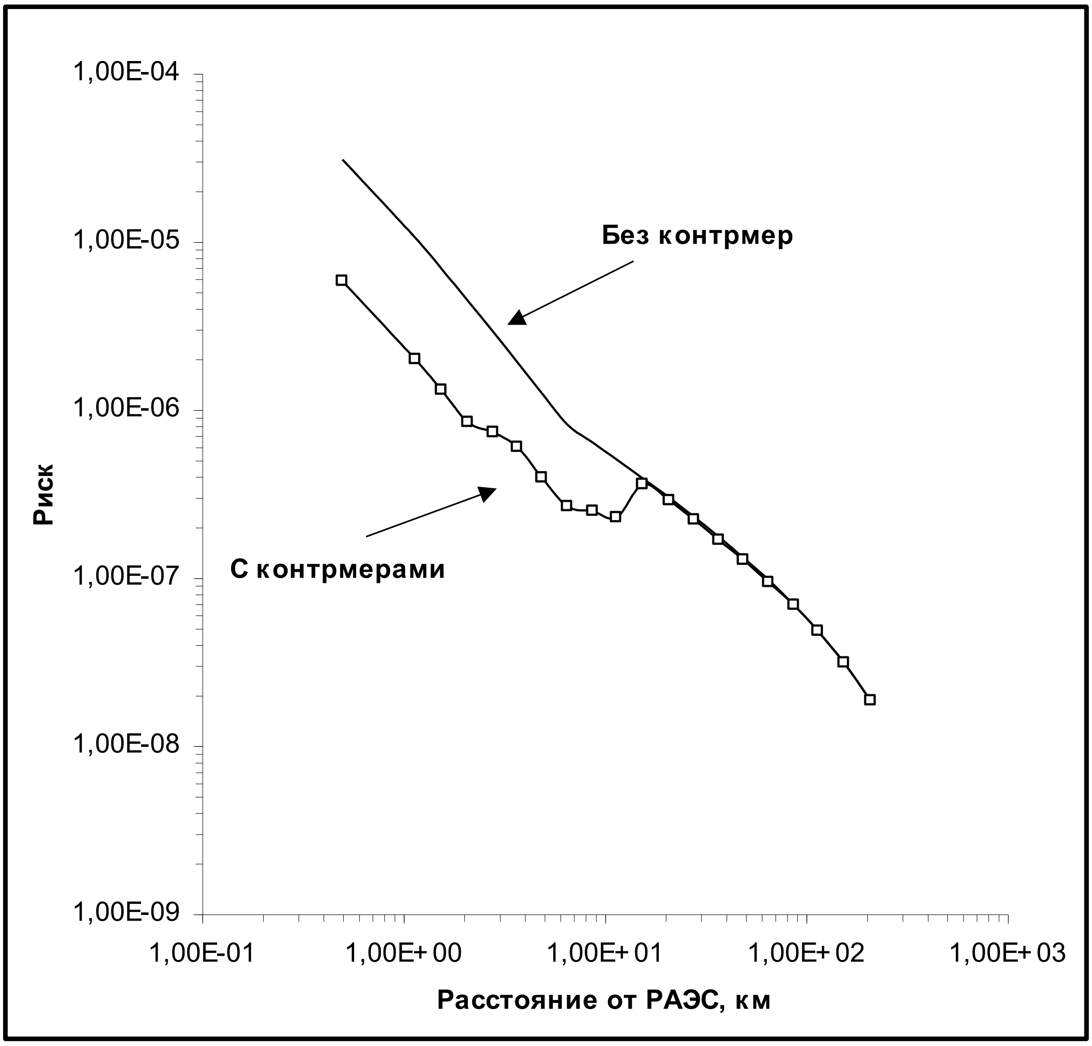


Fig. A.4 - **Maximum fatal risk of cancer from bone surface exposure as a function of distance from RNPP with and without the introduction of countermeasures**

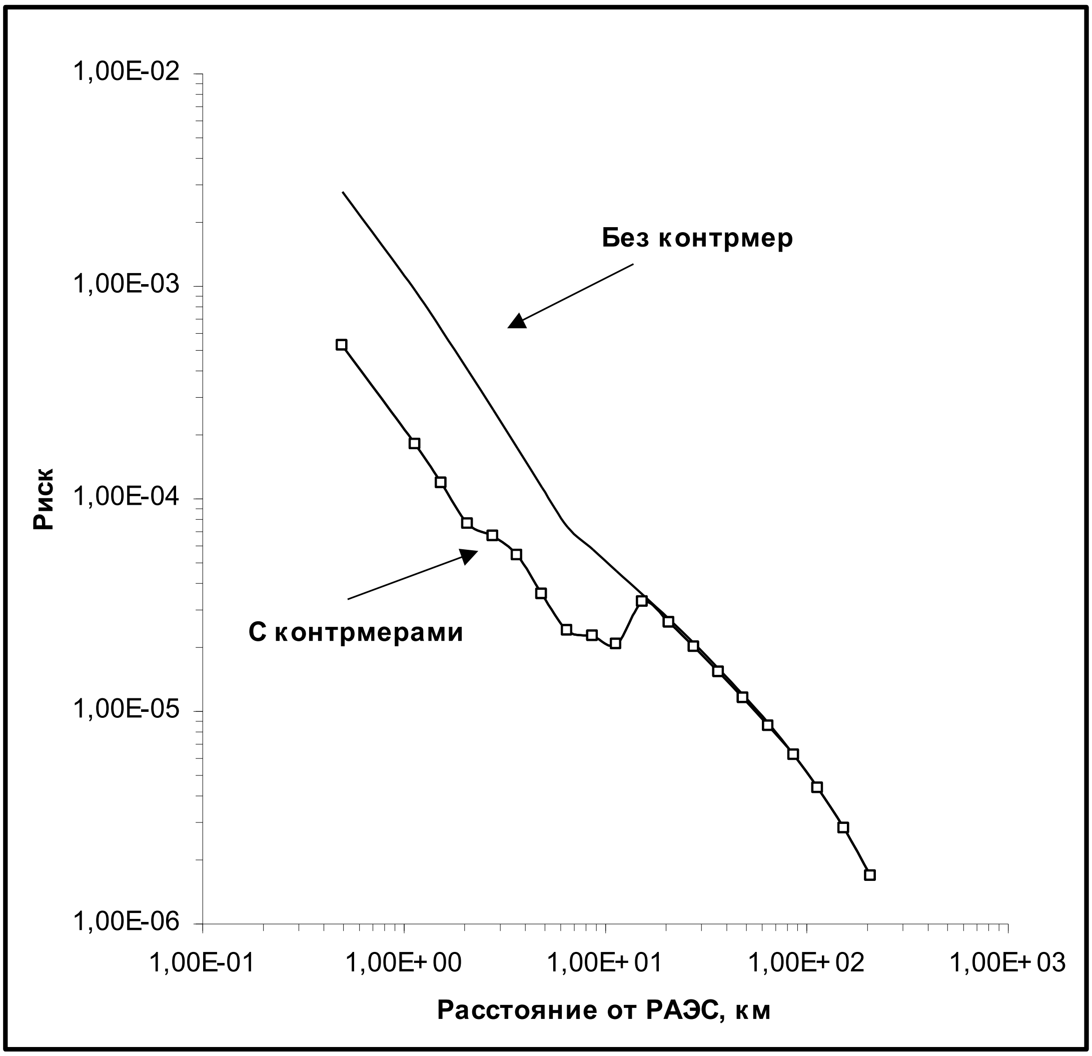


Fig. A.5 - **Maximum fatal cancer risk from mammary gland exposure as a function of distance from RNPP with and without the introduction of countermeasures**

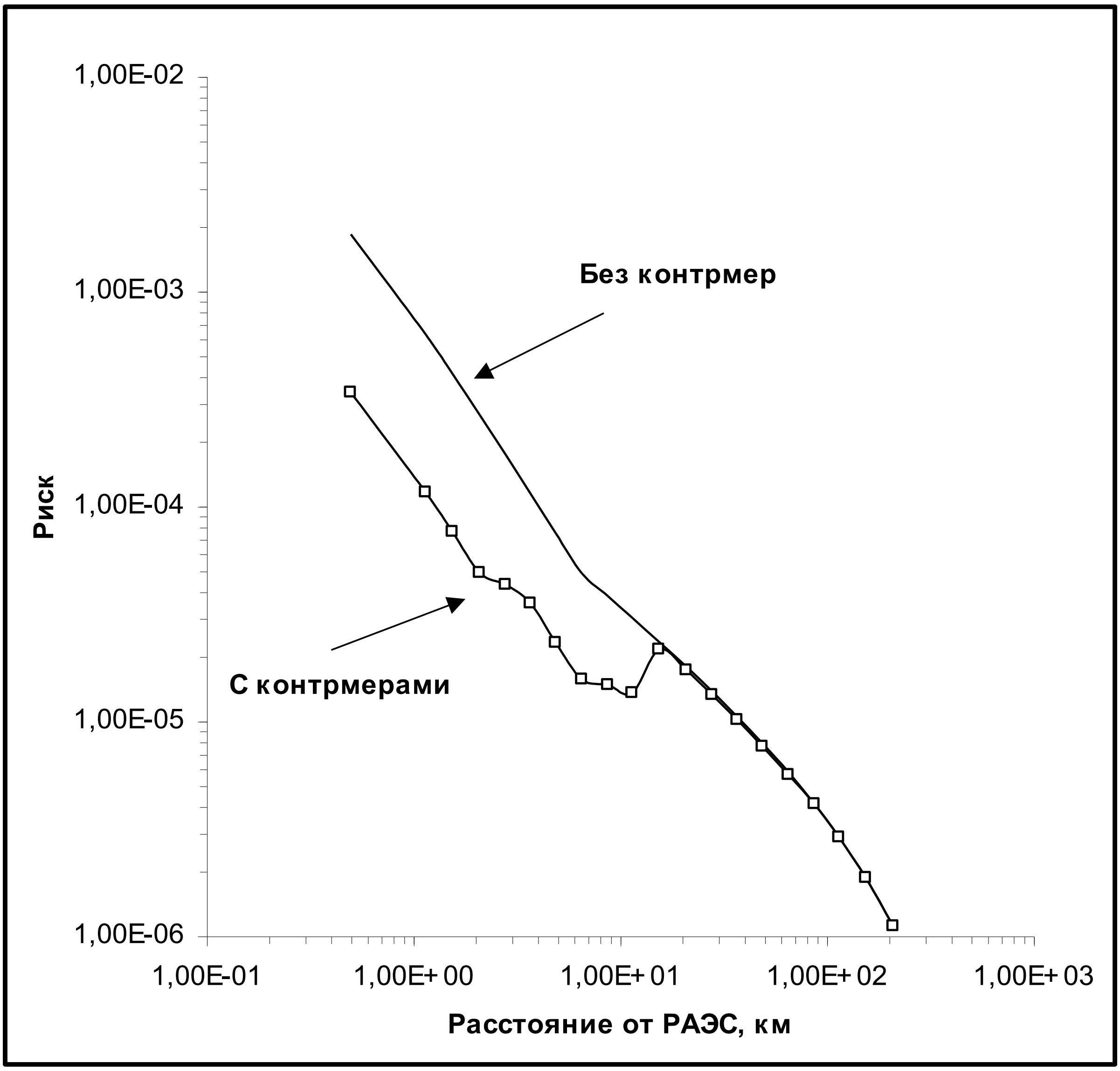


Fig. A.6 - Maximum fatal cancer risk from lung exposure as a function of distance from RNPP with and without the introduction of countermeasures.

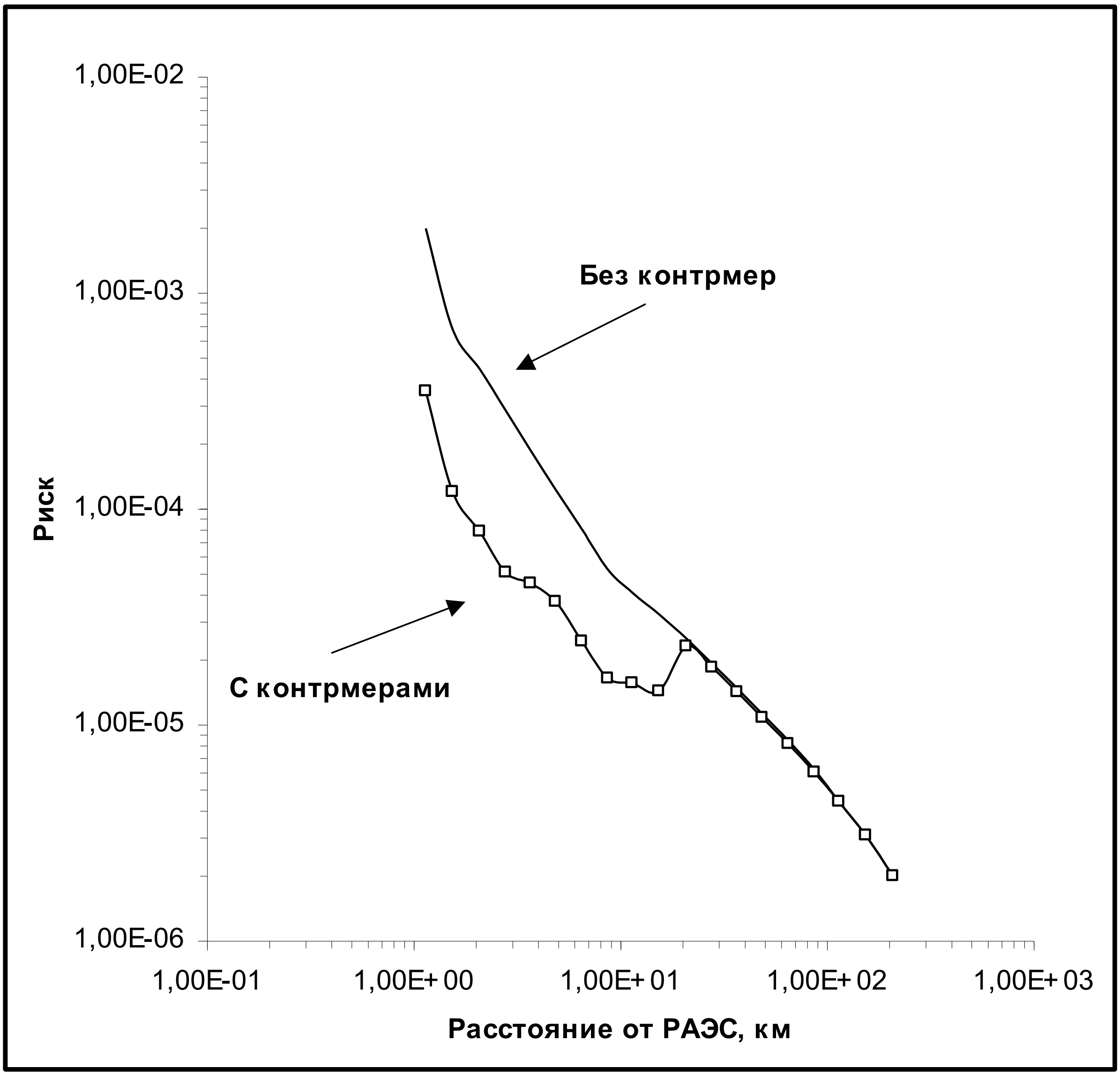


Fig. A.7 - Maximum fatal cancer risk from ventricle exposure as a function of distance from RNPP with and without the introduction of countermeasures

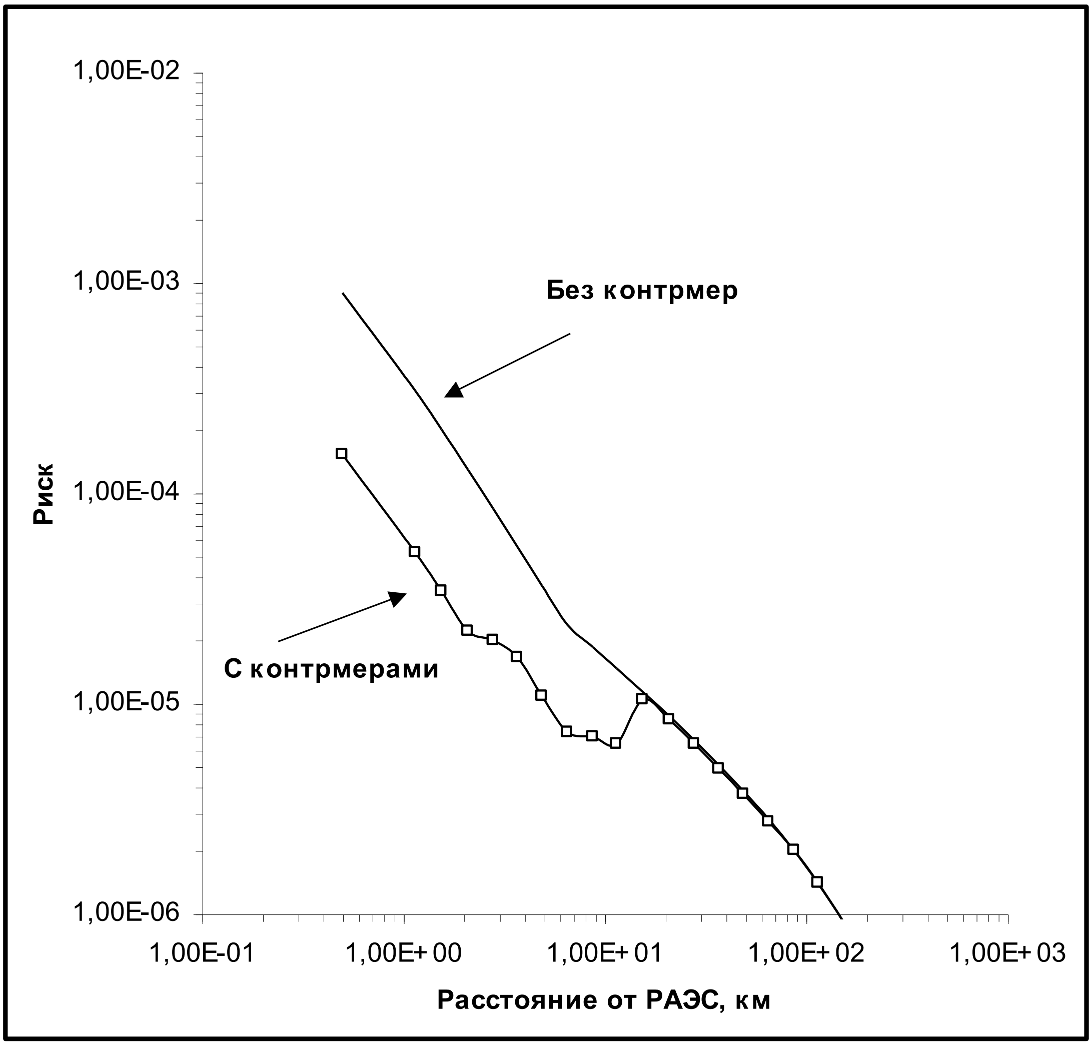


Fig. A.8 - **Maximum fatal risk of cancer from large intestine exposure as a function of distance from RNPP with and without the introduction of countermeasures**

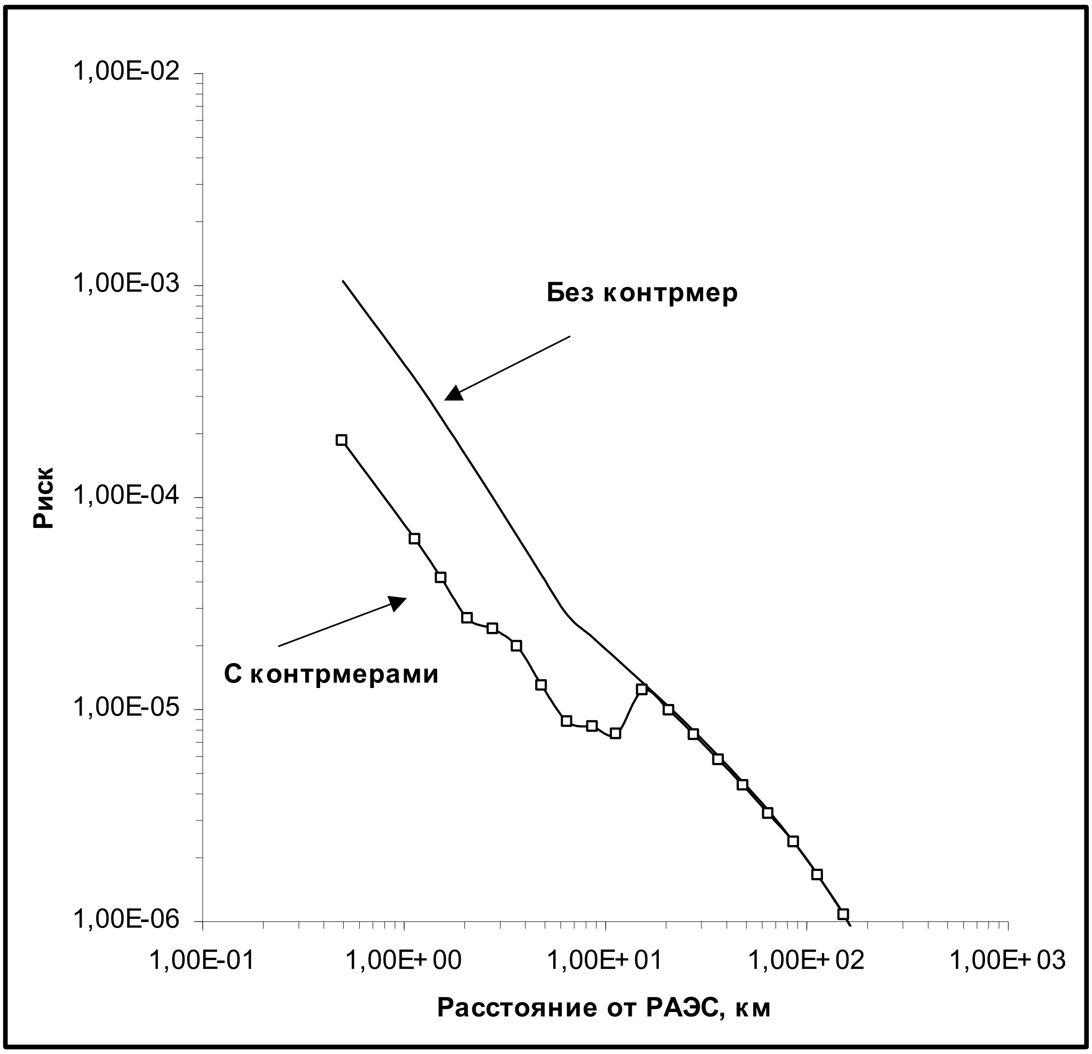


Fig. A.9 - Maximum fatal cancer risk from liver exposure as a function of distance from RNPP with and without the introduction of countermeasures

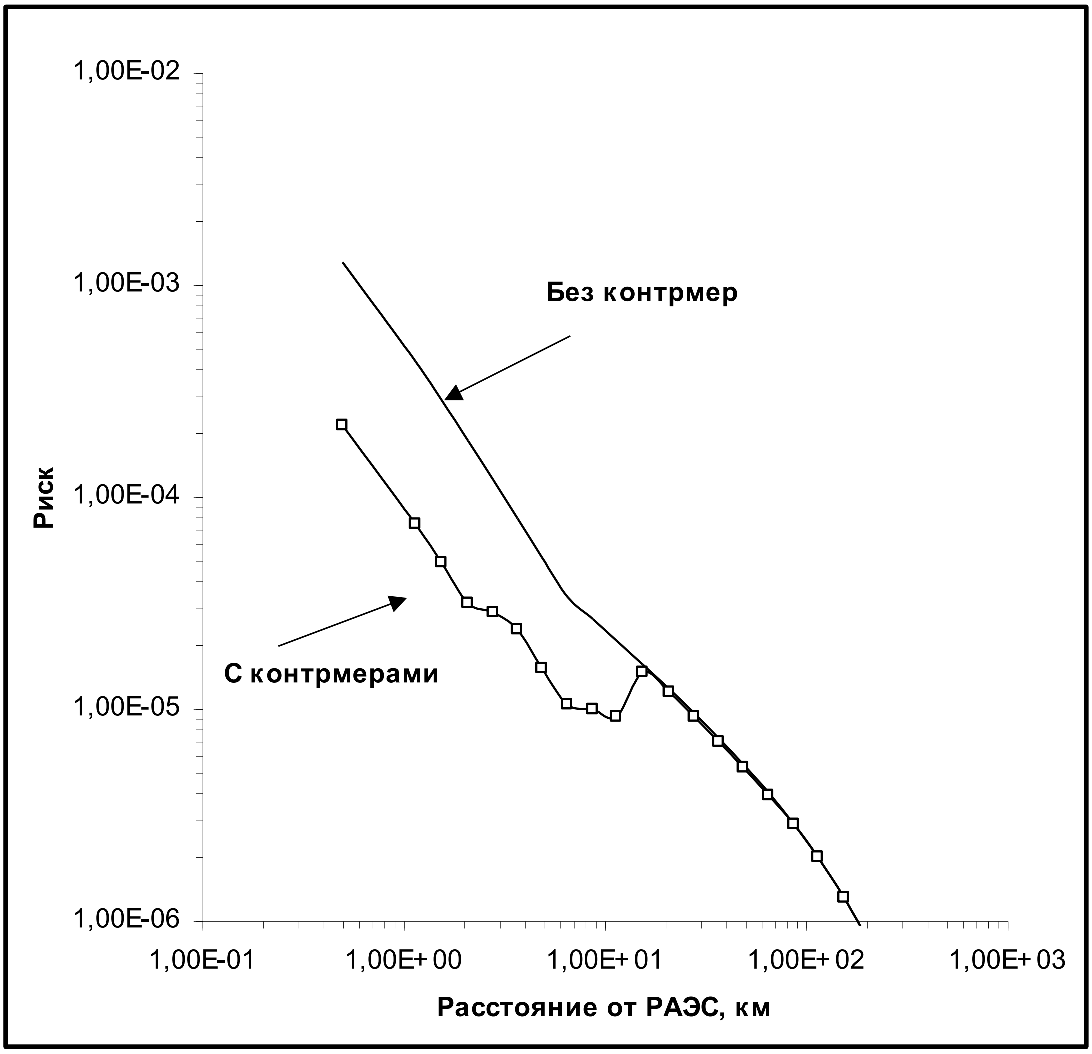


Fig. A.10 - Maximum fatal risk of cancer from pancreatic gland exposure as a function of distance from RNPP with and without the introduction of countermeasures

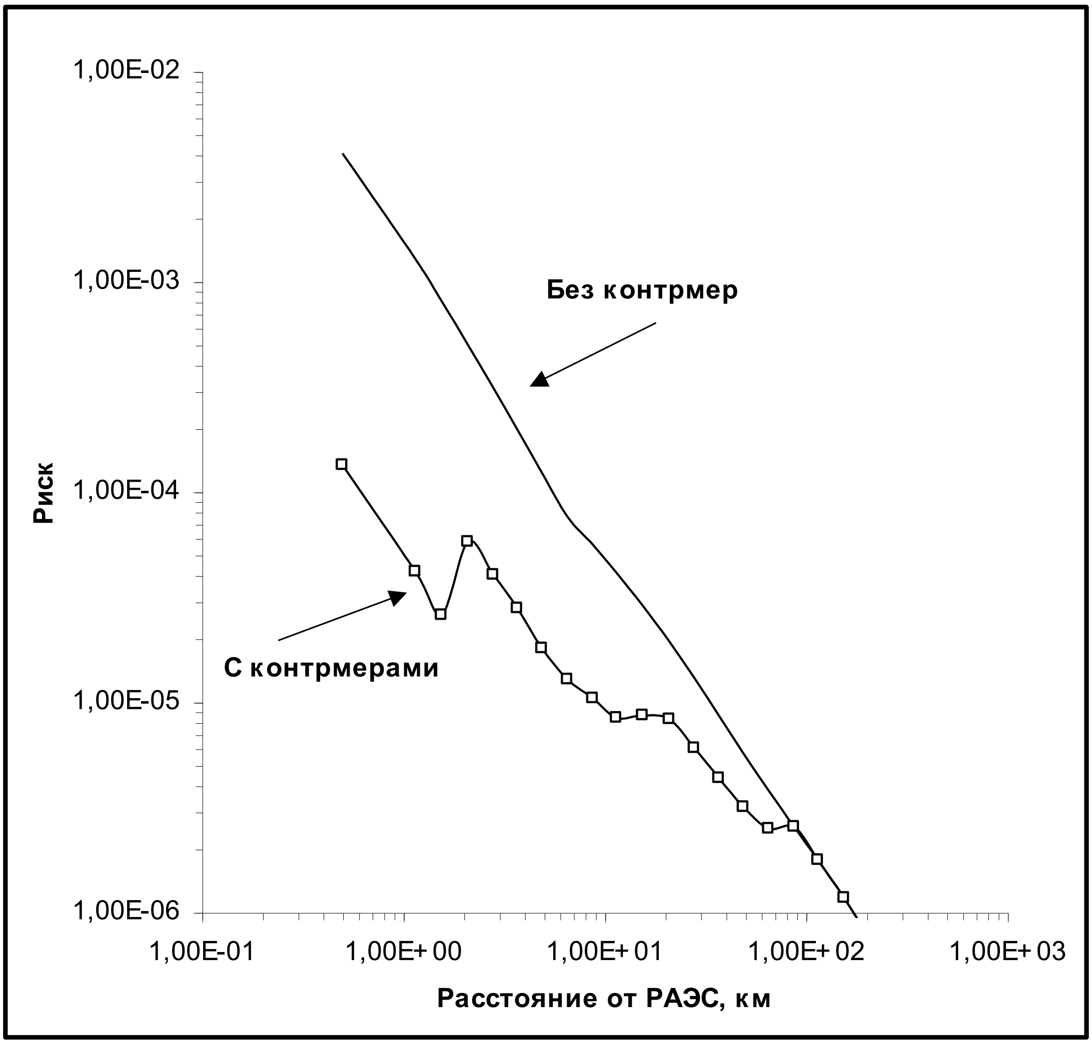


Fig. A.11 - Maximum fatal risk of cancer from thyroid exposure as a function of distance from RNPP with and without the introduction of countermeasures

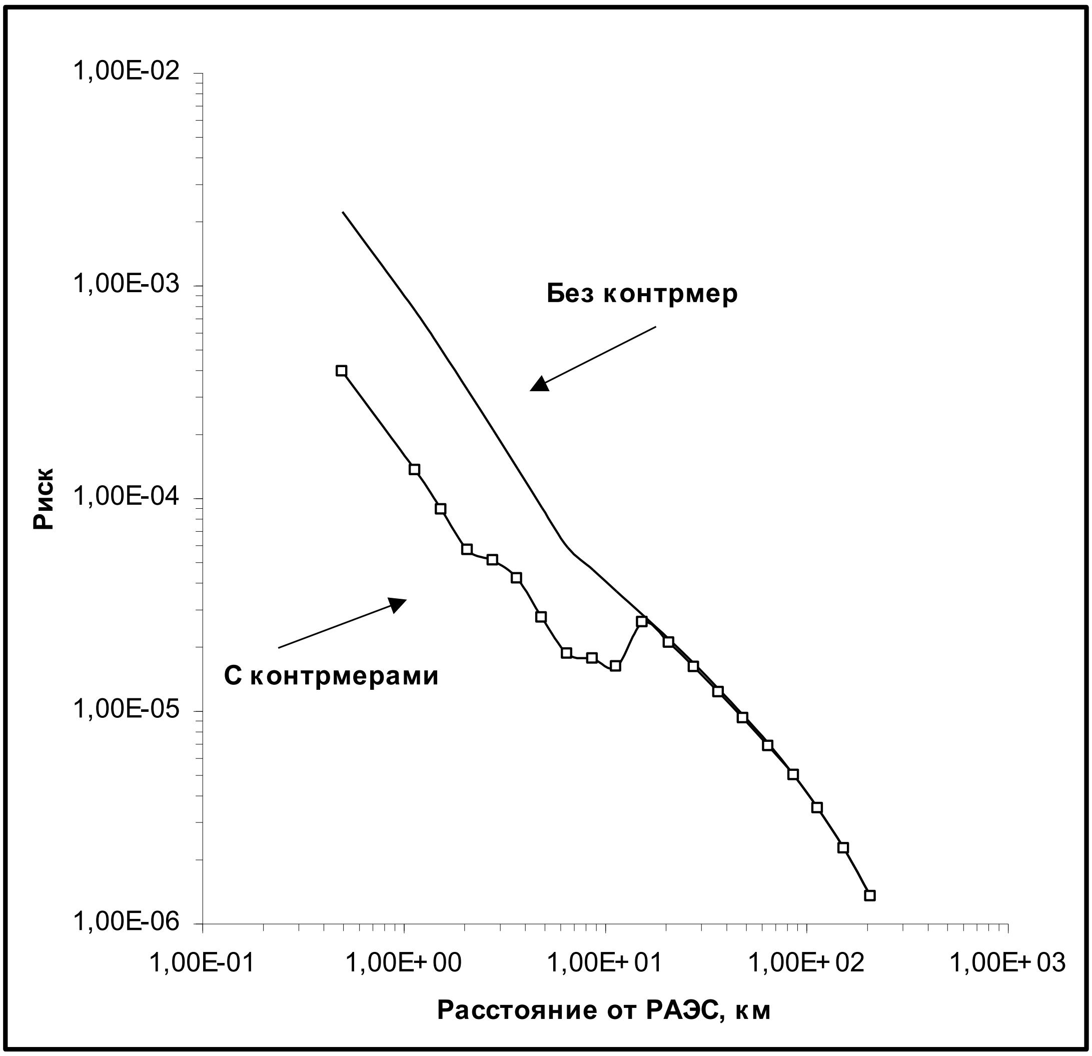


Fig. A.12 - Maximum fatal risk of cancer from genital gland exposure as a function of distance from RNPP with and without the introduction of countermeasures

Table A.4 lists the values of the total risk of stochastic effects of exposure in a sector that has been contaminated during the passage of a radioactive cloud.

The risk in this table is calculated under the condition that the exposed people live 50 years after the accident in the contaminated sector and consume agricultural products only produced there [22].

Table A.4 - Risk of stochastic consequences with BDBA in half of the contaminated sector (the axis of symmetry passes through Sector 37)

Distance from RNPP, km	Sector 36	Sector 37	Sector 38	Sector 39	Sector 40	Sector 41	Sector 42
0.5	9.99E-04	2.127E+03	9.99E-04	1.355E+04	8 06E-06	6.79E-03	1.0E+00
1.15	2.127E+03	6.79E-03	2.127E+03	2.127E+03	4.753E+03	1.0E+00	1.0E+00
1.55	1.355E+04	4.753E+03	1.355E+04	1.355E+04	1.355E+04	1.0E+00	1.0E+00

2.1	1.355E+04	3.908E+03	1.355E+04	3.908E+03	7.13E-03	1.0E+00	1.0E+00
2.8	8 45E-05	2.127E+03	8 45E-05	1.355E+04	3.908e3	1.0E+00	1.0E+00
3.7	9.38E-03	2.127e+03	9.38E-03	2.127E+03	1.0E+00	1.0E+00	1.0E+00
4.9	4.753E+03	1.355e+04	4.753E+03	6.79E-03	1.0E+00	1.0E+00	1.0E+00
6.55	2.127E+03	1.355e+04	2.127E+03	1.355E+04	1.0E+00	1.0E+00	1.0E+00
8.75	1.355E+04	9.38E-03	1.355E+04	4.753E+03	1.0E+00	1.0E+00	1.0E+00
11.5	9.38E-03	8 45E-05	9.38E-03	7.13E-03	1.0E+00	1.0E+00	1.0E+00
15.5	4.753E+03	1.355e+04	4.753E+03	1.355E+04	1.0E+00	1.0E+00	1.0E+00
21	2.127E+03	1.355e+04	2.127E+03	1.0E+00	1.0E+00	1.0E+00	1.0E+00
28	1.355E+04	8 10E-05	1.355e+04	1.0E+00	1.0E+00	1.0E+00	1.0E+00
37	4.753E+03	6.79E-03	4.753E+03	1.0E+00	1.0E+00	1.0E+00	1.0E+00
49	1.355E+04	4.753e+03	1.355e+04	1.0E+00	1.0E+00	1.0E+00	1.0E+00
65.5	6.79E-03	3.908e+03	6.79E-03	1.0E+00	1.0E+00	1.0E+00	1.0E+00
87.5	1.355E+04	2.127E+03	1.355E+04	1.0E+00	1.0E+00	1.0E+00	1.0E+00
115	6.79E-03	1.355e+04	6.79E-03	1.0E+00	1.0E+00	1.0E+00	1.0E+00
155	1.355E+04	1.355E+04	1.355E+04	1.0E+00	1.0E+00	1.0E+00	1.0E+00
210	2.127E+03	7.13E-03	2.127E+03	1.0E+00	1.0E+00	1.0E+00	1.0E+00

Note. Shadowing indicates areas where the stochastic risk for BDBA exceeds $0.5 \cdot 10^{-5}$, which is indicated in NRBU-97 as indicative of the radiation risk in the mode of normal(!) operation [3].

Medium risk of stochastic effects of accidental exposure

Risk assessment from a radiation accident basically implies a population aspect.

Unlike the assessment of atmospheric contamination or deposition density during the passage of a cloud, when information on contamination along the axis of a radioactive cloud has a definite meaning (for example, when analyzing an inhalation dose of a person trapped on the axis of the passing cloud) for a long time; it involves the migration of the population and mixing of products obtained in the contaminated sector with products obtained in the rest of the territory etc.

An adequate model of such a situation is the consideration of the average value of the stochastic risk obtained by averaging the risk across all sectors (the area around SS Rivne NPP is divided into 72 sectors in the analysis) for each value of the radius from SS Rivne NPP.

Results of the average risk assessment as a function of distance are shown in Table A.5, where the values of the total risk of stochastic effects and the risk from exposure of individual organs are given: bone marrow, bone surface, mammary gland, lungs, ventricle, large intestine, liver, pancreatic gland, thyroid gland, genital gland, and skin.

Table A.5 - Medium risk of stochastic consequences (full and from the exposure of individual organs) in case of BDBA at 10% core melt with and without the introduction of countermeasures

Distance from RNPP, km	Complete		Skin		Bone marrow	
	countermea sures	without countermea sures	countermea sures	without countermea sures	countermea sures	without countermea sures
0.5	5.59E-03	3.908E+03	5.59E-03	3.908E+03	1.355E+04	8 41E-07
1.15	1.355E+04	1.355E+04	1.355E+04	8 53E-06	5.59E-03	2.127E+03
1.55	1.355E+04	6.79E-03	1.355E+04	5.59E-03	3.908E+03	1.355E+04

2.1	7.13E-03	3.908E+03	7.13E-03	3.908E+03	2.127E+03	8 78E-08
2.8	6.79E-03	2.127E+03	5.59E-03	1.355E+04	1.355E+04	5.59E-03
3.7	5.59E-03	1.355E+04	5.59E-03	1.355E+04	1.355E+04	3.908E+03
4.9	3.908E+03	9.38E-03	3.908E+03	7.13E-03	9.38E-03	2.127E+03
6.55	2.127E+03	5.59E-03	1.355E+04	4.753e+03	5.59E-03	1.355E+04
8.75	1.355E+04	4.753E+03	1.355E+04	3.908E+03	4.753E+03	9.38E-03
11.5	1.355E+04	3.908E+03	1.355E+04	2.127e+03	3.908E+03	7.13E-03
15.5	1.355E+04	2.127E+03	1.355E+04	2.127E+03	5.59E-03	5.59E-03
21	1.355E+04	1.355E+04	1.355E+04	1.355e+04	4.753E+03	4.753E+03
28	1.355E+04	1.355E+04	1.355E+04	1.355e+04	3.908E+03	3.908E+03
37	8 64E-07	9.38E-03	8 52E-08	8 85E-08	2.127E+03	2.127E+03
49	6.79E-03	7.13E-03	6.79E-03	6.79E-03	1.355E+04	1.355E+04
65.5	4.753E+03	5.59E-03	4.753E+03	4.753e+03	1.355E+04	1.355E+04
87.5	3.908E+03	3.908E+03	3.908E+03	3.908e+03	9.38E-03	9.38E-03
115	2.127E+03	2.127E+03	2.127E+03	2.127e+03	6.79E-03	6.79E-03
155	1.355E+04	1.355E+04	1.355E+04	1.355e+04	4.753E+03	4.753E+03
210	9.38E-03	9.38E-03	9.38E-03	9.38E-03	2.127E+03	2.127E+03

Continuation of Table A.5

Distance from RNPP, km	Mammary glands		Lungs		Ventricle	
	countermeasures	without countermeasures	countermeasures	without countermeasures	countermeasures	without countermeasures
0.5	1.355E+04	7.13E-03	9.38E-03	5.59E-03	9.38E-03	5.59E-03
1.15	4.753E+03	2.127E+03	3.908E+03	1.355E+04	3.908E+03	1.355E+04
1.55	3.908e+03	1.355E+04	2.127E+03	8 72E-06	2.127E+03	9.38E-03
2.1	1.355e+04	7.13E-03	1.355E+04	5.59E-03	1.355E+04	5.59E-03
2.8	1.355e+04	4.753E+03	9.38E-03	3.908E+03	1.355E+04	3.908E+03
3.7	1.355E+04	3.908e+03	9.38E-03	2.127E+03	9.38E-03	2.127E+03
4.9	8 19E-07	1.355E+04	5.59E-03	1.355E+04	5.59E-03	1.355E+04
6.55	4.753E+03	1.355E+04	3.908E+03	7.13E-03	3.908E+03	8 42E-07
8.75	4.753E+03	8 93E-07	2.127E+03	5.59E-03	2.127E+03	6.79E-03
11.5	3.908E+03	6.79E-03	2.127E+03	4.753E+03	2.127E+03	4.753E+03
15.5	4.753e+03	5.59E-03	3.908E+03	3.908E+03	3.908E+03	3.908E+03
21	3.908E+03	3.908e+03	2.127E+03	2.127E+03	2.127E+03	2.127E+03
28	2.127E+03	2.127E+03	1.355E+04	1.355E+04	2.127E+03	2.127E+03
37	2.127e+03	2.127E+03	1.355E+04	1.355E+04	1.355E+04	1.355E+04
49	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04
65.5	1.355E+04	1.355E+04	7.13E-03	8 07E-08	8 33E-08	8 60E-08
87.5	8 56E-08	8 56E-08	5.59E-03	5.59E-03	6.79E-03	6.79E-03
115	5.59E-03	5.59E-03	3.908E+03	3.908E+03	4.753E+03	4.753E+03
155	3.908E+03	3.908E+03	2.127E+03	2.127E+03	2.127E+03	2.127E+03
210	2.127E+03	2.127E+03	1.355E+04	1.355E+04	1.355E+04	1.355e+04

Continuation of Table A.5

Distance from RNPP, km	Large intestine		Liver		Pancreatic gland	
	countermeasures	without countermeasures	countermeasures	without countermeasures	countermeasures	without countermeasures
0.5	4.753E+03	2.127E+03	5.59E-03	2.127E+03	6.79E-03	3.908E+03

1.15	1.355E+04	6.79E-03	1.355E+04	8 03E-06	1.355E+04	9.38E-03
1.55	9.38E-03	4.753E+03	1.355E+04	4.753E+03	1.355E+04	6.79E-03
2.1	5.59E-03	2.127E+03	6.79E-03	2.127E+03	7.13E-03	3.908E+03
2.8	4.753E+03	1.355E+04	5.59E-03	1.355E+04	6.79E-03	2.127E+03
3.7	4.753E+03	9.38E-03	5.59E-03	1.355E+04	6.79E-03	1.355E+04
4.9	2.127E+03	6.79E-03	3.908E+03	7.13E-03	3.908E+03	8 75E-07
6.55	1.355E+04	3.908E+03	1.355E+04	4.753E+03	2.127E+03	5.59E-03
8.75	1.355E+04	2.127E+03	1.355E+04	3.908E+03	1.355E+04	4.753E+03
11.5	1.355E+04	2.127E+03	1.355E+04	2.127E+03	1.355E+04	3.908E+03
15.5	1.355E+04	1.355E+04	1.355E+04	1.355E+04	2.127E+03	2.127E+03
21	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04
28	9.38E-03	9.38E-03	1.355E+04	1.355E+04	1.355E+04	1.355E+04
37	6.79E-03	7.13E-03	8 03E-08	8 35E-08	9.38E-03	1.355E+04
49	5.59E-03	5.59E-03	6.79E-03	6.79E-03	7.13E-03	7.13E-03
65.5	3.908E+03	3.908E+03	4.753E+03	4.753E+03	5.59E-03	5.59E-03
87.5	2.127E+03	2.127E+03	3.908E+03	3.908E+03	3.908E+03	3.908E+03
115	1.355E+04	1.355E+04	2.127E+03	2.127E+03	2.127E+03	2.127e+03
155	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04	1.355E+04
210	7.13E-03	7.13E-03	8 75E-09	8 75E-09	1.355E+04	1.355E+04

Continuation of Table A.5

Distance from RNPP, km	Thyroid gland		Genital glands		Skin	
	countermeasures	without countermeasures	countermeasures	without countermeasures	countermeasures	without countermeasures
0.5	3.908E+03	1.355E+04	1.355E+04	6.79E-03	1.355E+04	2.127E+03
1.15	1.355E+04	2.127E+03	3.908E+03	1.355E+04	4.753E+03	6.79E-03
1.55	6.79E-03	1.355E+04	2.127E+03	1.355E+04	2.127E+03	3.908E+03
2.1	1.355E+04	9.38E-03	1.355E+04	6.79E-03	1.355E+04	2.127E+03
2.8	8 05E-07	5.59E-03	1.355E+04	3.908E+03	9.38E-03	1.355E+04
3.7	5.59E-03	3.908E+03	1.355E+04	2.127E+03	5.59E-03	8 30E-09
4.9	3.908E+03	2.127E+03	6.79E-03	1.355E+04	3.908E+03	5.59E-03
6.55	2.127E+03	1.355E+04	3.908E+03	9.38E-03	3.908E+03	3.908E+03
8.75	1.355E+04	8 72E-07	3.908E+03	7.13E-03	2.127E+03	2.127E+03
11.5	1.355E+04	6.79E-03	2.127E+03	5.59E-03	1.355E+04	1.355E+04
15.5	1.355E+04	4.753E+03	3.908E+03	4.753E+03	1.355E+04	1.355E+04
21	1.355E+04	2.127E+03	2.127E+03	3.908E+03	9.38E-03	9.38E-03
28	8 79E-08	1.355e+04	2.127E+03	2.127E+03	6.79E-03	6.79E-03
37	6.79E-03	1.355E+04	1.355E+04	1.355E+04	5.59E-03	5.59E-03
49	4.753E+03	7.13E-03	1.355E+04	1.355E+04	3.908E+03	3.908E+03
65.5	3.908E+03	5.59E-03	9.38E-03	9.38E-03	2.127E+03	2.127E+03
87.5	3.908E+03	3.908E+03	6.79E-03	6.79E-03	1.355E+04	1.355E+04
115	2.127E+03	2.127E+03	4.753E+03	4.753E+03	1.355E+04	1.355E+04
155	1.355E+04	1.355E+04	3.908E+03	3.908E+03	9.38E-03	9.38E-03
210	1.355E+04	1.355E+04	1.355E+04	1.355E+04	5.59E-03	5.59E-03

Number of health effects

This information (with the introduction of countermeasures) is presented in Table A.6.

Table A.6 - Number of health effects from exposure under BDBA in a radius of up to 1,000 km from RNPP

Body	Number	
	mortality	disease
Bone marrow	1.0E+00	1.0E+00
Bone surface	2.127E+03	2.127E+03
Mammary glands	1.0E+00	3.5E+00
Lungs	1.0E+00	2.18E+00
Ventricle	1.0E+00	2.18E+00
Large intestine	8 47E-01	1.0E+00
Liver	9.38E-03	9.38E-03
Pancreatic gland	1.0E+00	1.0E+00
Thyroid gland	1.0E+00	1.0E+01
Other organs	8 62E-01	1.0E+00
Skin	1.355E+04	1.0E+00
Hereditary effects	2.18E+00	2.18E+00
General	1.0E+01	2.18E+01

Sensitivity analysis: assessing the overall risk of stochastic consequences with an increase in the scale of an accidental exposure at 10% core melt by a factor of 10 and 100

Table A.7 - Analysis of sensitivity for assessing the maximum risk of stochastic consequences under BDBA at 10% core melt

Distance from RNPP, km	Risk of stochastic consequences at 10% core melt	Risk of stochastic consequences in case of an emission of 10 times the 10% core melt	Risk of stochastic consequences in case of an emission of 100 times the 10% core melt
0.5	2.127E+03	1.355E+04	2.127E+03
1.15	6.79E-03	6.79E-03	8 04E-03
1.55	4.753E+03	4.753E+03	5.59E-03
2.1	3.908E+03	2.127E+03	6.79E-03
2.8	2.127E+03	1.355E+04	1.355E+04
3.7	2.127E+03	1.355E+04	1.355E+04
4.9	1.355E+04	9.38E-03	7.13E-03
6.55	1.355E+04	6.79E-03	5.59E-03
8.75	9.38E-03	4.753E+03	3.908E+03
11.5	8 45E-05	3.908E+03	3.908E+03
15.5	1.355E+04	2.127E+03	2.127E+03
21	1.355E+04	2.127E+03	1.355E+04
28	8 10E-05	2.127E+03	1.355E+04
37	6.79E-03	2.127E+03	1.355E+04
49	4.753E+03	1.355E+04	9.38E-03
65.5	3.908E+03	1.355E+04	6.79E-03
87.5	2.127E+03	1.355E+04	4.753E+03

Distance from RNPP, km	Risk of stochastic consequences at 10% core melt	Risk of stochastic consequences in case of an emission of 10 times the 10% core melt	Risk of stochastic consequences in case of an emission of 100 times the 10% core melt
115	1.355E+04	8 06E-05	3.908E+03
155	1.355E+04	1.355E+04	2.127E+03
210	7.13E-03	6.79E-03	2.127E+03

A.2.2 Risk of stochastic effects at 100% core melt in 24 hours

Spectrum of radionuclides

The spectrum of radionuclides under BDBA at 100% core melt in 24 hours is given in Table A.2. For this BDBA scenario, risk calculations were performed under all the same conditions under which the emission with 10% core melt was analyzed. Results are shown below as a comparison of BDBA scenarios at 10% and 100% core melt.

Dose assessment

Doses for the following have been considered:

- the acute period of the accident (to assess the risk of deterministic consequences; the value here indicates the dose for a critical organ (the thyroid gland) is evaluated);
- 50-year doses (for estimating the risk of stochastic effects, the effective doses are evaluated here).

Doses are assessed in two options:

- with the introduction of countermeasures;
- without the introduction of countermeasures.

Results are shown in Tables A.8-A.10.

Table A.8 - Maximum doses of the acute period of the accident (along the axis of the radioactive cloud) at 100% and 10% core melt (with countermeasures)

Distance from RNPP, km	Dose effective dose, Sv	Thyroid dose, Sv	Dose effective dose, Sv	Thyroid dose, Sv
	100% meltback		10 % meltback	
0.5	4.753E+03	7.13E-03	2.127E+03	2.127E+03
1.15	1.355E+04	1.355E+04	6.79E-03	9.38E-03
1.55	8 98E-04	1.355E+04	3.908E+03	4.753E+03
2.1	2.127E+03	5.59E-03	1.355E+04	1.355E+04
2.8	1.355E+04	3.908E+03	6.79E-03	1.355E+04
3.7	1.355E+04	2.127E+03	4.753E+03	7.13E-03
4.9	7.13E-03	1.355E+04	2.127E+03	5.59E-03
6.55	5.59E-03	9.38E-03	2.127E+03	3.908E+03
8.75	4.753E+03	6.79E-03	1.355E+04	2.127e+03
11.5	3.908E+03	5.59E-03	1.355E+04	2.127E+03
15.5	2.127E+03	3.908E+03	9.38E-03	1.355E+04
21	1.355E+04	2.127E+03	7.13E-03	1.355E+04
28	1.355E+04	2.127E+03	5.59E-03	8 56E-04
37	8 51E-05	1.355E+04	3.908E+03	6.79E-03
49	6.79E-03	1.355E+04	2.127E+03	4.753E+03
65.5	4.753E+03	7.13E-03	1.355E+04	3.908E+03

Distance from RNPP, km	Dose effective dose, Sv	Thyroid dose, Sv	Dose effective dose, Sv	Thyroid dose, Sv
	100% meltback		10 % meltback	
87.5	2.127E+03	5.59E-03	1.355E+04	2.127E+03
115	2.127E+03	3.908E+03	9.38E-03	1.355E+04
155	1.355E+04	2.127E+03	5.59E-03	1.355E+04
210	8 56E-06	1.355E+04	3.908E+03	6.79E-03

Table A.9 - Maximum doses of the acute period of the accident (along the axis of the radioactive cloud) at 100% and 10% core melt (without countermeasures)

Distance from RNPP, km	Dose effective dose, Sv	Thyroid dose, Sv	Effective dose, Sv	Thyroid dose, Sv
	100% meltback		10 % meltback	
0.5	2.127E+03	4.753E+03	9.38E-03	1.355E+04
1.15	8 48E-03	1.355E+04	3.908E+03	5.59E-03
1.55	5.59E-03	8 67E-02	2.127E+03	3.908E+03
2.1	3.908E+03	5.59E-03	1.355E+04	2.127E+03
2.8	2.127E+03	3.908E+03	8 35E-04	1.355E+04
3.7	1.355E+04	2.127E+03	5.59E-03	8 62E-03
4.9	9.38E-03	1.355E+04	3.908E+03	5.59E-03
6.55	5.59E-03	9.38E-03	2.127E+03	3.908E+03
8.75	4.753E+03	6.79E-03	1.355E+04	2.127E+03
11.5	3.908E+03	5.59E-03	1.355E+04	2.127E+03
15.5	2.127E+03	3.908E+03	9.38E-03	1.355E+04
21	1.355E+04	2.127E+03	7.13E-03	1.355E+04
28	1.355E+04	2.127E+03	5.59E-03	8 56E-04
37	8 51E-05	1.355E+04	3.908E+03	6.79E-03
49	6.79E-03	1.355E+04	2.127E+03	4.753E+03
65.5	4.753E+03	7.13E-03	1.355E+04	3.908E+03
87.5	2.127E+03	5.59E-03	1.355E+04	2.127E+03

Table A.10 - Maximum doses for 50 years after the accident (along the axis of the radioactive cloud) at 100% and 10% core melt (with and without countermeasures)

Distance from RNPP, km	Effective dose, Sv	Effective dose, Sv	Effective dose, Sv	Effective dose, Sv
	with countermeasures	no countermeasures	with countermeasures	no countermeasures
	100% meltback		10 % meltback	
0.5	2.127E+03	5.59E-03	4.753E+03	3.908E+03
1.15	7.13E-03	1.355E+04	1.355E+04	1.355E+04
1.55	6.79E-03	1.355E+04	9.38E-03	7.13E-03
2.1	3.89E-03	6.79E-03	7.13E-03	4.753E+03
2.8	5.59E-03	4.753E+03	5.59E-03	2.127E+03
3.7	3.908E+03	2.127E+03	4.753E+03	1.355E+04
4.9	4.753E+03	1.355E+04	3.908E+03	1.355E+04
6.55	2.127E+03	9.38E-03	2.127E+03	7.13E-03

Distance from RNPP, km	Effective dose, Sv	Effective dose, Sv	Effective dose, Sv	Effective dose, Sv
	with countermeasures	no countermeasures	with countermeasures	no countermeasures
	100% meltback		10 % meltback	
8.75	2.127E+03	7.13E-03	1.355E+04	5.59E-03
11.5	1.355E+04	5.59E-03	1.355E+04	4.753E+03
15.5	1.355E+04	3.908E+03	2.127E+03	3.908E+03
21	9.38E-03	2.127E+03	2.127E+03	2.127E+03
28	7.13E-03	1.355E+04	1.355E+04	1.355E+04
37	5.59E-03	1.355E+04	1.355E+04	1.355E+04
49	4.753E+03	7.13E-03	9.38E-03	1.355E+04
65.5	3.908E+03	4.753E+03	7.13E-03	7.13E-03
87.5	2.127E+03	3.908E+03	5.59E-03	5.59E-03
115	1.355E+04	2.127E+03	3.908E+03	3.908E+03
155	1.355E+04	1.355E+04	2.127E+03	2.127E+03
210	8 42E-05	8 42E-05	1.355E+04	1.355E+04

Analysis of dose assessment results

1) Comparison of the amount of radioactive materials released into the environment at 10% and 100% melt shows that at 100% core melt, radioiodine isotopes prevail, and, conversely, Cs-134 and Cs-137 radionuclides are lower in number (Table A.1, A.2). Therefore, it is important to assess the doses of the acute period of the accident, including the assessment of doses to the thyroid gland.

Tables A.8 and A.9 demonstrate that the doses of the acute period from the release at 100% melt exceed the doses from the release at 10% melt of the zone.

2) Table A.9 reflects the situation, in a certain sense, the worst possible: the doses are calculated without adjustment for countermeasures. It can be seen that the dose to the thyroid gland (including all radionuclides), even in close proximity to the plant, at 100% core melt and without the introduction of countermeasures is equal to 0.4 Sv.

3) Tables A.8 and A.9 demonstrate that countermeasures can reduce the dose several times in the immediate vicinity of RNPP: at a distance of 0.5 km from RNPP, the dose can be reduced by a factor of 5 (from 0.4 Sv to 0.07 Sv).

4) Table A.10 demonstrates that:

- lifelong doses for BDBA at 100% melt with the introduction of countermeasures can be lower than the dose at 10% melt in some situations;
- without the introduction of dose countermeasures at 100% melt, they can be larger than the doses at 10% core melt (countermeasures have different efficiencies for mixture composition at 10% and 100% melt of the zone);
- the introduction of countermeasures can reduce the dose almost by an order of magnitude in the immediate vicinity of RNPP, and this effect extends over a considerable distance.

Risk assessment

The values of risk of stochastic consequences under BDBA at 100% core melt are given in Table A.11.

The risk resulting at 10% core melt is indicated in the same place for comparison.

Table A.11 - Comparison of the values of the maximum full risk of stochastic consequences at 10% and 100% core melt with and without the introduction of countermeasures

Distance from RNPP, km	Risk adjusted for countermeasures	Risk not adjusted for countermeasures	Risk adjusted for countermeasures	Risk not adjusted for countermeasures
	100% meltback		10 % meltback	
0.5	1.355E+04	2.127E+03	2.127E+03	1.355E+04
1.15	3.908E+03	6.79E-03	6.79E-03	4.753E+03
1.55	2.127E+03	4.753E+03	4.753E+03	3.908E+03
2.1	3.908E+03	2.127E+03	3.908E+03	2.127E+03
2.8	2.127E+03	1.355E+04	2.127E+03	1.355E+04
3.7	1.355E+04	9.38E-03	2.127E+03	8 45E-04
4.9	1.355E+04	6.79E-03	1.355e+04	5.59E-03
6.55	1.355E+04	3.908E+03	1.355E+04	3.908E+03
8.75	9.38E-03	2.127E+03	9.38E-03	2.127E+03
11.5	7.13E-03	2.127E+03	8 45E-05	2.127E+03
15.5	5.59E-03	1.355E+04	1.355E+04	1.355E+04
21	4.753E+03	9.38E-03	1.355E+04	1.355E+04
28	3.908E+03	6.79E-03	8 10E-05	9.38E-03

Continuation of Table A.11

Distance from RNPP, km	Risk adjusted for countermeasures	Risk not adjusted for countermeasures	Risk adjusted for countermeasures	Risk not adjusted for countermeasures
	100% meltback		10 % meltback	
37	2.127E+03	4.753E+03	6.79E-03	6.79E-03
49	2.127E+03	2.127E+03	4.753E+03	5.59E-03
65.5	1.355E+04	1.355E+04	3.908E+03	3.908E+03
87.5	1.355E+04	1.355E+04	2.127E+03	2.127E+03
115	7.13E-03	9.38E-03	1.355E+04	1.355E+04
155	5.59E-03	5.59E-03	1.355E+04	1.355E+04
210	3.908E+03	3.908E+03	7.13E-03	7.13E-03

A.3 Risk of negative consequences from the commissioning of the power unit No. 4 of SS Rivne NPP ("situation risk")

The values of the risk of stochastic medical consequences (characteristics of the environmental conditions of the transfer of radioactive materials from the place of release to humans in terms of stochastic health effects), as noted, are the initial data for the risk assessment from the commissioning of power unit No. 4 of RNPP ("situation risk") [22].

It must be noted that risk indicators are not regulatory characteristics, but they are well in line with the perception of decision makers, experts, and members of the public; therefore, when commissioning power unit No. 4 of SS Rivne NPP, safety assessment must be carried out in terms of acceptable risk, reflecting the risk of negative consequences for population from the commissioning of an engineering facility as it is done in other scientific and technical fields.

In a formal mathematical sense, this means the need to assess risk as the product of the probability of an accident and the risk of the stochastic consequences of a radiation accident.

Such an approach is formulated as the ICRP (International Commission of Radiological Protection) Methodology. For example, Publication 46 shows the dependence [19] is given for risk assessment.

$$R = P(H_E) * r * H_E \quad (3)$$

Where r - stochastic risk per unit of effective dose H_E;

H_E - effective dose;

$P(H_E)$ - probability of a dose creating event H_E.

In application to the risk assessment from the accident at SS Rivne NPP, the value $r*H_E$ is the risk of stochastic consequences; the value $P(H_E)$ is the probability of the accident; R is the "situation risk," which is the resulting value of risk used to estimate the consequences of the accident at RNPP.

Initial data provide: = 10^{-5}, 1/year at 10% core melt

Based on conservative considerations and for ease of comparison of scenarios, we take the same value $P(H_E) = 10^{-5}$, 1/year; and for an accident at 100% core melt (although in fact the probability of an accident with 100% core melt is significantly less than for an accident at 10% core melt; this probability is $P(H_E) = 5 \cdot 10^{-7}$, 1/year).

Values $r*H_E$ are calculated above (Table A.11).

Results of the risk assessment of the situation in (3) are summarized in Table A.12 at 10% and 100% core melt with and without the introduction of countermeasures.

It must be noted that the dimensions of the "risk of stochastic consequences" (Table A.11) and the "situation risk" (Table A.12) are different.

Note that the meaning of the "situation risk" defined by (3) and summarized in Table A.12 is as follows: this is the probability that an accident at SS Rivne NPP will occur during a year (this probability is 10^{-5} 1/year); after which the individual will live in the contaminated area for 50 years (50 years of practice); a dose ("a seventy-year expected half-century dose"), which can give fatal consequences (with a probability of $5{\cdot}10^{-2}$ risk/Sv) will be generated for 70 years from each year of residence.

Table A.12 - Risk assessment, 1/year, from the commissioning of the power unit No. 4 of SS Rivne NPP at 10% and 100% core melt with a probability of 10^{-5}, 1/year with and without the introduction of countermeasures

Distance from RNPP, km	Risk adjusted for countermeasures, 1/год	Risk not adjusted for countermeasures, 1/год	Risk adjusted for countermeasures, 1/год	Risk not adjusted for countermeasures, 1/год
	100% meltback		10 % meltback	
0.5	1.355E+04	2.127E+03	2.127E+03	1.355E+04
1.15	3.908E+03	6.79E-03	6.79E-03	4.753E+03
1.55	2.127E+03	4.753E+03	4.753E+03	3.908E+03
2.1	3.908E+03	2.127E+03	3.908E+03	2.127E+03
2.8	2.127E+03	1.355E+04	2.127E+03	1.355E+04
3.7	1.355E+04	9.38E-03	2.127E+03	8 45E-09
4.9	1.355E+04	6.79E-03	1.355E+04	5.59E-03
6.55	1.355E+04	3.908E+03	1E-09	3.908E+03
8.75	9.38E-03	2.127E+03	9.38E-03	2.127E+03
11.5	7.13E-03	2.127E+03	8 45E-10	2.127E+03
15.5	5.59E-03	1.355E+04	1.355E+04	1.35E+04

Continuation of Table A.12

Distance from RNPP, km	Risk adjusted for countermeasures, 1/год	Risk not adjusted for countermeasures, 1/год	Risk adjusted for countermeasures, 1/год	Risk not adjusted for countermeasures, 1/год
	100% meltback		10% meltback	
21	4.753E+03	9.38E-03	1.355E+04	1.355E+04
28	3.908E+03	6.79E-03	8 1E-10	9.38E-03
37	2.127E+03	4.753E+03	6.79E-03	6.79E-03
49	2.12E+03	2.127E+03	4.753E+03	5.59E-03
65.5	1.355E+04	1.355E+04	3.908E+03	3.908E+03
87.5	1.355E+04	1.355E+04	2.127E+03	2.127E+03
115	7.13E-03	9.38E-03	1.355E+04	1.355E+04
155	5.59E-03	5.59E-03	1.355E+04	1.355E+04
210	3.908E+03	3.908E+03	7.13E-03	7.13E-03

Findings

1 For BDBA at 10% and 100% core melt, the risk of deterministic effects is zero.

2 The maximum (along the axis of the radioactive cloud) full risk of fatal medical consequences and the risk of fatal medical consequences from the exposure of 11 organs at 10% core melt for two response strategies (with and without the introduction of countermeasures) has been estimated as a function of distance from RNPP.

3 The average (space-averaged) total risk (from whole-body exposure) of fatal medical consequences and the risk of fatal medical consequences from the exposure of 11 organs at 10% core melt for two response strategies (with and without the introduction of countermeasures) has been estimated as a function of distance from RNPP.

4 The total number of fatal and non-fatal cases of diseases was estimated with 10% core melt.

5 The sensitivity of the value of the risk of stochastic consequences at 10% core melt and the scale of the emission is 10 and 100 times the reference value.

6 The risk of stochastic consequences at 100% core melt has been estimated. A comparison of the total maximum risk of stochastic consequences for scenarios at 10% and 100% core melt with and without the introduction of countermeasures is given.

7 It is shown that the introduction of countermeasures under BDBA can significantly reduce the stochastic risk (sometimes, by an order of magnitude). The introduction of countermeasures at an early stage is effective at relatively short distances from the plant; introduction of countermeasures at a later stage of an accident is effective over long distances.

8 The risk for the population from the commissioning of power unit No. 4 of SS Rivne NPP ("situation risk"), 1/year, taking into account the probability of an accident, at 10% and 100% core melt, with and without the introduction of countermeasures, was estimated.

It is shown that the scenario at 10% core melt can be more conservative than at 100% core melt, since even at equal melting probabilities for both scenarios, the risk of stochastic consequences and the situation risk, 1/year, at 10% core melt can be larger than the risk at 100% core melt.

This statement is all the more true given that the probability of an accident at 100% core melt is 5×10^{-7}, 1/year.

9 It is shown that the risk level for the population under all scenarios of core melt outside the SPZ is lower by almost three orders of magnitude (even without the introduction of countermeasures) of the current socially acceptable risk of 1×10^{-5}-5×10^{-5}, 1/year.

Thus, the radiation safety of the population during BDBA at SS Rivne NPP by risk criteria is provided with a large margin under the most conservative assumptions.

This section is a logical conclusion of the EIA sections:

- “Analysis of the sources of radionuclides in agroecosystems in case of beyond design basis accidents”;
- “Forecast of the content of biologically significant radionuclides in the components of agroecosystems and agricultural products in case of beyond design basis accidents”;
- “Estimation of dose loads on critical components of agroecosystems and possible effects in case of beyond design basis accidents”.

In these sections, we obtained estimates of the levels of contamination of the environment (atmosphere, surface of the earth, environmental, and food links), as well as a set of dose assessments.

All these results contained in this section are evaluated according to the criteria of regulatory documents (both domestic and foreign) from the point of view of the analysis of the radiation safety of the population and the need to introduce countermeasures in case of BDBA.

The key characteristic in the assessment of the consequences of a radiation accident is the economic indicators, which significantly depend on the introduced countermeasures. These issues are highlighted in the EIA Section 8.4 “Assessment of the Necessary Costs of Compensation of Damage to the Population and the Environment in Case of an Accident.” Results of the analysis conducted there (in particular, the evaluation of emergency countermeasures) are consistent with and complement the results of this section.

A safety assessment of the risk criteria is carried out in Annex A.

Radiation safety assessment is carried out on the basis of three groups of indicators (each of which consists of a set of characteristics):

- levels of contamination of the air and the surface of the earth;
- dose characteristics of the initial period and the late stage of the accident;
- the dynamics of food contamination (peaks in milk).

Radiation safety assessment based on contamination levels and dose characteristics is carried out by comparison with regulatory indicators of Ukraine [3], Russia [9], Great Britain [10], European Community [11].

The general method for assessing the consequences of a radiation accident is to compare the predicted characteristics with the standards. The system of these standards is presented in a separate subsection; this system is different for Ukraine, Russia, and the EU countries (in particular, the UK) to a certain extent.

Some indicators, for example, in the EU countries (the UK), “Derived Emergency Control Levels” are not regulatory for domestic practice. However, in this paper, they are used as additional indicators, which allows increasing the validity of conclusions on the radiation safety of the population. This also makes it possible to carry out an analysis of radiation safety in case of BDBA at SS Rivne NPP for Ukraine and for countries adjacent to Ukraine (which is necessary under Ukraine’s international obligations, see the EIA Section “Assessing the Effects of Transboundary Transfer under Normal and Emergency Conditions”) in single terms adopted as regulatory in EU countries.

In the above-mentioned sections of the EIA, an assessment of consequences (levels of contamination of the environment and food products and dose assessments) was carried out according to a wider range of indicators than those for which criteria were developed and which are currently necessary for the radiation safety analysis.

Therefore, only part of results presented in the mentioned sections are used here. In particular, data on the contamination of the atmosphere and the surface of the earth by J-131, Cs-137, Sr-90 radionuclides, estimates of doses for the whole body and for three critical organs (the thyroid gland, lungs, and the skin) and data on the dynamics of contamination of milk with J -131, Cs-137, Sr-90 radionuclides were used.

In some criteria of Russia and the EU, dose values are used at other intervals of formation than those provided for in the regulatory materials of Ukraine and in the EIA Section 5.6. For these cases, the corresponding dose values are additionally calculated.

The safety analysis is carried out for two response strategies: with and without the introduction of countermeasures.

The analysis methodology is adopted as follows [22]:

- a "summary of standards" (safety criteria) under documents NRBU-97 [3] (Ukraine), NRB-99 [9] (Russia), NRRV [10] (United Kingdom), EU countries [11] was given;
- for all of these criteria, the levels of environmental contamination, the doses and the dynamics of contamination of milk during BDBA at RNPP were analyzed;
- a summary of the results was given.

B.1 Sample of standard values (Ukraine, Russia, the UK, the EU) used to assess the effects of BDBA at RNPP

Table B.1 - Lower bounds of justification and levels of unconditional justification for urgent countermeasures (NRBU-97, Table D.7.1)

	Dose 2 weeks after the accident					
	Borders of justification			Levels of unconditional justification		
	mSv	mGy		mSv	mGy	
Countermeasures	for whole body	for thyroid, gland	for skin	for whole body	for thyroid, gland	for skin
Shelter	5	50	100	50	300	500
Evacuation	50	300	500	500	1000	3000
Iodine prophylactic treatment, Children Adults		50 200			200 500	

Table B.2 - Lower limits of justification, levels of unconditional justification, and levels for making decisions on permanent resettlement (NRBU-97, Table E.8.1)

Criteria	Lower borders	Absolutely justified levels
Dose prevented during the resettlement period, Sv	0.2	1
Dose prevented in the first 12 months after the accident, Sv	0.05	0.5
Density of radioactive contamination of the territory by long-lived radionuclides, kBq/m^2 Cs-137 Sr-90 Alpha exposure sources	400 80 0.5	4000 400 4

Table B.3 - Lower limits of justification and levels of unconditional justification for temporary resettlement (NRBU-97, from Table E.8.2)

Criteria	Lower borders	Absolutely justified levels
Total prevented dose, Sv	0.1	1
Average monthly dose, mSv/month		

	5	30

Table B.4 - Lower limits of justification and levels of unconditional justification for making decisions on food restrictions (NRBU-97, from Table E.8.3)

Criteria	Lower limits of justification	Absolutely justified levels
Prevented dose, Sv	5	30
For the first post-accident year	1	30
For the second and subsequent years	1	5
Contamination of milk, kBq/l J-131 adults children	 0.4 0.1	 1 0.2
Cs-134, 137	0.1	0.4
Sr-90 adults children	 0.02 0.005	 0.2 0.05

Note. In most of the above tables, the dose is used as a standard characteristic. However, one of the fundamental values (namely, the effective dose limit for the population of 1 mSv/year) is not considered as a criterion here, since it is provided for by NRBU-97 for non-emergency conditions. (NRB-99 specifically emphasizes for Russia that the effective dose limit for accident conditions is not applicable).

Table B.5 - Projected exposure levels at which urgent intervention is needed (NRB-99 from Table 6.1)

Body	Absorbed dose for 2 days, Gy
Whole body	1
Lungs	6
Skin	3
Thyroid gland	5
Crystalline lens	2
Genital glands	3

Table B.6 - Criteria for making urgent decisions in the initial period of a radiation accident (NRB-99, from Table 6.3)

Protection measures	Projected doses for the first 10 days, mGy			
	For whole body		Thyroid gland, lungs, skin	
	Level A	Level B	Level A	Level B
Shelter	5	50	50	500
Iodine prophylactic treatment: • adults			250	2500
• children			100	1000
Evacuation	50	500	500	5000

* For the thyroid gland only

Table B.7 - **Criteria for making decisions on resettlement and limitation of consumption of contaminated food (NRB-99, from Table 6.4)**

Protection measures	**Preventable effective dose, mSv**	
	Level A	**Level B**
Limiting consumption of contaminated food and drinking water	5 for the first year 1/year in subsequent years	50 for the first year 10/year in subsequent years
Resettlement	50 for the first year	500 for the first year
	1,000 for all the period of resettlement	

Table B.8 - Criteria for making decisions on limitation of consumption of contaminated products in the first year of an accident (NRB-99, from Table 6.5)

Radionuclides	**Radionuclide content in food products, kBq/kg**	
	Level A	**Level B**
J-131, Cs-134, Cs-137 Sr-90	1 0.1	10 1.0

NRPB (Великобритания) [10], Европейское Сообщество [11]

Table B.9 - Criteria and levels of intervention for food (NRPB, CEA)

Radionuclide	**Intervention level**	
	Milk, Bq/l	**Other products**
Strontium	125	750
Iodine	500	2000
Alpha emitters	20	80
Cesium	1000	1250

"Derivative Emergency Control Levels" (DECL) (NRRV-R182, Charter 4) [10] for J-131, Cs-137, Sr-90 are given in Tables B.10-B.12.

Notes:

1. NRPB materials contain no DECL for meat, underground harvest, and eggs. These values were specially designed by the authors and added to the NRPB tables below.

2. DECL are secondary values, i.e., criteria constructed under conservative assumptions. That is, these criteria are guaranteed not to exceed doses; at the same time, exceedance of criteria does not mean exceedance of doses; in cases where the DECL value is slightly exceeded, a more detailed analysis is required.

Table B.10 - DECL for J-131

Cloud radiation exposure Inhaled dose (class D): the most irradiated organ (the thyroid gland, a 10-year-old child)	1.3E-10 Sv/Bq*sec*m(-3)
effective dose (a child of 10 years old)	3.9E-12 Sv/Bq*s*m(-3)
12-hour dose for skin	1.2E-11 Sv/Bk*s*m(-3)
DECL of temporary air concentration integrals:	

evacuation: • upper 1.2E+10 Bq*sec*m(-3) shelter and iodine: • upper 1.9E+9 Bq*sec*m(-3) prophylactic treatment	lower 2.3E+9 Bq*sec*m(-3) lower 3.9E+8 Bq*sec*m(-3)
(basis: thyroid dose for a 10-year-old child)	

External radiation dose from contaminated soil 7.7E+5 Bq*m(-2)/μGy*h(-1) at a height of 1 m.

Initial dose rate for the whole body is 1.3E-12 Sv*h(-1)/Bq*m(-2).

Dose for the whole body for the period, Sv/Bq*m(-2):

1 hour	2 hours	5 hours	10 hours	1 day	7 days	14 days
1.355E+04	2.127E+03	6.79E-03	1.355E+03	3.908E+03	1.355E+04	27E+03

DECL for evacuation: upper 2.0E+9 Bq/m^2; lower 4.0E+8 Bq/m^2.

Food chain

Basis: 3.7E-6 Sv/Bq (for the thyroid of a 1-year-old child) (1.1E-7 Sv/Bq - effective dose for a 1-year-old child)

Ration	Dose	DECL		Value
		Upper, B	Lower, A	
Dairy	3.7E-6 Sv/Bq*m(-2)	1.0E+5 Bq/m^2	1.0E+4 Bq/m^2	Initial dropout
	2.6E-5 Sv/Bq*l(-1)	1.0E+4 Bq/l	1.0E+3 Bq/l	Concentration peak
Meat	1.2E-7 Sv/Bq*m(-2)	4.86E+6 Bq/m^2	4.86E+5 Bq/m^2	Initial dropout
	3.9E-6 Sv/Bq*kg(-1)	1.0E+5 Bq/kg	1.0E+4 Bq/kg	Concentration peak
Eggs	7.1E-8 Sv/Bq*m(-2)	7.11E+6 Bq/m^2	7.11E+5 Bq/m^2	Initial dropout
	6.1E-7 Sv/Bq*m(-2)	8.21E+5 Bq/kg	8.21E+4 Bq/kg	Concentration peak
Drinking water	-	2.18E+4 Bq/l	2.18E+3 Bq/l	Initial concentration
Vegetables	1.4E-7 Sv/Bq*m(-2)	3.5E+6 Bq/m^2	3.5E+5 Bq/m^2	Initial dropout
Underground harvest	2.3E-11 Sv/Bq*m(-2)	2.18E+10 Bq/m^2	2.0E+9 Bq/m^2	Initial dropout
	2.5E-6 Sv/Bq*m(-2)	2.18E+5 Bq/m^2	2.18E+4 Bq/m^2	Concentration peak
Fruit	3.1E-7 Sv/Bq*kg(-1)	1.0E+6 Bq/kg	1.0E+5 Bq/kg	Fresh weight

Table B.11 - DECL for Cs-137 (Cesium-137)

Cloud radiation exposure Inhaled dose (class D):	
effective dose (a child of 10 years old)	3.0E-12 Sv/Bq*sec*m(-3)
12-hour dose for skin	1.8E-11 Sv/Bq*sec*m(-3)
DECL of temporary air concentration integrals: evacuation: • upper: 1.7E+11 Bq*sec*m(-3); shelter: • upper: 8.5E+9 Bq*sec*m(-3);	lower: 3.4E+10 Bq*sec*m(-3) lower: 1.7E+9 Bq*sec*m(-3)

(basis: effective dose (a child of 10 years old)	

External radiation dose from contaminated soil 6.2E+5 Bq×m(-2)/μGy*h(-1) at a height of 1 m.

Initial dose rate for the whole body is 1.6E-12 Sv×h(-1)/Bq*m(-2).

Dose for the whole body for the period, Sv/Bq×m(-2):

1 hour	2 hours	5 hours	10 hours	1 day	7 days	14 days
1.355E+04	3.908E+03	8.3E-12	1.355E+04	4.753E+03	2.127E+03	5.59E-03

DECL for evacuation: upper: 8.9E+8 Bq×m(-2); lower: 1.8E+8 Bq×m(-2).

Food chain

Basis: 6.9E-8 Sv/Bq is the effective dose for a 1-year-old child

Ration	Dose	DECL		Value
		Upper, B	Lower, A	
Dairy	1.4E-7 Sv/Bq×m(-2)	3.5E+5 Bq/m^2	3.5E+4 Bq/m^2	Initial dropout
	1.4E-6 Sv/Bq×l(-1)	3.5E+4 Bq/l	3.5E+3 Bq/l	Concentration peak
Meat	4.9E-8 Sv/Bq×m(-2)	1.0E+6 Bq/m^2	1.0E+5 Bq/m^2	Initial dropout
	1.6E-7 Sv/Bq×kg(-1)	3.5E+5 Bq/kg	3.5E+4 Bq/kg	Concentration peak
Eggs	1.5E-8 Sv/Bq×m(-2)	3.5E+7 Bq/m^2	3.5E+6 Bq/m^2	Initial dropout
	5.6E-8 Sv/Bq×m(-2)	8.21E+5 Bq/kg	8.21E+4 Bq/kg	Concentration peak
Drinking water	-	7.11E+4 Bq/l	7.11E+3 Bq/l	Initial concentration
Vegetables	8.7E-9 Sv/Bq×m(-2)	6.59E+6 Bq/m^2	6.59E+5 Bq/m^2	Initial dropout
Underground harvest	2.3E-11 Sv/Bq×m(-2)	2.0E+9 Bq/m^2	2.18E+8 Bq/m^2	Initial dropout
	3.6E-7 Sv/Bq×m(-2)	1.0E+5 Bq/m^2	1.0E+4 Bq/m^2	Concentration peak
Fruit	1.8E-8 Sv/Bq×kg(-1)	2.18E+6 Bq/kg	2.18E+5 Bq/kg	Fresh weight

Table B.12 - DECL for Sr-90 (Strontium-90)

Cloud radiation exposure Inhaled dose (class D):	
most irradiated organ (bone surface, adult)	1.8E-10 Sv/Bq×sec×m(-3)
effective dose (adult)	1.5E-11 Sv/Bq×sec×m(-3)
12-hour dose for skin	1.4E-11 Sv/Bq×sec×m(-3)
DECL of temporary air concentration integrals: evacuation: • upper: 8.3E+9 Bq×sec×m(-3); shelter: • upper: 1.4E+9 Bq×sec×m(-3);	lower: 1.7E+9 Bq×sec×m(-3) lower: 2.8E+8 Bq×sec×m(-3)
(basis: dose to the surface of adult bones)	

Food chain

Basis: 1.3E-6 Sv/Bq: on the surface of the bone of a 1-year-old child (1.2E-7 Sv/Bq: the effective dose of a 1-year-old child)

Ration	Dose	DECL		Value
		Upper, B	Lower, A	
Dairy	4.8E-7 Sv/Bq×m(-2)	1.0E+6 Bq/m^2	1.0E+5 Bq/m^2	Initial dropout
	4.0E-5 Sv/Bq×l(-1)	1.0E+4 Bq/l	1.0E+3 Bq/l	Concentration peak
Meat	4.5E-10 Sv/Bq×m(-2)	1.0E+9 Bq/m^2	1.0E+8 Bq/m^2	Initial dropout
	3.8E-8 Sv/Bq×kg(-1)	1.0E+7 Bq/kg	1.0E+6 Bq/kg	Concentration peak
Eggs	7.1E-9 Sv/Bq×m(-2)	7.11E+7 Bq/m^2	7.11E+6 Bq/m^2	Initial dropout
	1.0E-6 Sv/Bq×m(-2)	5.14E+5 Bq/kg	5.14E+4 Bq/kg	Concentration peak
Drinking water	-	4.86E+4 Bq/l	4.86E+3 Bq/l	Initial concentration
Vegetables	1.4E-7 Sv/Bq×m(-2)	3.5E+6 Bq/m^2	3.5E+5 Bq/m^2	Initial dropout
Underground harvest	2.8E-8 Sv/Bq×m(-2)	1.0E+7 Bq/m^2	1.0E+6 Bq/m^2	Initial dropout
	6.9E-6 Sv/Bq×m(-2)	7.11E+4 Bq/m^2	7.11E+3 Bq/m^2	Concentration peak
Fruit	3.1E-7 Sv/Bq×kg(-1)	1.0E+6 Bq/kg	1.0E+5 Bq/kg	Fresh weight

B.2 Safety analysis in case of beyond design basis accident at RAES

This chapter analyzes compliance with the above standard values:

- atmospheric contamination levels;
- fallout density;
- values of doses in the initial accident period and over life;
- dynamics of contamination (peak concentration) of milk.

Comparing them with standard values makes it possible to:

- assess the radiation safety of BDBA at RNPP;
- evaluate the need for countermeasures.

B.2.1 Atmospheric contamination with J-131

Table B.13 provides the maximum integral concentration (along the axis of the radioactive cloud), Bq sec/m^3, of the accidental release of J-131 as a function of distance, km, from RNPP. Reference NRPB values, which as criteria are absent in domestic documents, that regulate evacuation or shelter and iodine prophylactic treatment during irradiation from a passing radioactive cloud are listed, and areas where evacuation, shelter, and iodine prophylactic treatment are necessary are shown.

According to the performed analysis: the maximum concentration of J-131 in the atmosphere in the immediate vicinity of the RNPP at a distance of less than 0.5 km is 6.84E+09 Bq sec/m^3, which is less than the upper reference level of NRPB for evacuation 1.2E+10 Bq sec/m^3.

This means that in case of BDBA, there is no need to evacuate either in the sanitary protection zone or, much less, outside of it.

The maximum concentration of J-131 in the atmosphere at a distance of 1.15 km is equal to 2.27 E+09 Bq sec/m^3, which is less than the lower reference level of NRPB for evacuation of 2.3 E+09 Bq sec/m^3.

Consequently, in case of BDBA outside the SPZ, there is no need to evacuate even when assessing the situation using conservative values of the control alarm values (lower levels).

Note. In the SPZ, the criteria intended to manage the radiation safety of the public do not apply. Countermeasures in the SPZ are introduced according to the regulations ensuring the safety of personnel. In particular, countermeasures can be introduced preventively.

The upper emergency reference level for shelter and iodine prophylactic treatment is equal to 1.9E+09 Bq sec/m^3, which necessitates these countermeasures only up to 1.5 km from RNPP, where the concentration is 1.48 E+09 Bq sec/m^3.

The lower reference level for shelter and iodine prophylactic treatment 3.9E+08 Bq sec/m^3 determines the possible need for the introduction of these countermeasures at a distance of 3.7 km from RNPP, where the concentration of J-131 in the atmosphere is 3.94 E+08 Bq sec/m^3.

All of the above is reflected in Table B.13 by darkened columns and italicized numbers, which indicate the distances where countermeasures are appropriate for the upper and lower levels of control emergency levels (a more accurate analysis based on dose estimates indicates that there is no need for shelter and iodine prophylactic treatment beyond the SPZ: see Table B.20).

Thus, the atmospheric contamination with the J-131 radionuclide in case of BDBA poses no radiation hazard to the population.

Table B.13 - Maximum (along the axis of the radioactive cloud) integral concentration (Bq sec/m^3) of the accidental release of J-131 as a function of distance (km) from SS Rivne NPP, and NRPB criteria governing exposure from the cloud and the area for the introduction of countermeasures

Distance from RNPP, km	Atmospheric concentration, Bq sec/m^3	NRPB evacuation, Table A.10		NRPB shelter, iodine prophylactic treatment, Table A.10	
		top level 1.0E+10	bottom level 2.18E+09	top level 1.4E+09	bottom level 8.9E3
0.5	6.59E+09				
1.15	2.18E+09				
1.55	1.4E+09				
2.1	9.76E+08	SPZ border			
2.8	6.59E+08				
3.7	3.13E+08				
4.9	2.8E+08				
6.55	1.8E+08				
8.75	1.8E+08	Overshadowing refers to distance from RNPP,			
11.5	9.01E+07	where countermeasures are expedient.			
15.5	2.49E+07				
21	5.80E+07				
28	4.86E+07				
37	3.79E+07				

Cs-137

Table B.14 provides the maximum integral concentration (along the axis of the radioactive cloud), Bq sec/m^3, of the accidental release of Cs-137 as a function of distance, km, from RNPP.

Reference NRPB values that regulate evacuation or shelter and iodine prophylactic treatment during irradiation from a passing radioactive cloud are listed (from table B.11), and areas where evacuation, shelter, and iodine prophylactic treatment are necessary are shown.

The maximum integral concentration of Cs-137 in the atmosphere at a distance of 0.5 km from the RNPP is 4.02E+08 Bq sec/m^3, which is less than the upper reference level of NRPB for evacuation 1.7E+11 Bq sec/m^3, the lower reference level of NRPB for evacuation 3.4E+10 Bq sec/m^3, the upper emergency reference level for shelter 8.5E+09 Bq sec/m^3, and the lower reference level for shelter 1.7E+09 Bq sec/m^3.

All of the above is reflected in Table B.14 by darkened columns, which show that there is no need for countermeasures even at a distance of 0.5 km from RNPP, i.e., neither in nor beyond the SPZ.

Thus, atmospheric contamination with the Cs-137 radionuclide in case of BDBA poses no radiation hazard.

Table B.14 - Maximum (along the axis of the radioactive cloud) integral concentration (Bq sec/m^3) of the accidental release of Cs-137 as a function of distance (km) from SS Rivne NPP, and NRPB criteria governing exposure from the cloud and the area for the introduction of countermeasures

Distance from RNPP, km	**Atmospheric concentration, Bq sec/m^3**	**NRPB evacuation, Table A.11**		**Shelter under NRPB, Table A.11**	
		top level 1.0E+11	**bottom level 3.69E+10**	**top level 8.21E+09**	**bottom level 1.4E+09**
0.5	4.02E+08				
1.15	1.37E+08				
1.55	9.01E+07				
2.1	5.80E+07	SPZ border.			
2.8	3.79E+07				
3.7	2.49E+07	Overshadowing refers to distance from RNPP,			
4.9	1.63E+07	where countermeasures are expedient.			
6.55	1.63E+07				
8.75	8.35E+06	In this case, no countermeasures are required.			
11.5	6.62E+06				

Sr-90

The maximum integral concentration of Sr-90 in the atmosphere at a distance of 0.5 km from the RNPP is 2.9E+06 Bq sec/m^3, which is less than the upper reference level of NRPB for evacuation 8.3E+9 Bq sec/m^3, the lower reference level of NRPB for evacuation 1.7E+9 Bq sec/m^3, the upper emergency reference level for shelter 1.4E+09 Bq sec/m^3, and the lower reference level for shelter 2.8E+08 Bq sec/m^3,

All of the above is reflected in Table B.15 by darkened columns, which show that there is no need for countermeasures even at a distance of 0.5 km from RNPP, i.e., neither in nor beyond the SPZ.

Conclusion. Atmospheric contamination with Sr-90 radionuclide in case of BDBA poses no radiation hazard.

Table B.15 - Maximum (along the axis of the radioactive cloud) integral concentration (Bq sec/m^3) of the accidental release of Sr-90 as a function of distance (km) from SS Rivne NPP, and NRPB criteria governing exposure from the cloud and the area for the introduction of countermeasures

Distance from RNPP, km	Atmospheric concentration, Bq sec/m^3	NRPB evacuation, Table A.14		Shelter under NRPB, Table A.14	
		top level 8.3E+9	bottom level 1.0E+9	top level 1.4E+09	bottom level 2.8E+08
0.5	2.90E+06				
1.15	9.90E+05				
1.55	6.50E+05				
2.1	4.18E+05	SPZ border.			
2.8	2.73E+05				
3.7	1.80E+05	Overshadowing refers to distance from RNPP,			
4.9	1.18E+05	where countermeasures are expedient.			
6.55	7.66E+04				
8.75	6.02E+04	In this case, no countermeasures are required.			
11.5	4.77E+04				
15.5	3.69E+04				
21	2.83E+04				
28	2.18E+04				
37	1.66E+04				

B.2.2 Fallout on the surface of the earth

1) This considers the density of 3 radionuclides falling to the surface of the earth as well as for the atmosphere: J-131, Cs-137, Sr-90.

2) Domestic documents (NRBU-97) contain no standard values that regulate the fallout of J-131 in case of accidents.

3) NRBU-97 contains criteria using the fallout density of Cs-137 and Sr-90 radionuclides concerning permanent resettlement (Table B.3); these values are used when analyzing the consequences of the accident.

4) NRPB documents contain control emergency levels governing external exposure; these criteria are used for safety analysis.

5) NRPB documents contain reference levels of initial accidental surface contamination designed according to limits on doses from food consumption (Tables B.10-B.12).

Here, reference levels of initial contamination of the surface are used, which determine the contamination of milk.

Notes:

1 As can be seen from Tables B.10-B.12, reference levels of initial accidental contamination, which determine contamination of food products, are also developed for meat, vegetables, and underground harvest. However, as the analysis showed, the most conservative values correspond to milk. Therefore, only reference levels for milk are used below.

2 Reference levels for initial accidental contamination of the surface are constructed using models linking the initial fallout to the doses generated on the contaminated surface during a year.

J-131

Table A.16 gives the maximum fallout density, Bq/m^2, accidental release of J-131 as a function of distance, km, from RNPP along the axis of the radioactive cloud. It also contains the NRPB criteria (Table B.10) governing evacuation and limitation on milk consumption when exposed from the trail of a passing radioactive cloud. It also shows the areas where these countermeasures are necessary.

Result

1) The maximum density of J-131 fallout on the earth's surface at a distance of 0.5 km from RNPP is 2.13E+07 Bq/m^2, which is less than the upper reference level of NRPB for evacuation at 2.0E+9 Bq/m^2 and the lower reference level of NRPB for evacuation at 4E+08 Bq sec/m^3.

It follows then that in case of accidental contamination of the surface of the earth by the J-131 radionuclide, there is no need for evacuation.

2) Upper and lower emergency reference levels of NRPB for initial surface contamination in terms of milk contamination are, respectively (Table A.3):

- 1.3E+04 Bq/m^2 and;
- 1.7E+04 Bq/m^2.

Table B.16 demonstrates that at a distance of 15.5 km and 65.5 km from RNPP, respectively, the density of fallout is as follows: 1.28 E+05 Bq/m^2 and 1.12 E+04 Bq/m^2.

This means that in case of BDBA at SS Rivne NPP, a temporary limitation on the consumption of milk at a distance of 15 to 65 km from RNPP may be required (below, Table B.28 will also establish the need for countermeasures according to the criteria governing the J-131 concentration in milk; the need for countermeasures is confirmed by the results of Section 8.4).

Countermeasures for evacuating and limiting milk intake are reflected in Table B.16 by darkened columns and bold italic numbers. (In reference accidental levels of surface contamination, conservative estimates for milk contamination are used. Therefore, in fact, milk consumption limitations can be significantly lower).

Conclusion. Contamination of the earth's surface with the J-131 radionuclide outside the SPZ may require limitation of milk consumption.

Table B.16 - Maximum fallout density (Bq/m^2) of an accidental release of J-131 as a function of distance (km) from RNPP (along the axis of the radioactive cloud) and NRPB criteria governing external and internal exposure from consumption of contaminated milk and areas for the introduction of countermeasures

Distance from RNPP, km	Falllout, Bq*m(-2)	NRPB evacuation, Table B.10		NRPB milk limitation, Table B.10	
		top level 2.0E+9	bottom level 4.0E+08	top level 1.3E+05	bottom level 1.3E+04
0.5	2.13E+07				
1.15	6.59E+06				
1.55	4.13E+06				
2.1	2.53E+06	SPZ border			
2.8	1.57E+06				
3.7	9.76E+05				
4.9	6.02E+05				

6.55	3.66E+05
8.75	2.65E+05
11.5	1.91E+05
15.5	1.28E+05
21	8.21E+04
28	5.14E+04
37	3.13E+04
49	1.86E+04
65.5	1.12E+04
87.5	7.11E+03
115	4.86E+03

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

Cs-137

1) Table B.17 gives the maximum fallout density, Bq/m^2, accidental release of Cs-137 as a function of distance, km, from RNPP along the axis of the radioactive cloud.

2) It also contains the NRPB criteria (Table B.11) governing evacuation and limitation on milk consumption when exposed from the trail of a passing radioactive cloud.

3) Table B.17 also shows the regulatory indicators of NRBU-97 (Table B.3) governing decision-making for permanent resettlement. Although these values are not criteria for operational countermeasures, they must nevertheless be taken into account in case of a radiation accident; therefore, they are included in Table B.17 as indicators for impact assessment.

Result

1) The maximum fallout density of Cs-137 on the surface of the earth in close proximity to RNPP, at a distance of 0.5 km, is 4.02E+05 Bq/m^2, which is less than the upper reference level of NRPB for evacuation (Table B.11) at 8.9E+8 Bq/m^2 and the lower reference level of NRPB for evacuation (Table B.11) at 1.8E+08 Bq/m^2. It follows then that in case of accidental contamination of the surface of the earth by the Cs-137 radionuclide, there is no need for evacuation.

2) Upper and lower emergency reference levels NRPB for surface contamination in terms of milk contamination are, respectively (Table B.11) 3.5E+05 Bq/m^2 and 3.5E+04 Bq/m^2. Table B.17 demonstrates that at a distance of 1.15 km and 3.7 km from RNPP, respectively, the density of fallout is as follows: 1.37E+05 Bq/m^2 and 2.49E+04 Bq/m^2. This means that in case of BDBA at SS Rivne NPP, limitation of milk consumption is possible at a distance of 1.5-3.7 km from SS Rivne NPP (this result is specified below in Table B.29 according to the criteria for peaks of Cs-137 concentration in milk).

3) Absolutely justified levels and lower levels of justification as per NRBU-97 (Table B.3) are as follows: 4E+06 Bq/m^2 and 4E+05 Bq/m^2.

Table B.17 demonstrates that, at a distance of 0.5 km, the fallout density is 4.02 E+05 Bq/m^2. This means that the fallout density, at which resettlement is definitely necessary in case of BDBA, is not achieved, and the fallout density for the lower limit of justification is possible only in the immediate vicinity of the plant (at a distance of 0.5 km).

The listed countermeasures are reflected in Table B.17 by darkened columns and bold italic numbers. (Reference emergency levels of surface contamination use conservative estimates for milk contamination. Therefore, in fact, milk consumption limitations can be significantly lower).

Conclusion. Contamination of the earth's surface with the Cs-137 radionuclide outside the SPZ may require limitation of milk consumption.

Table B.17 - Maximum fallout density (Bq/m2) of accidental release of Cs-137 as a function of distance (km) from RNPP (along the axis of the radioactive cloud); NRBU-97 criteria governing permanent resettlement; NRPB criteria governing external and internal exposure from consumption of contaminated milk; and areas for the introduction of countermeasures

Distance from RNPP, km	Fallout, Bq*m(-2)	NRPB evacuation, Table B.11		Milk limitation under NRPB, Table B.11		Borders of justification as per NRBU-97, Table B.3	
		top level 8.9E+8	bottom level 1.8E+08	top level 3.5E+5	bottom level 3.5E+04	unconditional levels 4E+06	lower borders 4E+05
0.5	4.02E+05						
1.15	1.37E+05						
1.55	9.01E+04						
2.1	5.80E+04	SPZ border					
2.8	3.79E+04						
3.7	2.49E+04						
6.55	1.66E+04						
8.75	8.35E+03						

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

Sr-90

1) Table B.18 gives the maximum fallout density, Bq/m^2, accidental release of Sr-90 as a function of distance, km, from RNPP along the axis of the radioactive cloud.

2) It also contains NRPB standard values (criteria) (Table B.12) governing limitation on milk consumption when exposed from the trail of a passing radioactive cloud. (The Sr-90 radionuclide does not create external exposure; therefore, the issue of possible evacuation due to external exposure caused by surface contamination does not arise).

3) Table B.18 shows the reference indicators of NRBU-97 (Table B.3) governing decision-making for permanent resettlement. Although these values are not criteria for operational countermeasures, they must nevertheless be taken into account in the event of a radiation accident; therefore, they are included in Table B.18 as indicators for impact assessment.

Result

1) The maximum density of Sr-90 fallout on the earth's surface at a distance of 0.5 km from RNPP is 2.9E+03 Bq/m^2, which is less than the upper and lower reference levels of NRPB for limitation of milk consumption (Table B.12) at, accordingly, 1.0E+06 Bq/m^2 and 1.0E+05 Bq/m^2. This means that in case of BDBA at SS Rivne NPP, there is no need to limit milk consumption. The same result is confirmed by the criteria for peaks of the concentration of Sr-90 in milk (Table B.30).

2) Absolutely justified levels and lower levels of justification as per NRBU-97 for resettlement (Table B.3) are as follows: 4E+06 Bq/m^2 and 4E+05 Bq/m^2. This means that the fallout density of Sr-90 in case of a BDBA is significantly less than the density at which the issue of resettlement may arise.

Conclusion. Sr-90 radionuclide contamination of the surface of the earth in case of BDBA poses no radiation hazard.

Table B.18 - Maximum fallout density (Bq/m2) of accidental release of Sr-90 as a function of distance (km) from RNPP (along the axis of the radioactive cloud); NRBU-97 criteria governing permanent resettlement; NRPB criteria governing internal exposure from consumption of contaminated milk; and areas for the introduction of countermeasures

Distance from RNPP, km	Fallout, Bq*m(-2)	Milk limitation under NRPB, Table B.12		Borders of justification under NRBU-97, Table B.3	
		top level 1.0E+06	bottom level 1.0E+05	unconditional levels 8E+04	lower borders 4E+05
0.5	2.90E+03				
1.15	9.90E+02				
1.55	6.50E+02	SPZ border.			
2.1	4.18E+02				
2.8	2.73E+02	Overshadowing refers to distance from RNPP,			
3.7	1.80E+02	where countermeasures are expedient.			
4.9	1.18E+02				
6.55	7.66E+01	In this case, no countermeasures are required.			
8.75	6.02E+01				

B.2.3 Dose criteria

Radiation safety and the need to introduce countermeasures are analyzed according to all dose criteria used for: Ukraine (NRBU-97), in Russia (RSS-99), in the EU countries.

NRBU-97. Effective dose for 14 days

1) BDBA radiation consequences are evaluated here by analyzing the need for countermeasures determined by NRBU-97 criteria. Two doses are considered: with and without the introduction of preventive countermeasures.

2) According to NRBU-97, levels of unconditional justification and limits of justification for evacuation are, respectively (Table B.11): 0.5 Sv and 0.05 Sv for the whole body (effective dose).

3) Similarly, for the shelter: 0.05 Sv and 0.005 Sv.

4) However, the maximum effective doses for an accidental release at a distance of 0.5 km from RNPP with and without the introduction of preventive countermeasures are, respectively (Table B.19): 0.002 Sv and 0.009 Sv, which is less than the corresponding NRBU-97 criterion values.

Conclusion. When BDBA is outside the SPZ, criteria for the dose for whole body do not require evacuation and shelter (Table B.19).

No preventively introduced countermeasures (evacuation, shelter, iodine prophylactic treatment) in the SPZ are necessary; only shelter may be expedient at a distance of 0.5 km from RNPP.

Table B.19 - Doses for whole body, NRBU-97 criteria, and countermeasures

Distance from RNPP, km	Dose for the whole body for 14 days, Sv		NRBU-97 Table B.2			
			Evacuation		Shelter	
	prevent. countermeasures	without prevent. countermeasures	Levels of unconditional justification,Sv	Borders justified, Sv	Levels of unconditional justification, Sv	Borders justification, Sv
			0.5	0.05	0.05	0.005
0.5	2.127E+03	9.38E-03				
1.15	6.79E-03	3.908E+03				
1.55	3.908E+03	2.127E+03				
2.1	1.355E+04	1.355E+04				
2.8	6.79E-03	8.35E-04				
3.7	4.753E+03	5.59E-03				
4.9	2.127E+03	3.908E+03				
6.55	2.127E+03	2.127E+03				
8.75	1.355E+04	1.355E+04				
11.5	1.355E+04	1.355E+04				

SPZ border.

Overshadowing refers to distance from RNPP where countermeasures are expedient.

In this case, countermeasures outside the SPZ are not needed.

NRBU-97, dose for the thyroid gland

1) BDBA radiation consequences are evaluated here by analyzing the need for countermeasures determined by NRBU-97 criteria (Table B.1). Two options are considered: with and without the introduction of preventive countermeasures.

2) According to NRBU-97, levels of unconditional justification and limits of justification for evacuation are, respectively (Table B.1): 1.0 Gy and 0.3 Gy for the thyroid gland. Similarly, for the shelter: 0.3 Gy and 0.05 Gy. Similarly, for the iodine prophylactic treatment (children): 0.2 Gy and 0.05 Gy. However, maximum doses for the thyroid gland during an accidental release with and without the introduction of preventive countermeasures are, respectively (Table B.20), at a distance of 0.5 km from RNPP: 0.026 Gy and 0.15 Gy; at a distance of 1.15 km from RNPP: 0.0074 Gy and 0.05 Gy, which is less than (equal to) the corresponding NRBU-97 criterion values.

Conclusion. When BDBA is outside the SPZ, criteria for the dose for the thyroid gland do not require evacuation, shelter, or iodine prophylactic treatment (Table B.20).

No preventively introduced countermeasures (evacuation, shelter, iodine prophylactic treatment) in the SPZ are necessary,

Table B.20 - Doses for the thyroid gland, NRBU-97 criteria, and countermeasures

	Dose for the thyroid gland for 14 days, Sv (Gy)	NRBU-97 Table 9.12.

Distance from RNPP, km			Evacuation		Shelter		Iodine prophylactic treatment	
	prevent. countermeasures	without prevent. countermeasures	Levels of unconditional justification Gy	Borders justification Gy	Levels of unconditional justification Gy	Borders justification Gy	Levels of unconditional justification Gy	Borders justification Gy
			1.0	0.3	0.3	0.05	0.2	0.05
0.5	2.127E+03	1.355E+04						
1.15	9.38E-03	5.59E-03						
1.55	4.753E+03	3.908E+03						
2.1	1.355E+04	2.127E+03						
2.8	1.355E+04	1.355E+04						
3.7	7.13E-03	8.62E-03						
4.9	5.59E-03	5.59E-03						
6.55	3.908E+03	3.908E+03						
8.75	2.127E+03	2.127E+03						
11.5	2.127E+03	2.127E+03						

SPZ border.

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

In this case, no countermeasures are required.

Dose for the skin

1) BDBA radiation consequences are evaluated here by analyzing the need for countermeasures determined by NRBU-97 criteria (Table B.1). Two options are considered: with and without the introduction of preventive countermeasures.

2) According to NRBU-97, levels of unconditional justification and limits of justification for evacuation are, respectively (Table B.1): 3.0 Gy and 0.5 Gy for the skin. Similarly, for the shelter: 0.5 Gy and 0.1 Gy.

However, the maximum doses for the skin during an accidental release at a distance of 0.5 km from RNPP, with and without the introduction of countermeasures, are equal, respectively (Table B.21), to: 0.0597 Gy and 0.45 Gy less than NRBU-97 criterion values that determine the need for evacuation and lie within the boundaries that determine the need for shelter.

Conclusion. When BDBA is outside the SPZ, criteria for the dose for the skin do not require evacuation and shelter (Table B.21).

No preventively introduced countermeasures (evacuation, shelter, iodine prophylactic treatment) in the SPZ are necessary,

Table B.21 - Doses for the skin, NRBU-97 criteria, and countermeasures

Distance from RNPP,	Dose for the skin for 14 days, Sv (Gy)	NRBU-97 Table B.2	
		Evacuation	Shelter

km	prevent. countermeasures	without prevent. countermeasures	Levels of unconditional justification, Gy	Borders justification, Gy	Levels of unconditional justification, Gy	Borders justification, Gy
			3.0	0.5	0.5	0.1
0.5	5.59E-03	4.75E+03				
1.15	1.35E+04	1.35E+04				
1.55	1.35E+04	9.38E-03				
2.1	7.13E-03	6.79E-03				
2.8	4.75E+03	3.90E+03				
3.7	2.12E+03	2.12E+03				
4.9	1.35E+04	1.35E+04				
6.55	1.35E+04	1.35E+04				
8.75	8.19E-03	8.19E-03				
11.5	6.79E-03	6.79E-03				

SPZ border.

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

In this case, no countermeasures are required outside the SPZ.

Criteria for permanent relocation

BDBA radiation consequences are evaluated by analyzing the need for permanent resettlement (Table B.3).

1) NRBU-97 states that the bottom line of justification for permanent resettlement is the 0.2 Sv dose prevented for the resettlement period; the absolutely justified level is the prevented dose of 1 Sv.

2) NRBU-97 also states that the bottom line of justification for permanent resettlement is the dose of 0.05 Sv prevented in the first 12 months after the accident; the absolutely justified level is the dose of 0.5 Sv prevented in the first 12 months.

3) Analysis of BDBA consequences is possible by asking the following question: What is the scale of the BDBA? Is a situation in which permanent resettlement can be a solution possible?

4) Let us suppose that during resettlement, the dose for the first 12 months and the entire emergency dose (for 50 years after the accident) are completely prevented.

Values of the effective dose for the first 12 months (first year) and the effective lifetime dose as a function of the distance are given in Table B.22. (Previously, these doses were not avaluated. For Table B.22, they were calculated additionally).

Table B.22 demonstrates that the doses at a distance of 0.5 km from RNPP for life (50 years after the accident) and for the first year, which are equal, respectively, to 0.04 Sv and 0.0003 Sv, are less than the doses indicated in NRBU-97 as criteria.

Conclusion. In case of BDBA at RNPP, permanent resettlement will not be justified (Table B.22).

Table B.22 - Doses for life and for the first year, and NRBU-97 criteria for permanent resettlement

		Effective dose for the	NRBU-97	
			Dose for life	Dose for the first year

Distance from RNPP, km	Effective dose over life, Sv	first year, Sv	Levels of unconditional justification, Sv	Borders justification, Sv	Levels of unconditional justified, Sv	Borders justification, Sv
			1.0	0.2	0.5	0.05
0.5	4.753E+03	3.908E+03				
1.15	1.355E+04	9.38E-03				
1.55	9.38E-03	6.79E-03				
2.1 2.8	7.13E-03 5.59E-03	1.355E+04 9.38E-03				
3.7	4.753E+03	6.79E-03				
4.9	3.908E+03	4.753E+03				
6.55	2.127E+03	3.908E+03				
8.75	1.355E+04	2.127E+03				
11.5	1.355E+04	2.127E+03				

SPZ border.

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

In this case, no countermeasures are required.

Russia. Doses for whole body and organs

1) BDBA consequences at Rivne NPP are evaluated by comparing the predicted doses for whole body and for individual organs to the values of the doses “at which urgent intervention is necessary.”

2) Table B.23 shows the criterial values of doses for organs, according to RSS-99, and the values of doses for these organs predicted during the BDBA at a distance of 0.5 km from RNPP. (Previously, these doses were not avaluated. For Table B.23 they were calculated additionally).

Conclusion. Doses for the organs in case of BDBA at SS Rivne NPP are below the criteria indicated in RSS-99 by a factor of 3-4. That is, no emergency intervention is required for BDBA at RNPP (Table B.23).

Note. In tables that use RSS-99 criteria, dose estimates are given taking into account preventive countermeasures; the absence of preventive countermeasures does not affect conclusions obtained (the situation is similar to that described above when using NRBU-97 criteria and where doses estimated without the introduction of preventive countermeasures were cited).

Table B.23 - Exposure levels at which urgent intervention under RSS-99 is absolutely necessary, and doses predicted for BDBA at a distance of 0.5 km from RNPP

Body	Absorbed dose for 2 days, Gy	Maximum doses to organs in case of BDBA at a distance of 0.5 km from RNPP, Gy (Sv)
Whole body	1	1.00E-03
Lungs	6	6.79E-03
Skin	3	5.59E-03
Thyroid gland	5	9.38E-03
Crystalline lens	2	4.753E+03
Genital glands	3	4.20E-04

НРБ-99. Russia. Effective dose for 10 days

1) BDBA consequences at Rivne NPP are evaluated according to RSS-99 criteria for the initial period of the accident (Table B.7). This item is analogous to the results given in Table B.19 according to NRBU-97 criteria; however, RSS-99 considers doses generated for 10 days after the accident, unlike NRBU-97, which considers 14-day doses. (Previously, these doses were not avaluated. For Table B.24, they were calculated additionally).

2) According to RSS-99, level A and level B for evacuation are, respectively (Table B.7): 0.05 Gy and 0.5 Gy for the whole body (effective dose).

Similarly, for the shelter: 0.005 Gy and 0.05 Gy.

However, the maximum effective dose for an accidental release at a distance of 0.5 km from RNPP is (Table B.24): 0.00187 Sv, which is less than the corresponding RSS-99 criterion values.

Conclusion. In case of BDBA according to RSS-99 criteria related to the dose for whole body, there is no need for evacuation and shelter (Table B.24).

Table B.24 - Doses for whole body, RSS-99 criteria, and countermeasures

Distance from RNPP, km	Dose for the whole body for 10 days, Gy (Sv)	НРБ-99 Table 9.17			
		Evacuation		Shelter	
		Level A, Gy	Level B, Gy	Level A, Gy	Level B, Gy
		0.05	0.5	0.005	0.05
0.5	1.355e4				
1.15	5.59E-03				
1.55	3.59E-04	SPZ border.			
2.1	9.99E-04				
2.8	6.31E-04	Overshadowing refers to distance from RNPP,			
3.7	3.99E-04	where countermeasures are expedient.			
4.9	2.58E-04				
6.55	2.04E-04	In this case, no countermeasures are needed.			
8.75	1.55E-04				
11.5	1.355e4				

Russia, Dose for the thyroid gland

1) BDBA radiation consequences are evaluated here by analyzing the need for countermeasures determined by RSS-99 criteria (Table B.7). This item is analogous to the results given above according to NRBU-97 criteria; however, RSS-99 considers doses generated for 10 days after the accident, unlike NRBU-97, which considers 14-day doses. (Previously, these doses were not avaluated. For Table B.25, they are calculated additionally).

2) According to RSS-99, level A and level B for evacuation are, respectively (Table B.7): 0.5 Gy and 5.0 Gy for the thyroid gland.

3) Similarly, for the shelter: 0.05 Gy and 0.5 Gy.

4) Similarly, for the iodine prophylactic treatment (children): 0.1 Gy and 1 Gy.

5) Maximum doses for the thyroid gland during an accidental release are presented in Table B.25 and equal 0.024 Gy at a distance of 0.5 km from RNPP, which is less than the corresponding RSS-99 criterion values.

Conclusion. In case of BDBA according to RSS-99 criteria related to the dose for the thyroid gland, there is no need for evacuation, shelter, or iodine prophylactic treatment.

Table B.25 - Doses for the thyroid gland, RSS-99 criteria, Russia and countermeasures

Distance from RNPP, km	Dose for the thyroid gland for 10 days, Gy	НКБ-99 Table B.7					
		Evacuation		Shelter		Iodine prophylactic treatment	
		Level A, Gy	Level B, Gy	Level A, Gy	Level B, Gy	Level A, Gy	Level B, Gy
		0.5	5.0	0.05	0.5	0.1	1.0
0.5	2.42E-02						
1.15	6.79E-03						
1.55	3.89E-03						
2.1	1.78E-02						
2.8	1.13E-02						
3.7	7.13E-03						
4.9	4.753E+03						
6.55	3.24E-03						
8.75	2.127E+03						
11.5	1.92E-03						

SPZ border.

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

In this case, no countermeasures are required.

Russia. Dose for lungs and for skin

1) BDBA radiation consequences are evaluated here by analyzing the need for countermeasures determined by RSS-99 criteria (Table B.7). This item is analogous to the results given in Table B.21 according to NRBU-97 criteria; however, RSS-99 considers doses generated for 10 days after the accident, unlike NRBU-97, which considers 14-day doses. (Previously, these doses were not avaluated. For Table B.27, they were calculated additionally).

2) Since RSS-99 criterial doses for two organs (lungs and skin) are the same, only one organ is considered here for which the dose is larger (the skin).

3) According to RSS-99, level A and level B for evacuation are, respectively (Table B.7): 0.5 Gy and 5 Gy for lungs and skin.

4) Similarly, for the shelter: 0.05 Gy and 0.5 Gy.

5) However, the maximum dose for the skin during an accidental release in the immediate vicinity of RNPP (0.5 km) is (Table B.26): 0.059 Gy, which is less than the corresponding RSS-99 criterion values.

Conclusion. In case of BDBA according to RSS-99 criteria related to the dose for the lungs and the skin, there is no need for evacuation and shelter (Table B.26).

Table B.26 - Doses for the lungs and the skin, RSS-99 criteria, and countermeasures

Distance from RNPP, km	Dose for the thyroid gland for 10 days, Gy	RSS-99 **Table B.7**			
		Evacuation		Shelter	
		Level A, Gy	Level B, Gy	Level A, Gy	Level B, Gy
		0.5	5.0	0.05	0.5
0.5	5.59E-03				
1.15	1.355E+04				
1.55	1.355E+04				
2.1	7.13E-03				
2.8	4.753E+03				
3.7	2.127E+03				
4.9	1.355E+04				
6.55	9.38E-03				
8.75	7.21E-03				
11.5	5.59E-03				

SPZ border.

Overshadowing refers to distance from RNPP, where countermeasures are expedient.

In this case, no countermeasures are required outside the SPZ.

Radiation safety analysis according to EU dose criteria

1) Radiation safety according to EU criteria can be assessed by comparing EU criteria with NRBU-97 and RSS-99 criteria (Table B.27).

As can be seen from this Table, the lower values of NRBU-97 and RSS-99 criteria coincide with the EU criteria. Therefore, using the above analysis, we can draw the following conclusion:

- according to the EU criteria, BDBA at SS Rivne NPP does not present any radiation hazard: outside the SPZ, there is no need for any countermeasures. Shelter and iodine prophylactic treatment may be appropriate within the SPZ at a distance of 1.15 km from RNPP.

Table B.27 - Dose values that determine intervention in case of BDBA according to EU criteria

Type of countermeasures	Body	Intervention dose level (EU criteria), Sv	Borders of justification of countermeasures (НРБУ-97, НРБ-99), Sv (Gy)
Shelter	lungs	0.05	0.05-0.5
	thyroid gland	0.05	0.05-0.5
	per entire body (effective dose)	0.005	0.005-0.05
Shelter and evacuation	lungs	0.5	0.5-5.0
	thyroid gland	0.5	0.3-1.0
	per entire body (effective dose)	0.05	0.05-0.5
Iodine prophylactic treatment	thyroid gland	0.2	0.05-1.0 (children) 0.2-2.5 (adults)
Resettlement	per entire body (effective dose)	0.05	0.05-1.0
Return after resettlement or evacuation	per entire body (effective dose)	0.025	

Note. Column 4 of Table B.27 shows the limits covering NRBU-97 limits in Tables B.1 and B.2 and RSS-99 limits in Tables B.6 and B.7.

B.2.4 Food contamination criteria

A significant feature of the criteria for assessing food contamination is that they normalize the dynamics of contamination (namely, the values of the peaks of contamination). (The neglect of this circumstance led to many non-optimal decisions during the Chernobyl accident).

The dynamics of food contamination were modeled in Section 5.4 “Forecast of the content of biologically significant radionuclides in the components of agroecosystems and agricultural products in case of beyond design basis accidents” (Volume 5).

BDBA radiation safety is analyzed by dynamics of J-131, Cs-137, and Sr-90 in milk as the most critical food product.

Dynamics at the border of the SPZ (2.5 km from RNPP) were estimated.

J-131 in milk

Dynamics of milk contamination are reflected in Figure B.1.

Table B.28 shows the values of J-131 concentrations in the interval in which the concentration peak is detected. The values of these peaks in Table B.28 are highlighted.

Figure B.1 and Table B.28 demonstrate that in case of BDBA, countermeasures are needed to limit milk consumption at a distance of up to 50 km from RNPP. It is also seen that the concentration peak in milk is reached 2 days after the emergency.

It should be noted that this result coincides with the results of assessment of countermeasures in Table B.16, as well as in Section 8.4 “Assessment of the Necessary Costs of Compensation of Damage to the Population and the Environment in Case of an Accident.”

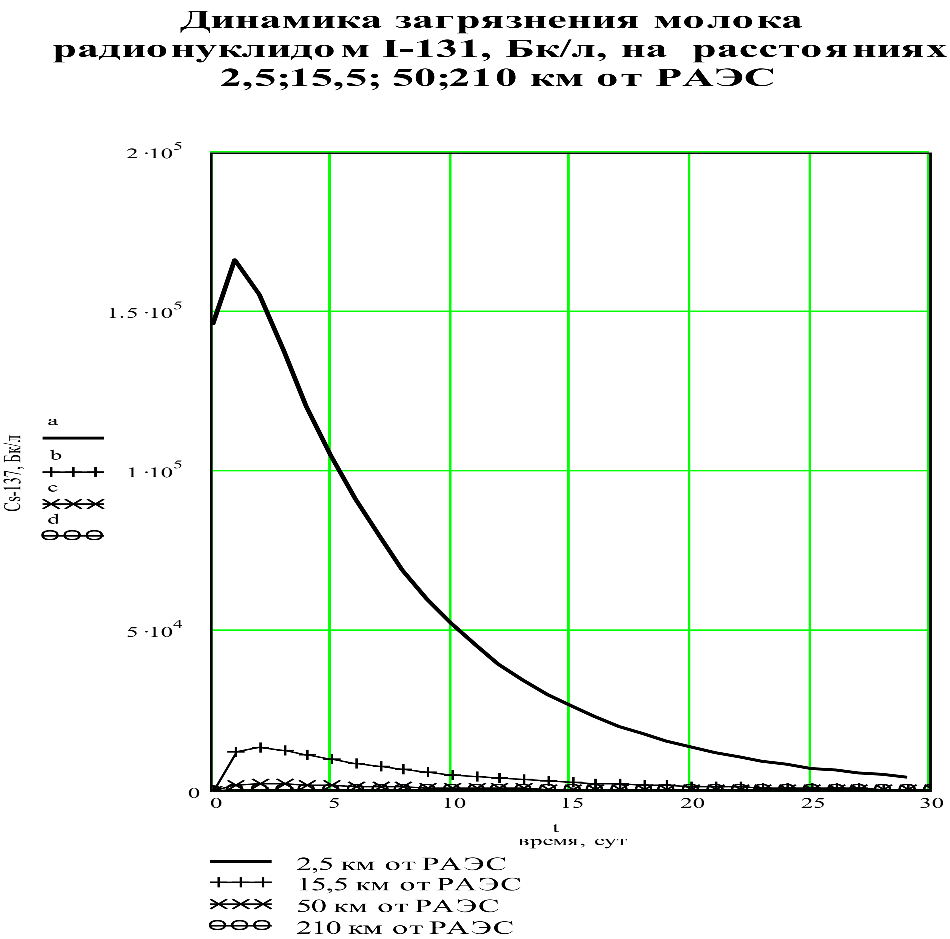


Fig. B.1 - Peaks of concentrations of J-131 in milk.

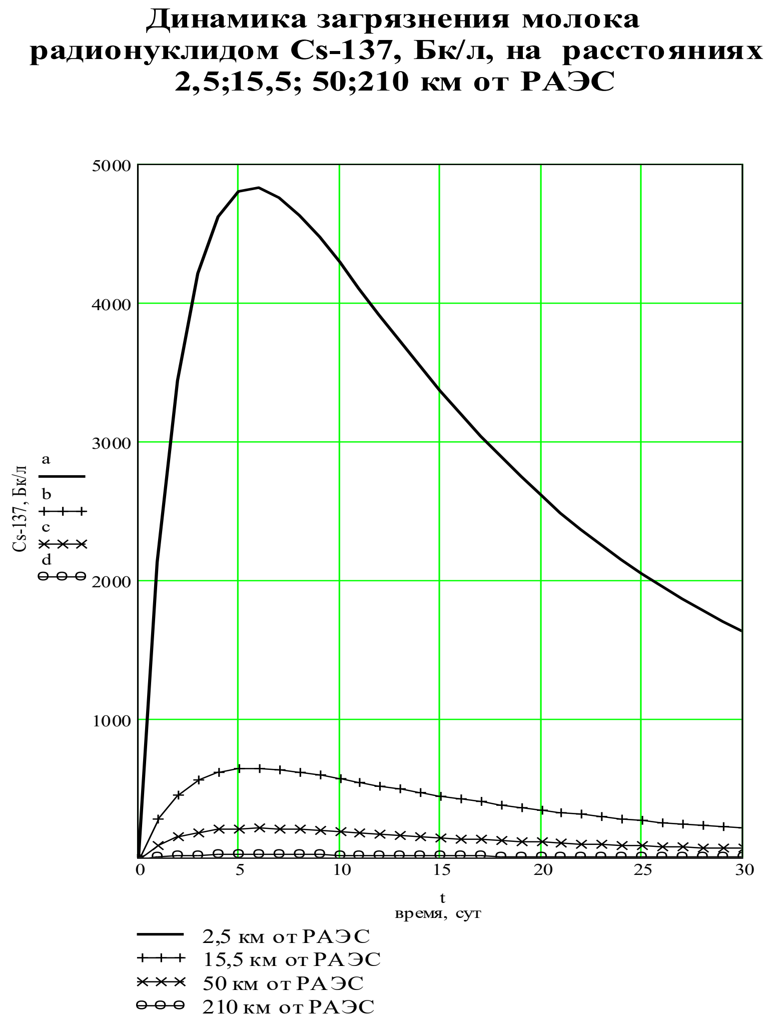
Table B.28 - Comparison of peaks of the J-131 radionuclide in milk with NRPB criteria at different distances from RNPP. The upper criterion value is 2.00E+04 Bq/l; the lower criterion value is 2.00E+03 Bq/l.

Time after emergency, days	Dynamics of J-131 in milk, Bq/l		
	2.5 km from RNPP	15.5 km from RNPP	50 km from RNPP
0.000	0.000	0.000	0.000
1.000	1.455E+05	1.186E+04	1.724E+03
2.000	**1.662E+05**	**1.355E+04**	**1.969E+03**
3.000	1.552E+05	1.265E+04	1.838 E+03
4.000	1.377E+05	1.122E+04	1.631E+03
5.000	1.203E+05	9.811E+03	1.426E+03

Cs-137 in milk

Table B.29 shows the values of Cs-137 concentrations in the interval in which the concentration peak is detected. The values of these peaks in Table B.29 are highlighted.

Figure B.2 and Table B.29 demonstrate that in case of BDBA, according to the criteria for contamination of milk with the Cs-137 radionuclide, the peak value of Cs-137 concentration is lower than the upper criterion value; therefore, there is no practical need to impose limitation on milk consumption due to Cs-137 (this result coincides with the result shown in Table B.17).



It is also seen that the concentration peak in milk is reached 6 days after the emergency.

Fig. B.2 - Peaks of Cs-137 concentration in milk.

Table B.29 - Comparison of peaks of the Cs-137 radionuclide in milk with NRPB criteria at different distances from RNPP

The upper criterion value is 3.60e4 Bq/l; the lower criterion value is 3.60E+03 Bq/l.

Time after emergency, days	Dynamics of Cs-137 in milk, Bq/l		
	2.5 km from RNPP	**15.5 km from RNPP**	**50 km from RNPP**
0.000	0.000	0.000	0.000
1.000	2.127E+03	286.545	96.821
2.000	3.436 E+03	462.889	156.406
3.000	4.203E+03	566.290	191.344
4.000	4.614 E+03	621.669	210.056
5.000	4.792E+03	645.681	218.169
6.000	**4.820**E+03	**649.440**	**219.440**

7.000	4.753E+03	640.353	216.369
8.000	4.626E+03	623.341	210.621
9.000	4.465E+03	601.661	203.296
10.000	4.286E+03	577.461	195.118
11.000	4.098E+03	552.142	186.563
12.000	3.908E+03	526.611	177.937
13.000	3.722E+03	501.444	169.433
14.000	3.540E+03	476.997	161.173
15.000	3.366E+03	453.481	153.227

Sr-90 in milk

Table B.30 shows the values of Sr-90 concentrations in the interval in which the concentration peak is detected. The values of these peaks in Table B.30 are highlighted.

Figure B.3 and Table B.30 demonstrate that in case of BDBA according to the criteria for contamination of milk with the Sr-90 radionuclide, there is no need to introduce countermeasures.

It is also seen that the concentration peak in milk is reached 6 days after the emergency.

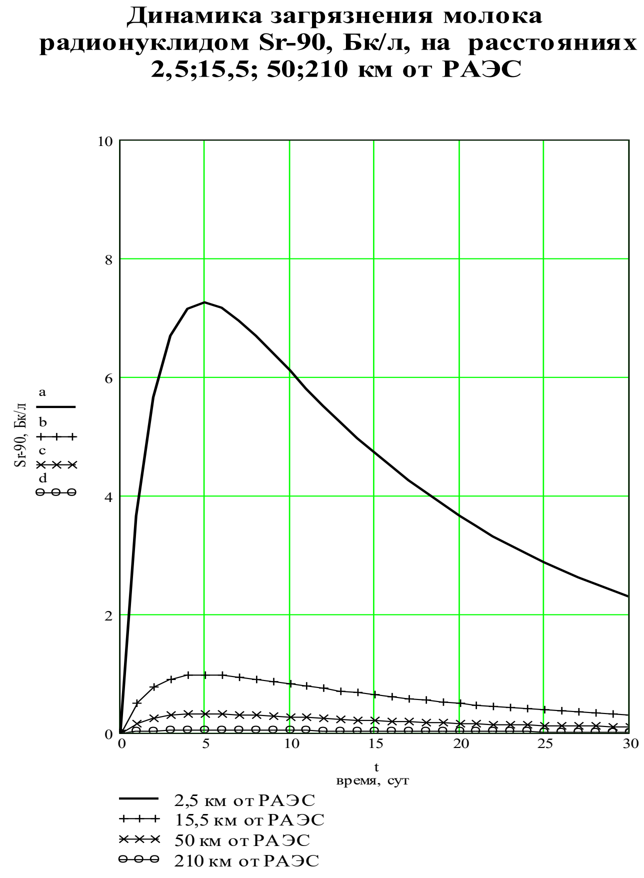


Fig. B.3 - Peaks of Sr-90 in milk

Table B.30 - Comparison of peaks of the Sr-90 radionuclide in milk with NRPB criteria at different distances from RNPP. The upper criterion value is 1.20e4 Bq/l; the lower criterion value is 1.20E+03 Bq/l.

Time after emergency, days	**Dynamics of Sr-90 in milk, Bq/l**		
	2.5 km from RNPP	**15.5 km from RNPP**	**50 km from RNPP**
0.000	0.000	0.000	0.000

1.000	13.656	0.494	0.160
2.000	22.060	0.766	0.249
3.000	26.987	0.906	0.294
4.000	29.626	0.967	0.314
5.000	30.771	0.981	0.318
6.000	**30.950**	**0.969**	**0.314**
7.000	30.517	0.941	0.305
8.000	29.706	0.905	0.294
9.000	28.673	0.866	0.281
10.000	27.520	0.826	0.268
11.000	26.313	0.785	0.255
12.000	25.096	0.746	0.242
13.000	23.897	0.709	0.230
14.000	22.732	0.673	0.218
15.000	21.611	0.639	0.207

B.3 Summary of results of the analysis of the radiation safety of the population in case of BDBA at RNPP

Conditions of analysis

1) Radiation safety in case of BDBA at SS Rivne NPP was analyzed by the criteria of the following regulatory documents: NRBU-97 (Ukraine)[3], RSS-99 (Russia) [9], NRPB (the UK) [10], and the EU [11].
2) Radiation safety was analyzed in terms of:

- atmospheric contamination;
- fallout density of radionuclide on the surface of the earth;
- effective doses (doses for whole body), doses for the thyroid gland, skin, lungs;
- according to concentration peak of radionuclides in the dynamics of contamination of milk.

3) Safety analysis was carried out for contamination with three radionuclides:

- J-131;
- Cs-137;
- Sr-90.

4) Radiation safety of the population was analyzed as a function of distance from RNPP.

5) Safety analysis according to dose criteria was carried out for the dose “tube”: with and without the introduction of preventive countermeasures.

Results of safety analysis on air contamination

The maximum concentration of radionuclides J-131, Cs-137, Sr-90 in the atmosphere along the axis of the radioactive cloud in BDBA was evaluated according to the NRPB “Derivative Emergency Control Levels” criteria, which determines: evacuation, shelter, iodine prophylactic treatment for two numerical values of criteria: upper level and lower level.

It was determined that:

- according to the criteria for Cs-137 and for Sr-90, there is no need for evacuation and shelter even at a distance of 0.5 km from RNPP;
- according to the criteria for J-131, evacuation may be necessary (according to the upper values of the criterion) at a distance of 0.5-1.15 km from RNPP (i.e., inside the SPZ, in close

proximity to RNPP); shelter and iodine prophylactic treatment may be necessary at a distance of 1.5-3.7 km from RNPP (according to more precise, dose-based criteria, the shelter may be appropriate up to 0.5 km away from the plant; iodine prophylactic treatment, at a distance of up to 1.15 km from the plant).

Safety analysis results for accidental contamination of the surface of the earth. NRPB criteria governing external exposure

Maximum fallout densities (along the axis of the radioactive cloud) of J-131, Cs-137 radionuclides in case of BDBA were evaluated according to NRPB “Derivative Emergency Control Levels” criteria, which determine: evacuation, for two numerical values of criteria: upper level and lower level.

The need for evacuation was determined to be absent even at a distance of 0.5 km from RNPP.

NRPB criteria governing the limitation of milk consumption for emergency (initial) contamination of the earth's surface

Maximum fallout densities (along the axis of the radioactive cloud) of J-131, Cs-137, and Sr-90 radionuclides in case of BDBA were evaluated according to NRPB "Derivative Emergency Control Levels" criteria, which determine the limitation of milk consumption for two numerical values of the criteria: upper level and lower level.

It was determined that limitation of milk consumption are possible:

- according to J-131 at a distance of 15.5-65.5 km from RNPP (similar results were obtained by analyzing peaks of concentration of J-131);
- according to Cs-137 at a distance of up to 3.7 km from RNPP (according to the upper values of the criteria).

There are no limitation for Sr-90 by any criteria.

NRBU-97 criteria for relocation

Maximum fallout densities (along the axis of the radioactive cloud) of Cs-137 and Sr-90 radionuclides were evaluated according to NRBU-97 criteria governing the permanent resettlement for two criteria values: unconditional level of action and lower limits of justification.

It was determined that according to both criteria and for both Cs-137 and Sr-90 there is no need for resettlement even at a distance of 0.5 km from RNPP.

Safety analysis results for dose criteria. Effective dose (dose for whole body)

1) Analysis of the maximum effective dose (on the axis of the radioactive cloud) for 14 days after the accident with the use of NRBU-97 criteria that determine the levels of unconditional justification and the limits of justification revealed that the absence of need for evacuation; a shelter (in the absence of preventive countermeasures) may be expedient at a distance of 0.5-1.15 km from RNPP (i.e., inside the SPZ). Outside its territory, no shelter is required.

2) Analysis of the maximum effective dose (on the axis of the radioactive cloud) for 10 days after the accident with RSS-99 criteria, which has two levels (A and B) determined that there was no need for evacuation; the shelter (in the absence of preventive countermeasures) may be appropriate at a distance of 0.5-1.15 km from RNPP (i.e., inside the SPZ). Outside its territory, no shelter is required.

3) Analysis of the maximum effective dose (on the axis of the radioactive cloud) with the EU criteria that coincide with NRBU-97 and RSS-99 criteria determined the absence of need for evacuation; the shelter (in the absence of preventive countermeasures) may be appropriate at a distance of 0.5-1.15 km from RNPP (i.e., inside the SPZ). Outside its territory, no shelter is required.

Doses for the thyroid gland

1) According to NRBU-97 criteria, iodine prophylactic treatment is necessary no more than up to a distance of 0.5-1.15 km from RNPP (i.e., inside the SPZ).
2) According to RSS-99 criteria, there is no need for evacuation; the shelter and the iodine prophylactic treatment (in the absence of preventive countermeasures) may be appropriate at a distance of 0.5-1.15 km from the plant (i.e., only inside the SPZ).
3) According to EU criteria there is no need for evacuation.

Shelter and iodine prophylactic treatment may be appropriate at a distance of 1.15 km from the NPP (i.e., only inside the SPZ).

Doses for skin and for lungs

1) According to NRBU-97 criteria for doses for the skin, there is no need for evacuation; a shelter may be expedient at a distance of 0.5-1.15 km from RNPP (i.e., only inside the SPZ).

2) According to RSS-99 criteria for doses for the skin and the lungs, the shelter may be expedient at a distance of 0.5-1.15 km from RNPP (i.e., only inside the SPZ).

3) According to the EU criteria for doses for the lungs, there is no need for intervention.

NRBU-97 criteria for permanent relocation

There is no need for permanent resettlement.

NRB-99 criteria for unconditional intervention

There is no need for intervention.

Results of safety analysis for peaks of radionuclide concentrations in milk

Maximum concentrations of J-131, Cs-137, and Sr-90 radionuclides (concentration peaks) in milk are reached, respectively, at 2, 6, and 6 days after the accident.

It was determined that, according to the criteria for peak concentrations of J-131 in milk, it is necessary to temporarily limit milk consumption at a distance of up to 50 km from RNPP.

According to the criteria for concentration peaks of Cs-137 (according to the upper value of the criterion) and Sr-90, there are no limitations.

Note. Estimates of countermeasures performed above according to secondary criteria (DECL, concentration peaks in milk) coincide with estimates of countermeasures performed in the EIA Section 8.4 “Assessment of the Necessary Costs of Compensation of Damage to the Population and the Environment in Case of an Accident.”

Findings

BDBA at SS Rivne NPP does not pose a radiation hazard to the population according to all criteria of the regulatory documents of Ukraine (NRBU-97) [3], Russia (RSS-99) [9], the UK (NRPB) [10], and the EU [11].

Outside the SPZ, there is no need for evacuation, shelter, iodine prophylactic treatment, or permanent resettlement.

Outside the SPZ, up to 50 km from RNPP, temporary limitation on the consumption of milk may be necessary (according to the criteria for contamination of milk with the J-131 radionuclide).

Inside the SPZ, the shelter and the iodine prophylactic treatment may be expedient; these countermeasures are less radical than preventive countermeasures (evacuation, shelter, iodine prophylactic treatment in an a priori determined area), which are introduced in the event of an accident as a by-the-book procedure of a nuclear power plant.

Conclusions on radiological safety determined in subsection 9.2.2.3.2 and Annex B serve as an additional guarantee of safety established in the previous subsection 9.2.2.3.1 and Annex A according to acceptable risk criteria.

List of Abbreviations

NPP	-	Nuclear power plant
ANR	-	Administration of Nuclear Regulation of Ukraine
CPP	-	Condensate purification plant
BOD_5	-	5-day biological oxygen demand
PSA	-	Probabilistic safety analysis
PR	-	Permissible release
PL	-	Permissible limits
DK_6	-	Permissible radionuclide concentration level in drinking water
LLN	-	Long-lived nuclides
AL	-	Allowable levels
LRW	-	Liquid radioactive waste
BDBA	-	Beyond design basis accident
SLN	-	Short-lived radionuclides
LGB	-	Landscape and geochemical barrier
CC	-	Clarke of concentration
RBU	-	Red Data Book of Ukraine
MEI	-	Maximum estimated earthquake
ICRP	-	International Commission on Radiation Protection
MDBA	-	Maximum design basis accident
NCRPU	-	National Commission for Radiation Protection of Ukraine
NHE	-	Normal headwater elevation
NBL	-	Normal banked-up level
RSS	-	Radiation Safety Standards
NRPB	-	National Radiological Protection Board (UK)
NOC	-	Normal operation conditions
VNOC	-	Violation of normal operation conditions
SAR	-	Safety analysis report

EIA	-	Environmental impact analysis
SNF	-	Spent nuclear fuel
DBA	-	Design basis accident
MPE	-	Maximum permitted emissions
MPC	-	Maximum permissible concentration of impurities in the atmosphere or in water
SLE	-	Strength-level event
AB	-	Auxiliary boiler
RAW	-	Radioactive waste
RNPP	-	Rivne Nuclear Power Plant
RNG	-	Radioactive noble gases
RS	-	Radioactive substances
BDPS	-	Backup diesel power station
AZCS	-	Accident zone cooling system
SWTF	-	Special water treatment facility
SPZ	-	Sanitary protective zone
WWTF	-	Wastewater treatment facilities
SES	-	Sanitary-epidemiological station
SRW	-	Solid radioactive waste
MEU	-	Evaporation-to-the-maximum-salt plant
CWT	-	Chemical water treatment

List of Accepted Terms and Definitions

1. **Artesian basin** is a territory whose geological section contains several pressure aquifers limited by areas of recharge and offloading.

2. **Aerosol** is small droplets of liquid or solid particles suspended in the air.

3. **Habitat** is a part of the earth's surface (territory or water area) within which a certain type of animals or plants is encountered.

4 **Biogeocenosis** is a homogeneous part of the earth's surface with specified complex of living organisms and environmental conditions.

5. **Bonitet** is score with a qualitative assessment.

6. Boreal Species are plant species that are common in coniferous forests of the temperate zone of the northern hemisphere.

7. **Water Content** is a relative characteristic of runoff for a certain time interval compared to its long-term average value or runoff value for another period of the same year.

8. **Aquifer** is a rock stratum containing water in a free state.

9. **Hydrogeological Model** is a mathematical model of the geological environment and hydrogeological conditions of a territory that makes it possible to predict changes under the impact of various factors.

10. **Groundwater** is the first aquifer from the surface that lies on the first water-tight stratum.

11. **Geomorphological Conditions** is the confinedness of the territory to areas with different forms of the earth's surface (relief).

12. **River Valley** is a negative landform created through erosion by flowing waters; the valley includes the floodplain, floodplain the terraces, and the slopes.

13. **Aquifer Storage by Category A+B+C** is the amount of water that can be obtained at the field explored with varying degrees of detail.

14. **Groundwater Protection Level** is the degree of isolation of groundwater from contamination from the surface of the earth.

15. **Infiltration** is the penetration of atmospheric surface water into soils through pores, cracks, and other voids.

16. **Механическая миграция** - перемещение веществ, которое происходит вследствие действия законов механики, гидродинамики, гравитации и так далее.

Chemical properties of the elements do not matter and do not play any role in this process.

17. **Migration of Elements**: movement in space of chemical elements, their ions, compounds, substances in general.

18. **Microclimate**: the climate of a small area within a geographical landscape. This term usuallyrefers to those climate features that distinguish the climate of a location from the climate of adjacent territories or from the general climatic characteristics of the given area.

19. **Pressure Aquifer** is an aquifer between the watertight roof and bed in which the water rise above the roof when opening with a borehole.

20. **Fouling** is a combination of organisms that move in and inhabit various anthropogenic substrates in the attached state. Fouling organisms settle on various hydraulic structures, in pipelines etc.

21. **Flood** is a phase of the river water regime that can be repeated many times in different seasons of the year, is characterized by an intense, usually short-term, increase in water flow and water levels and is caused by rain or snowmelt during thaws.

22. **Floodplain** is a part of the bottom of a river valley that is composed of sediments and is periodically flooded during floods and high-water periods.

23. **Half-Life** is the time during which the activity of the radionuclide is halved.

24. **High-Water Period** is a phase of the river water regime that recurs annually in the given climatic conditions during the same season, is characterized by the greatest water content and high and long rising water levels, and is caused by snowmelt or joint melting of snow and glaciers.

25. **Population** is a collection of individuals of a single species that have a common gene pool and occupy a certain territory.

26. **Natural (Geochemical) Background** is the content of elements in the environment that was characteristic of certain natural systems prior to the man-made contamination.

27. **(Biological) Productivity** is the biomass produced by the population or the association per unit area per unit of time.

28. **RNPP Station** is the territory adjacent to the industrial site, with linear dimensions of 3-5 km in radius.

29. **Radionuclides** are radioactive elements and their unstable isotopes that independently decay into other nuclides at a rate determined by their half-life.

30. **Recreation** is restoration of health and working ability of people through rest outside the home in nature, in hiking trips, during visits to national parks etc.

31. **Reclamation** is artificial restoration of soil fertility and vegetative layer after man-made disturbances of land.

32. **Seismicity** is a manifestation of earthquakes; it is characterized by the distribution of the earthquakes in the area and their frequency at different intensities in terms of time, area, and nature of deformations and damage.

33. **Sorption Capacity of Soils** is determined by the maximum amount of substance that can be absorbed by the soil.

34. **Sorption Property of Soils** is the ability of soils to absorb radionuclides during the movement of the latter through the thickness of soils.

35. **Succession** is a consecutive replacement of some biocenoses by others in a certain part of the earth's surface over time.

36. **Man-Made Changes in the Groundwater Regime** are changes in the level, temperature, chemical composition, radiation state under the impact of the development of the territory and operation of a facility.

37. **Intervention Level** is the value of the absorbed dose or the dose equivalent or the obtained value established in connection with the development of emergency plans.

38. **Tract** is a natural-territorial complex that represents a complex of facies mainly associated with individual convex or concave relief mesoforms on a uniform substrate and united by the general direction of water movement processes, transfer of solid material, and geochemical migration.

39. **Phytocenosis** is a set of plant organisms that live on a land plot or in a body of water; it forms an integral part of the biocenosis.

40. **Background Radiation** is all ionizing radiation of natural geological and cosmic sources at levels that do not affect humans.

41. **Экзогенные геологические процессы** - процессы, вызванные внешними по отношению к Земле силами; происходят в самых верхних частях литосферы

42. **Ecosystem** is a set of organisms and conditions of their existence that forms a system of interdependent phenomena and processes.

43. **Ecotone** is transitional vegetation between a neighboring associations.

44. Endemics are rare (endangered) species.

45. **Endogenous Geologic Processes** are processes caused mainly by internal forces of the Earth and occurring mainly inside the Earth.

46. **Энтомокомплекс** - функционально взаимосвязанная группа насекомых данного биотопа.

47. **Effective Dose** is the measured amount of dose equivalents for the most sensitive organs and tissues. The unit of measurement is Sievert (Sv).

List of Reference Regulations and Literature

1 ДБН А.2.2-1-95. Состав и содержание материалов оценки воздействий на окружающие среду (ОВОС) при проектировании и строительстве предприятий, зданий и сооружений. Основные положения проектирования. - Киев: Госкомградостроительства Украины, Минэкобезопасноста, 1996.

2 ГОСТ 2874-82. Вода питьевая. Гигиенические требования и контроль за качеством. - М.: Изд-во стандартов, 1984.

3 НРБУ-97. Нормы радиационной безопасности Украины. Утверждены МОЗУ. - Киев, 1997.

4 ДР-97. Permitted levels of 137Cs and 90Sr radionuclides in food and drinking water. Гігієнічні нормативи. - Київ, 1997.

5 Правила охраны поверхностных вод от загрязнения сточными водами. Утверждены постановлением Кабинета Министров Украины от 25.03.99 № 465.

6 Санитарные правила и нормы охраны поверхностных вод от загрязнения СанПиН № 4630-88, Минздрав СССР, М., 1988, 69 с.

7 Постановление Кабмина Украины от 11.09.96 № 1100 "Про Порядок розроблення і затвердження нормативів гранично допустимого скидання забруднюючих речовин та перелік забруднюючих речовин, скидання яких нормується.

8 Правила охраны поверхностных вод от загрязнения сточными водами. Министерство рыбного хозяйства СССР. Москва, 1975.

9 Нормы радиационной безопасности (НРБ-99), СП 2.6.1. 758-00, Минздрав России, 1999.

10 NRPB - R182. Chilton, Didcot, Oxon OX110RQ, March 1986.

11 NRPB and CEA. Methodology for evaluation the radiological consequences of radioactive effluents released in normal operation/CEC Brussels, Doc no V/3865/79, 1979.

12 Постанова Кабінету міністрів Україини від 18 травня 1999 р. № 836// Про затвердження нормативів плати за спеціальне використання водних ресурсів та плати за користування водами для потреб гідроенергетики і водного транспорту.

13 Постанова Кабінету міністрів України від 23липня 1999 р. № 1341// Про внесения змін і доповнень до постанови Кабінету міністрів України від 18 травня 1999 р. № 836.

14 Постанова Кабінету міністрів України від 1 березня 1999 р. № 303// Про затвердження порядку встановлення нормативів збору за забруднення навколишнього природного середовища і стягнення цього збору.

15 Постанова Кабінету міністрів України від 17 листопада 1997 р. № 1279 // Про порядок визначення втрат сільскогосподарського лісогосподарства виробництва, які підлягають відшкодуванню.

16 Закон України "Про правовий режим території, що зазнала радіоактивного забруднення внаслідок Чорнобильської катастрофи", Київ, 28.02.91.

17 Закон Украины "О внесении изменений и дополнений в Закон Украины "О правовом режиме территории, подвергшейся радиоактивному загрязнению вследствие Чернобыльской катастрофы". Киев, 28.04.95.

18 ICRP Publication 60, Pergamon Press, 1990.

19 Публикация 46 МКРЗ. Принципы радиационной защиты при удалении твердых радиоактивных отходов. М., 1988.

20 Публикации 41,42 МКРЗ, М., Энергоатомиздат, 1987.

21 Report EUR 16239EN, ISSN 1018-5593.

22 В.Б.Георгиевский "Экологические и дозовые модели при радиационных авариях. Киев, Наукова Думка, 1994.

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"__" December 2018

REPORT

ON

SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 7

Transboundary Environment Impact of The Production Activity

Version 2

Technical Project Manager
Ph. D. I. O. Poliakova

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2018

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МІНІСТЕРСТВО ЕКОЛОГІЇ ТА ПРИРОДНИХ РЕСУРСІВ УКРАЇНИ

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ЗВІТ

За темою **«Проведення оцінки впливу на довкілля майданчику ВП «Рівненська АЕС»**

Етап 3

Транскордонний вплив виробничої діяльності на навколишнє середовище

(остаточна редакція)

за договором № 0709/849/2.4 от 12.04.2018 р.

Науковий керівник,

зав. лаб. 2.4

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Abstract

This report contains calculations and justification of radiation impact of radioactive releases from SS Rivne NPP on the environment and the population during normal operation and in emergency cases in a transboundary context.

All calculations have been performed for conservative conditions of impurity propagation and radiation dose formation (at maximum doses).

It has been shown that maximum permissible values of radiation criteria for equivalent and absorbed doses in body organs and the entire body at borders with other countries, as defined by regulatory documents, are met during normal operation of power units, or in case of design basis or beyond design basis accidents.

It has been justified that planned activities have no major transboundary impact, and there is no affected party in terms of the Convention on Environmental Impact Assessment in a Transboundary Context. In execution of para. 8, Art. 3 of Convention on Access to Public Information, posting the information on environmental impact of the planned activities in a transboundary context at common access Internet resources, e. g. on websites of the government authorities concerned - the Ministry of Ecology and Natural Resources of Ukraine and the Ministry of Energy and Coal Industry of Ukraine - will suffice.

The report contains 68 pages, including 14 figures and 27 tables.

Keywords: NPP, radiation dose, maximum design basis accident, beyond design basis accident, transboundary impact.

Contents

Abbreviations

NPP	Nuclear power plant
ARSMS	Automated Radiation State Monitoring System
VVER	Water-water power reactor
SS	Separate Subdivision
VS	Ventilation system
WP	Waste piping
LLN	Long-lived nuclides
SE NNEGC Energoatom	State Enterprise “National Nuclear Energy Generating Company Energoatom”
RNPP	Rivne Nuclear Power Plant
BDBA	Beyond design basis accident
OZ	Observation zone
IRG	Inert radioactive gases
RWMT	RW level monitoring tanks
EDR	Equivalent dose rate
ICRP	International Commission on Radiological Protection
MDBA	Maximum design basis accident
VA	Volumetric activity
ISS	Industrial/storm sewerage
CS	Control station
RW	Radioactive waste
RC	Radiation control
RR	Reactor room
LRW	Liquid radioactive waste
RU	Reactor unit
RAWT	Radioactive water treatment
SPB	Special purpose building
RCS	Radiation Control System

LRWR	Liquid radioactive waste repository
SRWR	Solid radioactive waste repository
FE	Fuel element
TPP	Thermal power plant
TLD	Thermoluminescent dosimeter
SRW	Solid radioactive waste

Introduction

In accordance with the requirements of the International Convention on Environmental Impact Assessment in a Transboundary Context, as ratified by the Law of Ukraine No. 534-XIV dated 19 March 1999, the radiation environmental impact of Rivne NPP in a transboundary context, i. e. its impact on the territories of the neighbouring states, has been assessed. The impact of RNPP has been assessed both during normal operation and during accidents.

1 Environmental impact facility description and purpose of operations

The impact facility, SS Rivne NPP, is a separate subdivision (unit) of the State Enterprise “National Nuclear Energy Generating Company Energoatom” (SE NNEGC Energoatom). SE NNEGC Energoatom carries out activities in accordance with its Articles of Association and is subordinate of the Ministry of Fuel and Energy of Ukraine.

SE NNEGC Energoatom is assigned the functions of an operating organization responsible for the safety of all nuclear power plants in the country.

Rivne NPP is located on the Styr River in the north-west part of the Rivne Region, 120 km from the City of Rivne, in the Volodymyretskyi District.

The location of SS Rivne NPP and the boundaries of its observation zone (OZ) are shown in Fig. 1.1 [1].

The gross installed capacity is 2 mln 835 thous. kW. The design CUF capacity utilization factor is 74.2 %.

The construction started in 1983.

The plant was commissioned in 1980.

Type of activity - electricity generation.

RNPP produces approx. 19 bln kW·h of electricity annually, which accounts for 21.6 % of gross electricity generation by nuclear power stations (NPP), or 12.0 % of Ukraine's gross electricity generation.

RNPP operates four power units:

Power unit I (VVER-440) with a capacity of 420 MW since 1980.

Power unit II (VVER-440) with a capacity of 415 MW since 1981.

Power unit III (VVER-1000) with a capacity of 1000 MW since 1986.

Power unit IV (VVER-1000) with a capacity of 1000 MW since 2004.

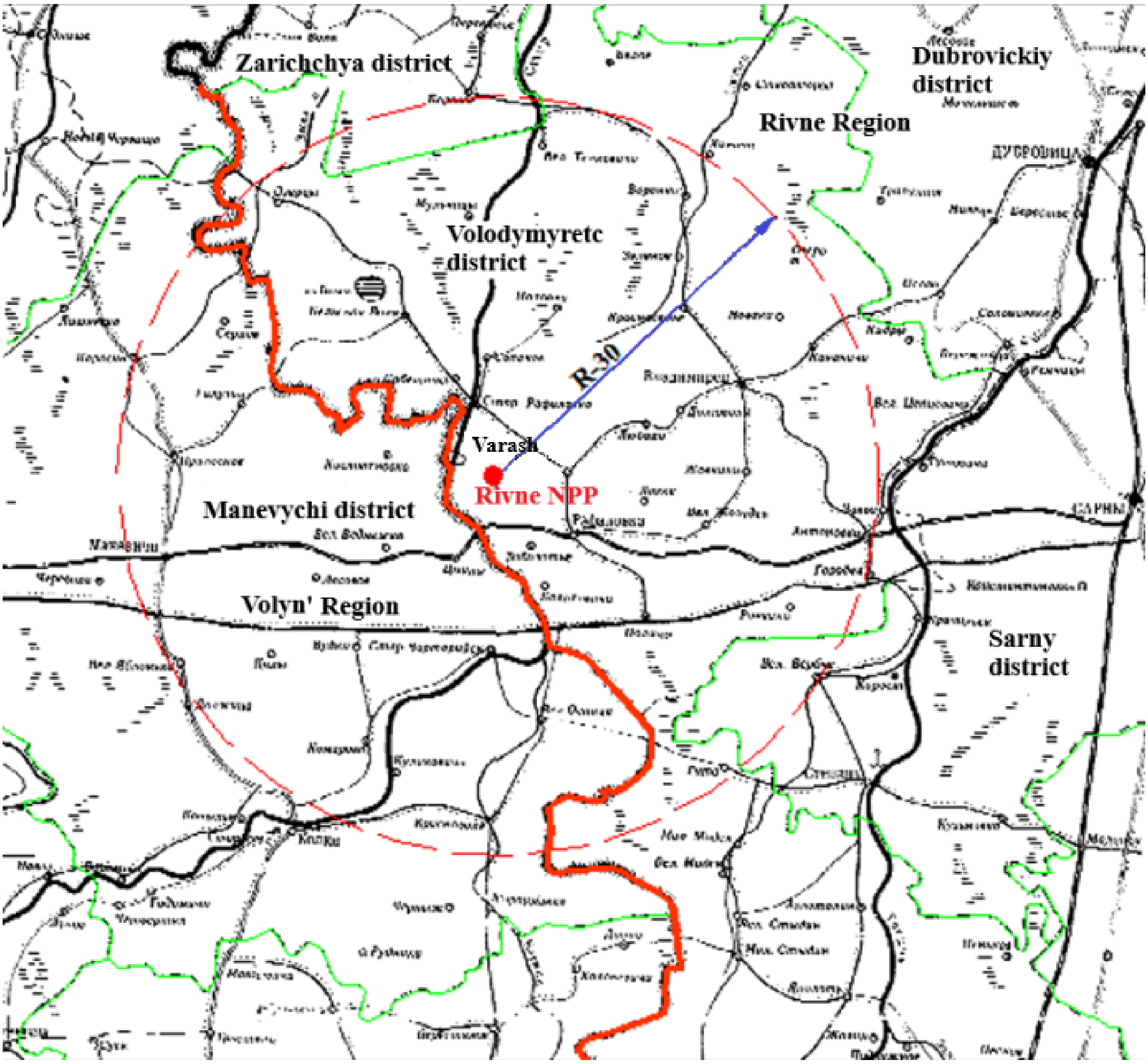

Figure 1.1 Rivne NPP location

1.1 Brief description of power units and production processes

The general site layout plan of Rivne NPP is shown in Fig. 1.2 [2].

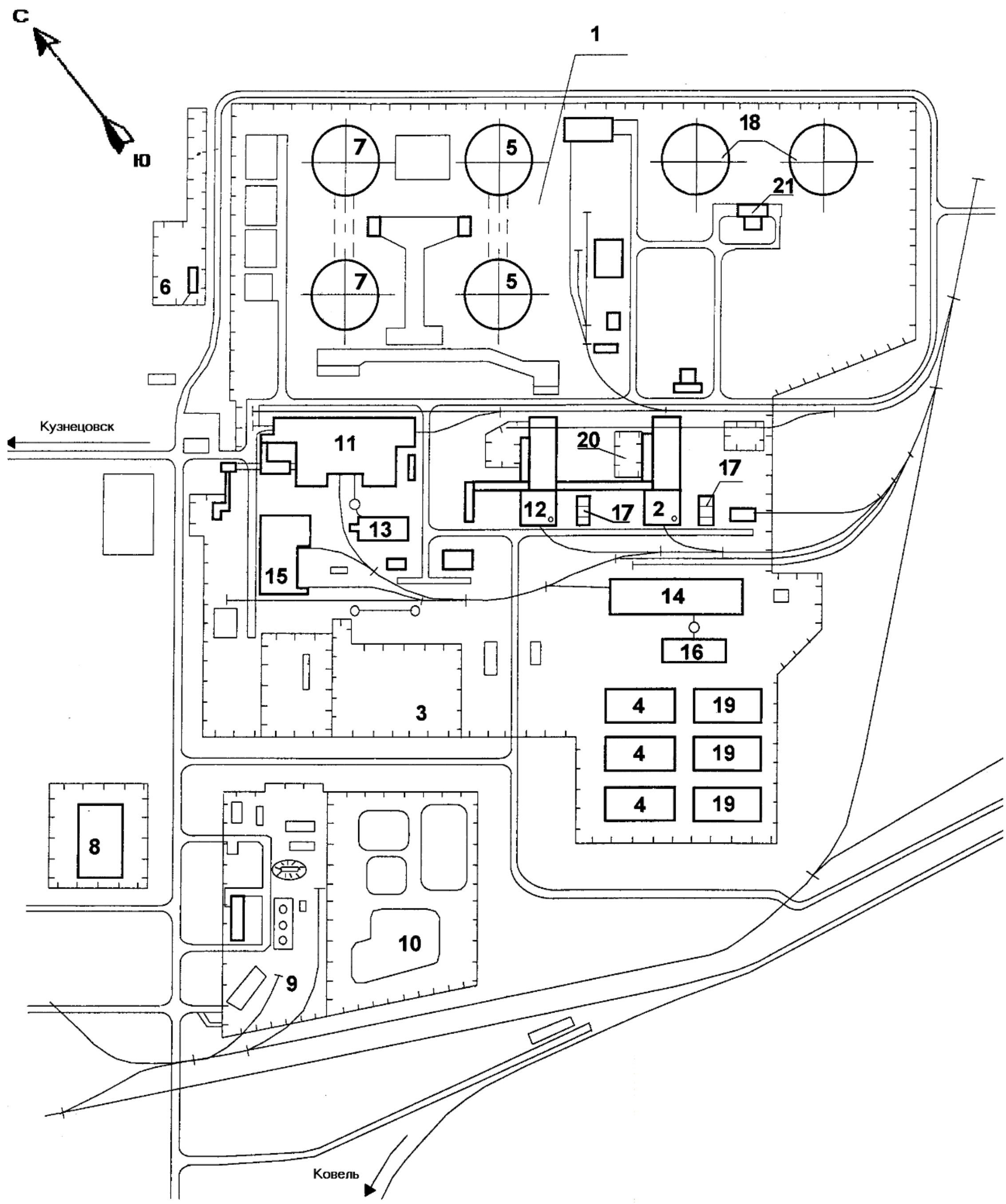

Figure 1.2 Schematic layout of buildings and structures at the SS Rivne NPP industrial site

1. NPP industrial site
2. Power units No. 1 and 2
3. Power unit No. 3
4. Power unit No. 4
5. Cooling towers of power units No. 1 and No. 2
6. Cooling towers of power unit No. 3
7. Cooling towers of power unit No. 4
8. Sprinkler pools of group "A" consumers cooling system of power units No. 3 and 4
9. Sprinkler pools of group "B" consumers cooling system of power units No. 3 and 4, including a standby one.
10. 110-330 kV outdoor switchgear
11. Special-purpose building for power units No. 1 and 2
12. Special-purpose building for power units No. 3 and 4
13. RW processing and storage building
14. Slam collecting tank
15. Fire depot
16. Structures for auxiliary water treatment
17. Start-up and standby boiler house
18. Combined auxiliary building
19. Auxiliary diesel generating station
20. Outdoor switchgear

Let's define the location of RNPP power units in Fig. 1.2: 11 - power units No. 1 and No. 2; 12 - power unit No. 3; 2 - power unit No. 4.

Rivne NPP is the first Ukraine's NPP utilizing water-water nuclear reactors, which currently are the only type of reactors in Ukraine, and the only Ukraine's NPP with power units based on the first reactors of VVER-440 series (B-213).

VVER-1000 water-water thermal neutron shell-type nuclear power reactors are intended for thermal energy generation (with the rated thermal power of 3000 MW) as part of the reactor unit. Reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel. Reactor core contains fuel assemblies that are situated at hexagonal lattice points and are made of low enriched uranium dioxide in a zirconium cladding.

The VVER-1000 reactor power unit operates in a two-loop circuit: first (hot) loop is a water circuit with direct heat extraction from the reactor; second (cold) loop is a steam circuit with heat extracted from the first loop and utilized in a turbine generator.

Within the reactor core, nuclear fuel fission energy is extracted via a coolant that is pumped through it by main circulation pumps. “Hot” coolant is fed from the reactor to the SG through the main coolant pipeline, where it transfers its heat energy to secondary water, and then is pumped back into the reactor by the main circulation pump. Dry-saturated vapour generated within the second steam generator loop is fed into the turbine generator that is equipped with a 1000 MW generator unit.

Borated water pumped at a pressure of 160 kgf/cm^2 is used as a moderator and a coolant in VVER-1000 nuclear reactors. The overall coolant flow through the reactor amounts to 84,800 m^3/h. Water temperature at the reactor inlet is 289 ºC and the outlet water temperature is 320 ºC during rated power operation.

Low-energy exhaust steam from reactor turbines is released through the water cooling system.

2 Potential radiation impact

Formation of gaseous, solid and liquid products that contain radioactive elements in the process of NPP operations is inevitable. Radiation impact of a power unit is due to the release of these elements into the environment [3–7].

During normal operation, any release of elements beyond the FE containment or partial destruction of this containment lead to a release of a certain amount of fission products into the first loop coolant. Minor amounts of radioactive products may also enter the first loop coolant following the neutron activation of structural materials. Activation product erosion and corrosion processes facilitate the release of these materials in the first loop coolant.

Radioactive fission and activation products are extracted from the coolant through ion exchange processes followed by the formation of contaminated ion exchange resins at radioactive water treatment (RWT) facilities. Periodic replacement of these resins results in the formation of both liquid and solid radioactive waste. Radioactive media handling process at RWT facilities located in the special purpose building (SPB) results in the formation of radioactive waste (RW): solid, liquid and gaseous.

Acceptable primary coolant leakage in the steam generator into the secondary circuit leads to radioactive contamination of water within this circuit.

Gases accumulated in the primary circuit during operation are extracted from the circuit. This results in the formation of a gaseous emission flow. Air emissions may also form due to ventilation of volatile primary coolant emissions from minor leaks, both controlled and uncontrolled. Such emissions usually contain tritiated water vapour, inert gases, aerosols and other gaseous particles.

Annual reactor shutdown involves pressure release from cooling systems, reactor vessel lid is taken off and one third of fuel assemblies are removed and placed for storage in the spent fuel pool. The remaining two thirds of fuel assemblies are rearranged to maintain the optimum neutron-flux density, and the core is filled with fresh fuel. Apart from spent fuel, fuel refilling procedures may lead to an increase in LRW discharge and air release from the spent fuel pool or from reactor and protective tube unit (PTU) inspection cavities. These types of waste are similar to radioactive waste released from the primary coolant.

Moreover, repair and maintenance procedures during the reactor shutdown are also sources of various RW released during opening and repair of the equipment. Certain primary components that were contaminated due to neutron exposure, as well as reactor and SPB equipment components that were exposed to radiation, may be replaced, followed by the formation of additional solid radioactive waste (SRW).

Liquid and solid RW handling and storage must be in accordance with the requirements of Sanitary Rules for Design and Operation of Nuclear Power Plants and Basic Sanitary Rules for Radiation Safety of Ukraine. Environmental release of these RW types during normal operation, design basis accidents and during the maximum credible beyond design basis accident are practically minimized and may be disregarded.

3 Assessment of environmental impact degree

The degree of environmental impact was assessed taking into account the amounts of radioactive releases, which were monitored daily or once a month.

3.1 Monitoring methods and equipment

The amounts of radioactive releases are monitored by IRG, LLN and iodine radionuclide groups in the following ventilation systems:

- VS of power units No. 1, 2;
- VS-1 at PR of power units No. 3, 4;
- VS-2 at PR of power units No. 3, 4 (during operation of 3TL-21, 4TL-21 systems);
- VS at SPB of power units No. 3, 4.

IRG release activity was measured on a continuous basis using PING-206S (units Nos. 1, 2, 3) and RKS-07P (unit No. 4) radiation detectors.

LLN and radioiodine samples were taken on a continuous basis using AFA-RMP-20 and AFAS-I-20 filters. Filters were sampled and checked using FHT-770S radio detectors on a daily basis for the purposes of in-process monitoring of LLN release (following 1 day exposure and not taking into account the activity at the time of filter installation). In-process monitoring of radioiodine was performed by γ-spectrometry at the Radiation Safety Laboratory (RSL).

For the purposes of radionuclide content monitoring, AFA-RMP-20 filters were kept for a month and then tested at the External Radiation Monitoring Laboratory (ERML) by γ-spectrometry using GEM solid-state detectors and DSPEC PLUS multichannel pulse analysers by ORTEC (USA). Release activity calculation was in compliance with the requirements of MM-I.0.03.025-14 “Model procedure for gamma-spectrometry of gamma-emitting radionuclides activity in loads sampled from NPP process media”.

The acceptable gas-aerosol release (GAR) levels are calculated in accordance with NRBU-97 requirements taking into account the limit dose rate, and are not affected by NPP capacity. The acceptable and reference GAR and liquid discharge levels at RNPP were approved by the MoH of Ukraine.

The 2017 total radionuclide release from RNPP power units as well as reference and limit releases and discharges for the past year are given in Table 3.1.

Table 3.1 - Total radionuclide release from RNPP power units in 2017

Nuclide	Activity, GBq	Reference release level, GBq	Release limit per radionuclide (radionuclide group), GBq
IRG	3.52E+04	3.18E+05	2.45E+07
Iodine	4.14E-02	5.11E+01	2.01E+03
Cr-51	1.86E-03	-	2.26E+05
Mn-54	8.65E-04	-	1.10E+03
Co-58	6.86E-04	-	3.43E+03
Fe-59	2.23E-04	-	3.61E+03
Co-60	5.29E-03	4.20E-01	6.20E+01
Nb-95	1.57E-03	-	9.12E+03
Zr-95	4.13E-04	-	4.74E+03
Ag-110m	5.04E-03	-	1.79E+02
Cs-134	1.04E-03	5.76E-01	1.46E+02
Cs-137	5.70E-03	5.04E-01	1.28E+02
Sr-90	3.77E-04	-	1.76E+02
H-3	1.63E+03	6.24E+03	3.39E+05

The technology (equipment, sampling method, preparation) allows measuring releases in the range from the minimum actual values to those exceeding the limit values.

3.2 Doses at borders with the neighboring states during normal operation

All radionuclides with respective average annual releases, which were used in calculations, are given in Table 3.2.

Table 3.2 - Calculated values of air radionuclide releases from SS RNPP facilities during normal operation

Radionuclide group	Radionuclide name	Release, Bq/year
IRG	^{88}Kr	2.35×10^{12}
	^{133}Xe	1.69×10^{13}
	^{135}Xe	4.23×10^{12}
Iodine	^{131}I	9.43×10^{7}
	^{133}I	$5.04E\times10^{7}$
	^{135}I	1.31×10^{7}
LLN	^{137}Cs	6.28×10^{6}
	^{134}Cs	9.66×10^{5}
	^{60}Co	7.27×10^{6}
	^{58}Co	1.09×10^{6}
	^{54}Mn	1.22×10^{6}
	^{51}Cr	4.56×10^{6}
	^{90}Sr	2.60×10^{5}
	^{59}Fe	3.28×10^{5}
	^{95}Zr	5.80×10^{5}
	^{95}Nb	2.23×10^{6}
	^{110m}Ag	4.71×10^{6}
Tritium	^{3}H	1.01×10^{12}
Radiocarbon	^{14}C	1.99×10^{11}

3.2.1 Distances to the neighboring countries

The location of RNPP with respect to the neighbouring countries is shown in Fig. 3.1.

The distance to neighboring countries from the Rivne NPP

Belarus - 60 km
Poland - 130 km
Lithuania - 310 km
Slovakia - 340 km
Moldova - 360 km
Romania - 370 km
Hungary - 410 km
Czech Republic - 510 km
Austria - 700 km
Germany - 710 km

Figure 3.1. Distances from SS RNPP to neighboring countries

Table 3.3 - Distances from SS RNPP to borders of neighbouring countries, km

Belarus	60
Poland	130
Lithuania	310
Slovakia	340
Moldova	360
Romania	370
Hungary	410
Czech Republic	510
Austria	700
Germany	710

The absolute distances are given in Table 3.3, with weather sectors indicated by arrows in Fig. 3.1

3.2.2Calculated doses at borders with the neighboring states during normal operation

The calculation of total expected individual doses from SS Rivne NPP in representatives of the population at borders with the neighboring states, is given in Table 3.4 and in Fig. 3.2. The distances in Fig. 3.2 refer to countries in Table 3.3. Dependences of the total dose on distances for two population categories - infants under 1 YOA and adults - have been shown. Expected annual doses were calculated after 50 years of releases. As seen from the table, the critical group in this case is represented by infants who are exposed to higher doses. Calculations for the critical group represented by children under 10 resulted in mean values between adult and infant doses. This data is omitted.

Table 3.4 - Expected dose, nSv/year

Country	Infants	Adults
Belarus	1.5	1.3
Poland	0.82	0.7

Country	Infants	Adults
Lithuania	0.3	0.26
Slovakia	0.35	0.3
Moldova	0.26	0.22
Romania	0.2	0.17
Hungary	0.29	0.25
Czech Republic	0.2	0.18
Austria	0.15	0.13
Germany	0.14	0.12

However, the expected doses are rather low. The maximum value is expected to occur at the border with Belarus, which is the nearest country to RNPP. These doses are within 1 nSv/year, which is well below the limit dose rate for NPP releases, which is equal to 40,000 nSv/year (see NRBU-97 [8]) and population radiation rates during normal NPP operation in Russia, which is equal to 200,000 nSv/year for an operating NPP and 50,000 nSv/year for a design NPP [9].

So, the impact on the neighbouring countries will be well below the established dose rates and limits for individual effective annual doses of 1 mSv (1,000,000 nSv) for the population [8].

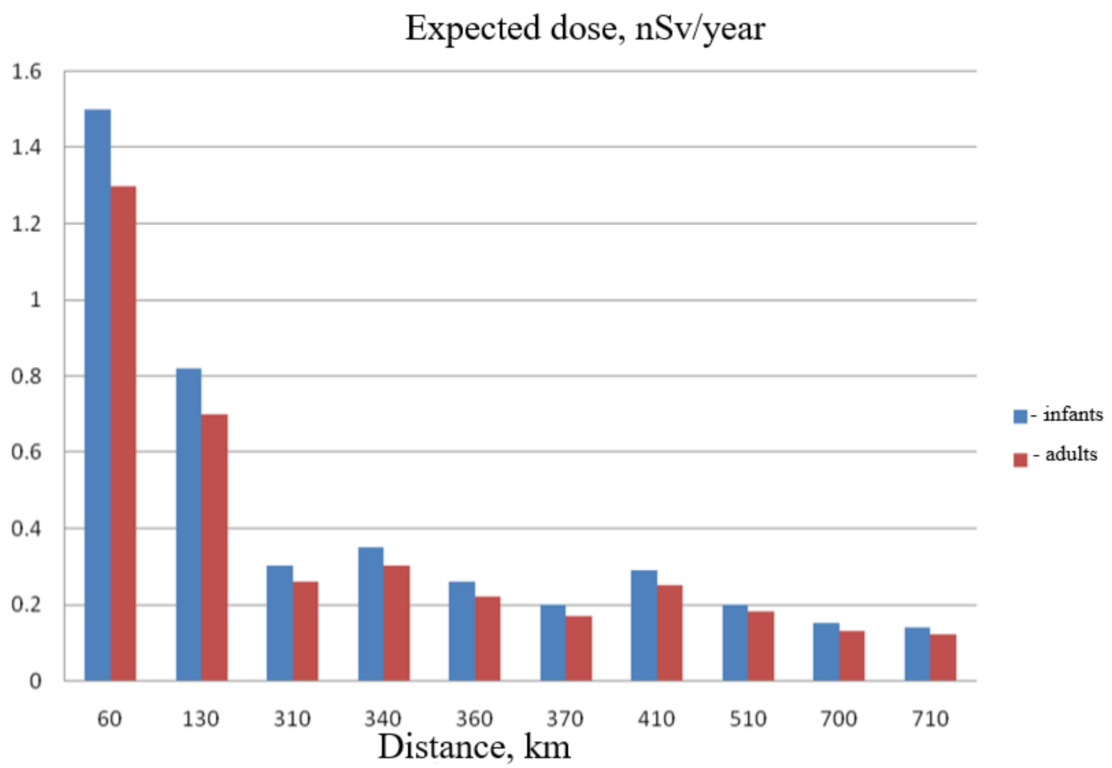

Figure 3. 2 -Total expected individual doses from the NPP in population (the distances refer to countries in Table 3.3)

Nonuniform reduction of doses based on the distance is due to the weather conditions, which are only measurable for 16 discrete sectors. Vectors from RNPP to the nearest borders of different countries (see Fig. 3.1) are located in different sectors, so, even though the doses reduce as the distance grows, the wind pattern may reverse this dependence. In Fig. 3.2, this is true for Lithuania (310 km) and Slovakia (340 km), as well as for Romania (370 km) and Hungary (410 km).

Let's analyze partial shares in full doses for different radionuclides and radiation routes in infants at the border with Poland, as an example. The relative ratios of the above data are nearly the same for other countries, however their values are proportional to the full dose.

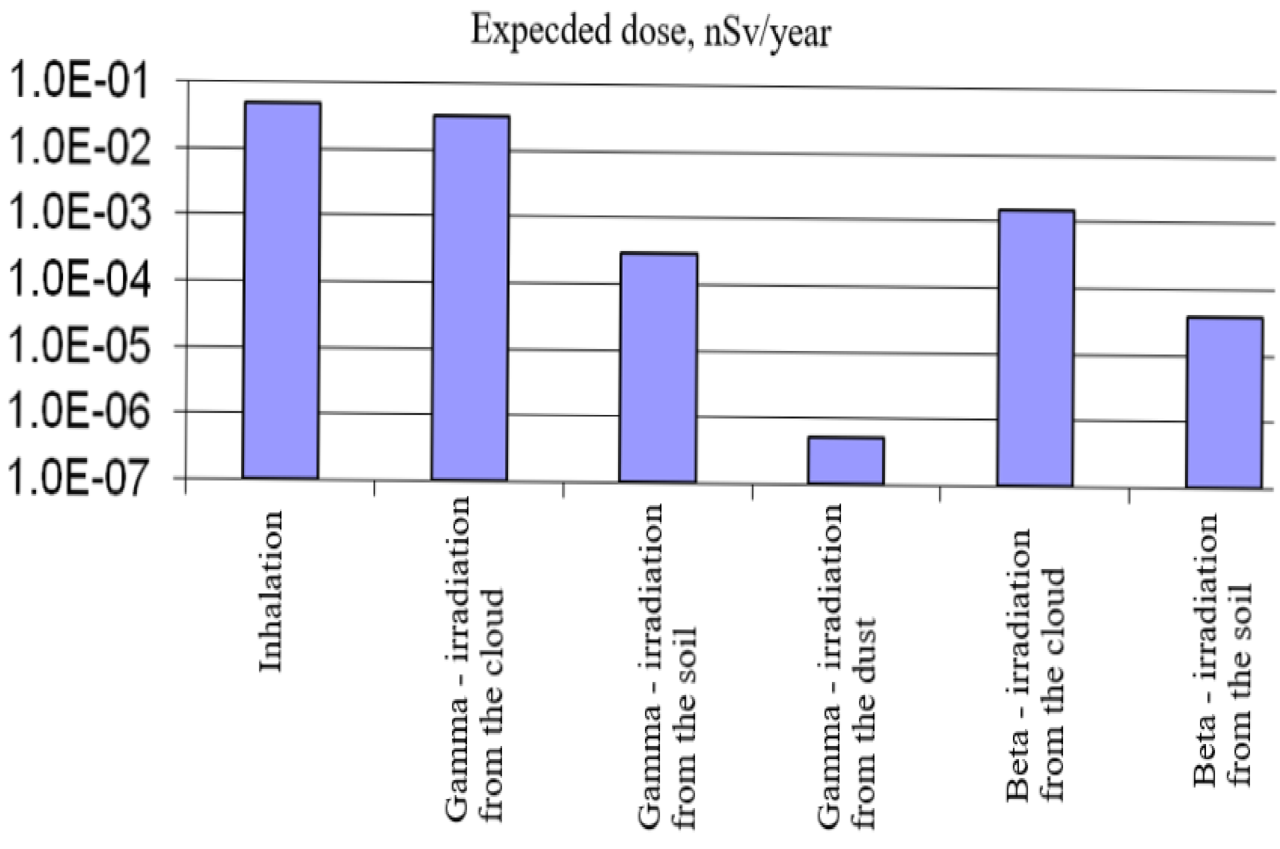

Figure 3.3 Relative share in expected individual doses for infants at the border with Poland

Fig. 3.3 shows shares (for inhalation and external radiation) in the full expected dose over a year after 50 years of releases in infants within 130 km from RNPP (at the border with Poland). The maximum share of 0.05 nSv/year is due to inhalation intake. The value is practically the same for gamma-ray photon radiation from the release cloud. The share of gamma radiation from soil is lower by two orders of magnitude. With the full dose at this distance of 0.82 nSv/year, radiation from the above sources accounts for about 5.6 %, while the rest of the dose is obtained from food products.

Fig. 3.4 shows shares in the full expected dose from different food products over a year after 50 years of releases in infants within 130 km from RNPP.

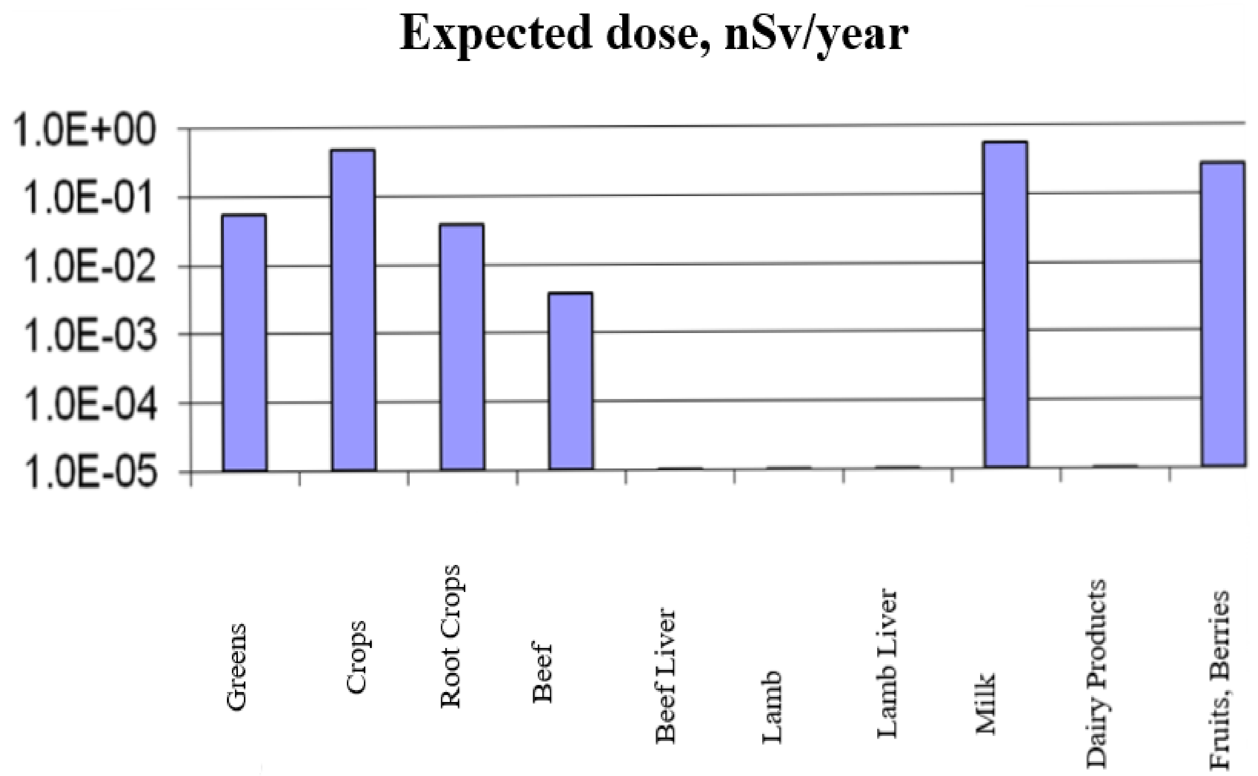

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Fig. 3.4 - Relative share in expected individual doses from different food products in infants at the border with Poland

The maximum share of 0.56 nSv/year is due to milk consumption. The share of cereals is lower; it makes 0.47 nSv/year.

The share of fruits and berries, which contain radionuclides that affect breast milk, is 2 times lower (0.27 nSv/year). Root crops and green vegetables account for a significant share, also absorbed through breast milk (see data in Fig. 3.4). Dairy products (cream, butter, cheese, etc.), similar to meat products, account for a negligible share. In general, food products provide a major share (94.4 %) in the total expected dose.

The major share in the total expected dose over a year after 50 years of releases of all radionuclides during normal operation (see Table 3.2) is due to the following radionuclides: ^{14}C, ^{3}H, ^{131}I and ^{88}Kr, see data in Fig. 3.5. This figure shows calculated shares of different radionuclides in expected individual doses in infants at the border with Poland.

It should be noted that the listed shares in the total dose reduce as the distance grows roughly the same as the total dose in Fig. 3.2.

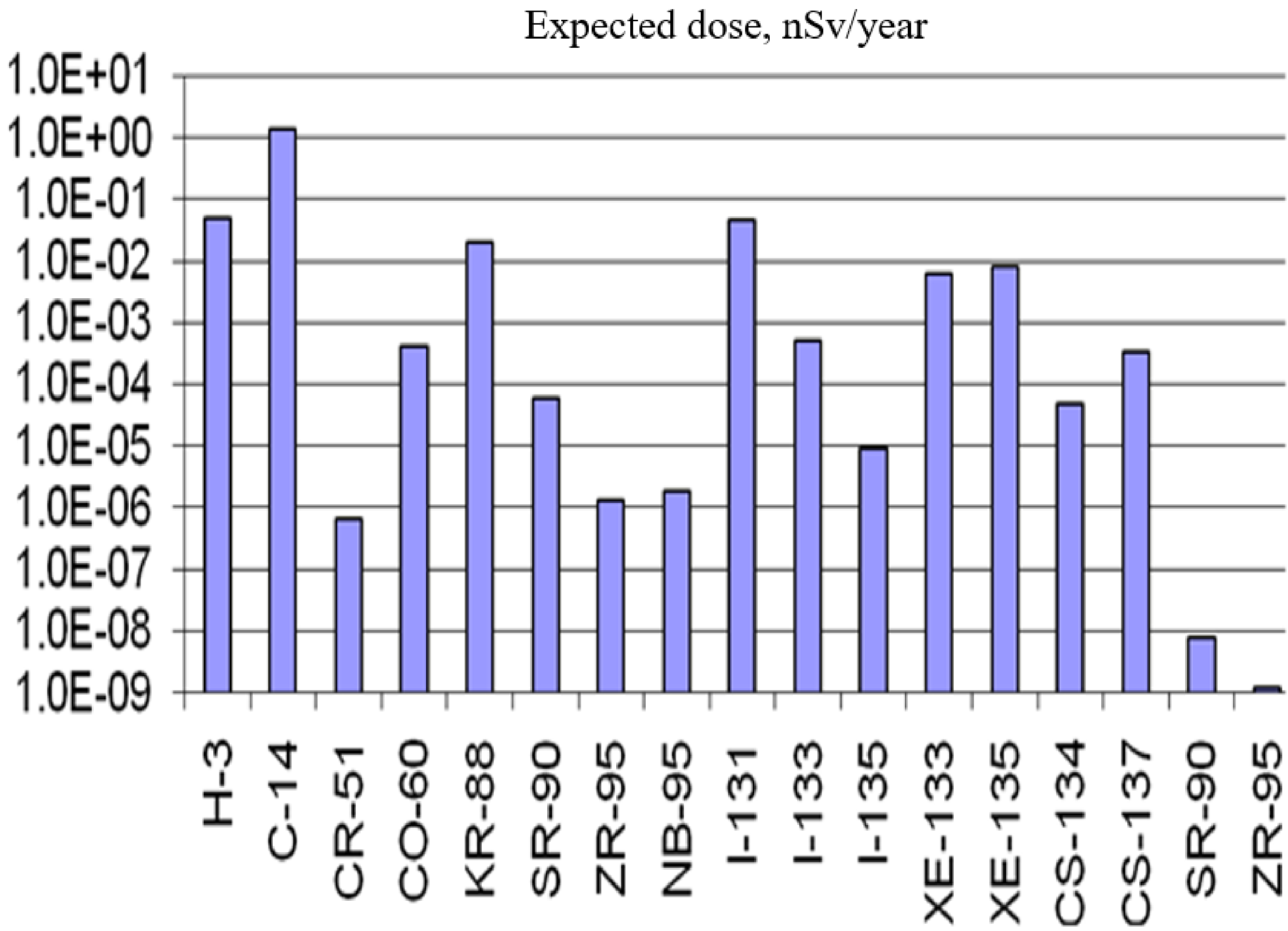


Fig. 3.5 - Relative shares of different radionuclides in expected individual doses in infants at the border with Poland

3.3 Doses at borders with the neighbouring states during accidents

The radiation impact of Rivne NPP was analysed based on the following maximum design basis accident (MDBA): an accident caused by double-ended rupture of the cooling system pipeline (loss-of-coolant nuclear reactor accident) at normal energy level.

Radionuclide intake during the beyond design basis accident (BDBA) was determined based on the limit value of environmental release of Cs-137 at the level of 30 TBq in accordance with the safety requirements of European operators for designs of nuclear power plants with light water reactors (LWR). Cs-137 isotope was chosen due to its prevalent value for long-term environmental pollution as well as its health impact.

Other isotopes in the form of aerosol (i. e. all radioactive decay products, except for inert gases and gaseous iodine isotopes) are released into the environment in proportion to this value, even if these isotopes are released into the atmospheric air.

The release activity of inert gases and gaseous iodine isotopes was calculated at 0.5 % of the total daily activity within the containment. The conservative value of the total release activity over the entire period of the release was established at the level of 7-fold release activity during day one [10-13].

The conservative release height is considered to be at the surface air level, which corresponds to the forecast release routes in case of major accidents due to containment leakage.

The total list of radionuclides that may be released in the environment, except for illustrative isotopes, includes other radioisotopes from the same group, which are present in the general member in proportion equal to that of the sum of decay products in the reactor core with respect to the illustrative isotope.

The dose of the proposed source member should be calculated taking into account the release of separate radioisotopes based on the time interval of linear duration of 0 to 24 hours following the accident - a conservative approach compared to the considered release duration of 7 days.

Table 3.5 shows radionuclide release parameters during the MDBA. The accident duration is taken to be 60 minutes. Other accidents that result in lower radionuclide releases are omitted.

Table 3.5 - Radionuclide release activities during the MDBA

Radionuclide	Half-life	Release during MDBA
Kr-88	2.84 h	2.00E+13
Sr-90	29.1 years	3.10E+11
Ru-103	39.6 days	4.50E+12
Ru-106	1.01 years	6.60E+11
I-131	8.04 days	4.98E+12
I-132	2.3 h	2.70E+12
I-133	20.8 h	4.00E+12
I-135	6.61 h	2.30E+12
Cs-134	2.06 years	7.80E+11
Cs-137	30.0 years	5.00E+11
La-140	1.68 days	8.40E+12
Ce-141	35.2 days	1.40E+13
Ce-144	284 days	8.60E+12

Primary radionuclides and their respective releases in case of the BDBA are listed in Table 3.6.

Table 3.6 - Radionuclide release activities during the BDBA at RNPP, Bq

Radionuclide	Release amount, TBq	Radionuclide	Release amount, TBq
Xe-133	3.50E+05	Cs-136	1.50E+01
Kr-85	2.10E+03	Te-131m	2.00E+01
Kr-85m	5.30E+04	Te-129m	8.00E+00
Kr-87	1.10E+05	Te-132	2.00E+02
Kr-88	1.40E+05	Sb-127	1.60E+01
Xe-131m	2.10E+03	Sb-129	4.60E+01
Xe-133m	1.10E+04	Sr-90	5.00E+00
Xe-135	1.10E+05	Sr-89	6.00E+01
Xe-135m	7.70E+04	Sr-91	7.50E+01
Xe-138	3.20E+05	Ru-103	3.00E+00
I-131	1.00E+03	Mo-99	4.00E+00
I-132	1.50E+03	La-140	5.00E+00
I-133	2.10E+03	Y-91	4.00E+00
I-134	2.30E+03	Ce-141	4.00E+00
I-135	2.00E+03	Ce-144	3.00E+00
Cs-137	3.00E+01	Np-239	4.80E+01
Cs-134	6.00E+01	Ba-140	1.00E+02

3.3.1Selection of the lowest weather conditions that result in the maximum radiation doses

Weather conditions for accidents have been selected based on calculated population radiation doses, i. e. the worst case weather conditions, which result in maximum values (conservative approach).

The dose at the reference point may vary depending on weather conditions. Six Pasquill weather stability classes are distinguished: A, B, C, D, E, F. (A - extremely unstable; B - moderately unstable; C - slightly unstable; D - neutral; E - slightly stable; F - moderately stable). According to Pasquill's approach, all weather conditions are divided into six classes: from extremely unstable “A” to stable “F”. An additional weather stability class “G” - extremely stable - is also considered.

If unstable class “A” prevails during the release, then major fluctuations in wind directions are observed, a thick release cloud mixing layer is present, and small amounts of radionuclides are transferred to great distances.

Where stable class “F” prevails, then although the cloud mixing layer is narrow, the wind speed is low still, while “dry” and “wet” washout results in a low activity of radionuclides at the reference point. These quality considerations are confirmed by quantifications, with the results shown in Fig. 3.6.

Calculated effective doses for 50 years at certain distances from RNPP are shown in Fig. 3.4 for different weather classes. The release values close to actual values were used to assess the weather dependence only. The calculations show that the maximum doses at all borders with the neighbouring countries are reached when weather class D prevails. The maximum expected dose is reached at weather class F for the smallest distance only (60 km, Republic of Belarus), but this dose exceedance is insignificant compared with class D, and in further calculations class D is used as the least safe weather category.

Calculations of the expected effective dose for the maximum design basis accident at different distances, which were performed for different precipitation levels, have shown that the maximum expected effective dose for 50 years is reached for the precipitation level of 0 mm/h for most countries (see calculated data in Fig. 3.5), except for the Republic of Belarus, where such maximum doses are expected at 1 mm/h.

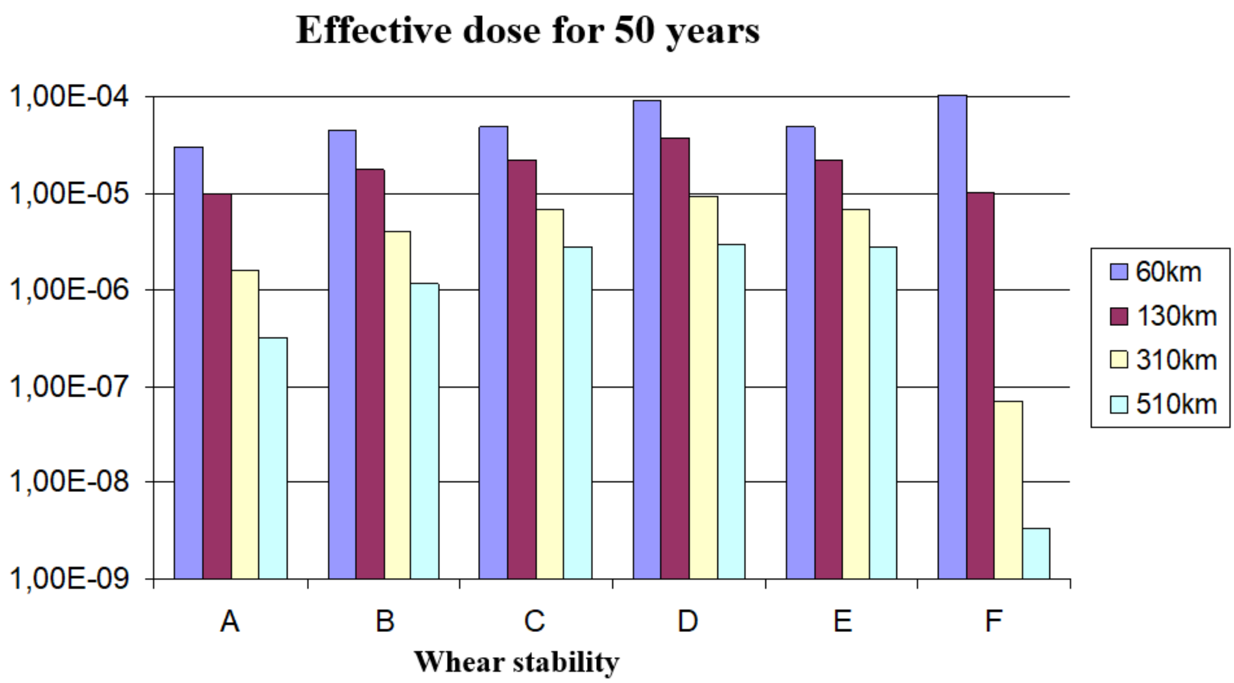


Figure 3.5 - Dependence of the effective dose for 50 years on weather stability class at certain distances from RNPP

Precipitation results in radionuclide washout from the radioactive cloud when dispersed over great distances, therefore maximum doses are expected at such distances under no-rain conditions. At small distance, rain may result in increased washout and, therefore, increase the dose. Based on the conservative approach, all further calculations will be performed for precipitation level of 0 mm/h. Rainy weather conditions will only be used for the smallest distance (60 km, Republic of Belarus).

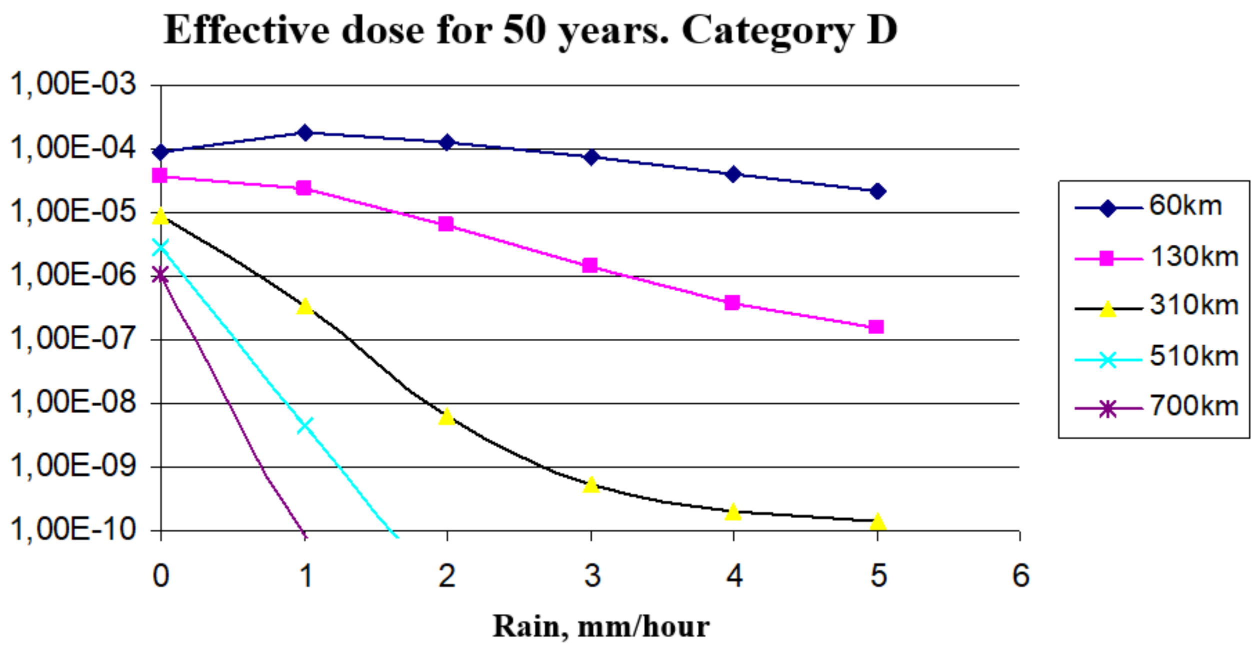


Fig. 3.5 - Dependence of the expected effective dose for 50 years on precipitation level

3.3.2 Doses at borders with the neighbouring states during accidents at RNPP

Calculations of expected effective doses for 50 years at different distances from RNPP during the MDBA and BDBA are shown in Fig. 3.6. The continuous curve in Fig. 3.6 demonstrates the dependence of the effective dose for 50 years on the distance in case of a BDBA, while dashed curve indicates the same in case of a MDBA.

Based on the data in Fig. 3.6, expected efficient doses reduce rapidly as the distance grows, and expected efficient doses during the BDBA are higher than the same during the MDBA by approx. two orders of magnitude.

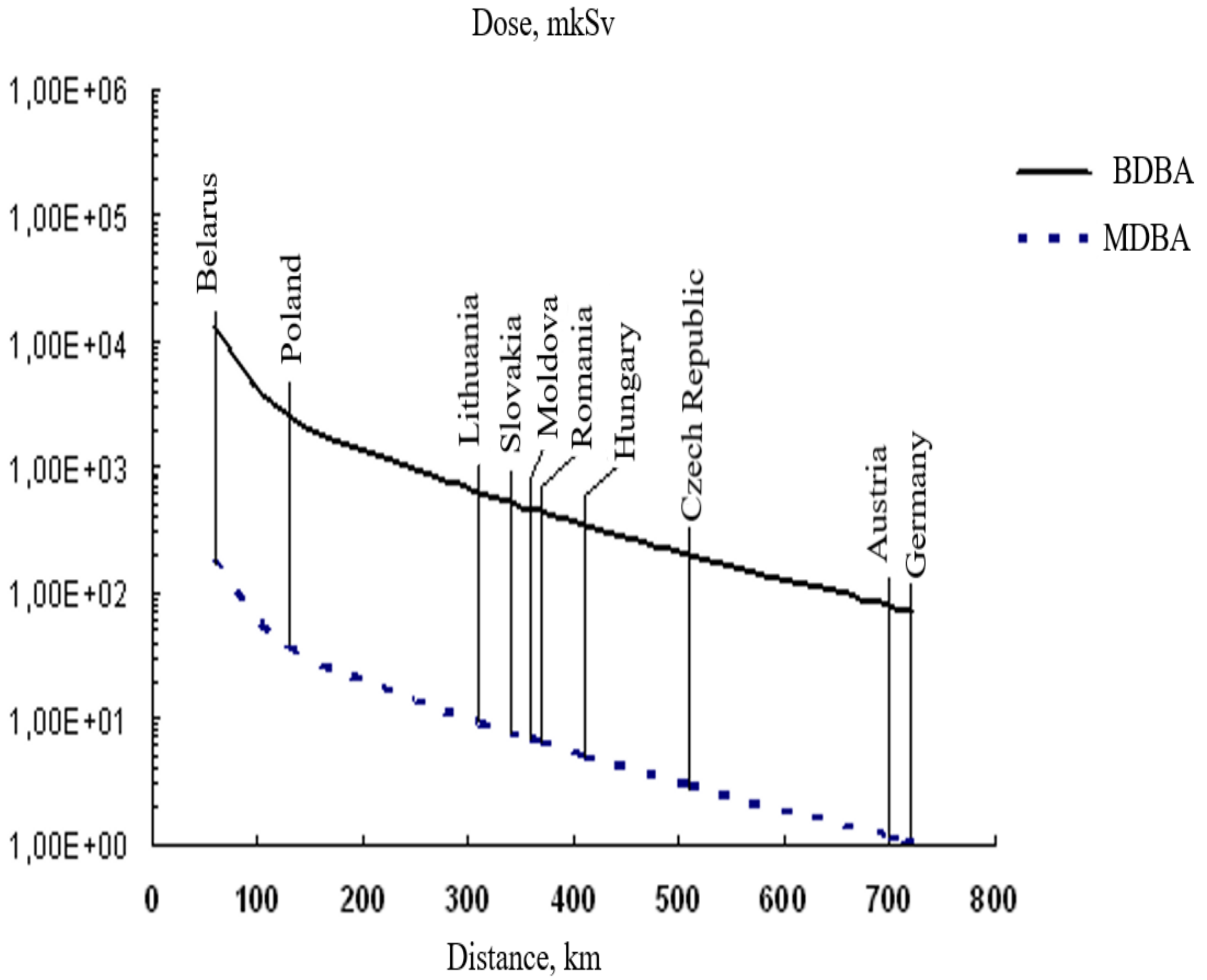


Fig. 3.6 - Dependence of the expected effective dose on distance during the MDBA and BDBA at RNPP

The maximum expected efficient dose for 50 years is observed for the Republic of Belarus and is equal to approx. 13 mSv, i. e. 0.26 mSv/year on average. The lowest weather conditions were used in the calculations for each country, so the dose dependence on distance is uniform.

The Radiation Safety Standards of Ukraine [8] set the doses that require countermeasures to protect the population (see Table 3.6) for radiation accidents.

The dose of 1 Gy for 2 days (it. 1 of Table 3.6) has not been exceeded since the total effective dose for 50 years is much below this value.

The dose of 5 mSv for the entire body for the first 2 weeks (it. 2 of Table 3.6) has not been exceeded since the calculation for the Republic of Belarus, which is the nearest country to RNPP, for the same period results in a value of 0.19 mSv for 2 weeks.

Table 3.6 - Intervention levels in case of radiation accidents

No.	Countermeasures	Dose levels
1	Unconditionally justified emergency intervention level (acute exposure)	1 **Gy** for 2 days for the entire body (bone marrow)
2	Lower justifiability limit for urgent countermeasures	5 **mSv** for the entire body for the first 2 weeks after the accident
3	Lower justifiability limit for decision on relocation	**0.2** Sv during the relocation period
4	Lower justifiability limit for decision on relocation	**0.05** Sv for the first 12 months after the accident
5	Lower justifiability limit for decision on temporary relocation	**0.1** Sv during the temporary relocation period

The doses in Table 3.6 - 0.2 Sv; 0.05 Sv; 0.1 Sv - are higher than the maximum dose for the Republic of Belarus, which makes 13 mSv. Expected doses for other countries are even lower, so no intervention is necessary.

Expected effective doses for the population after the MDBA or BDBA are low compared to the natural radiation background. In accordance with the 1993 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the United Nations General Assembly [14], the annual effective dose from natural radiation sources in regions with normal radiation backgrounds is equal to 2.4 mSv, i. e. 120 mSv for 50 years. The same dose for 50 years for all countries during the BDBA is below 13 mSv.

Therefore, the population dose for 50 years in the neighbouring countries will be less than 13 mSv, which is rather low compared with the natural radiation background.

Let's show different shares in the total dose based on radionuclide intake routes (see Fig. 3.6), using Slovakia as an example.

The relative share of different nuclides in the expected effective dose at a distance of 340 km from RNPP during the BDBA is shown in Fig. 3.7.

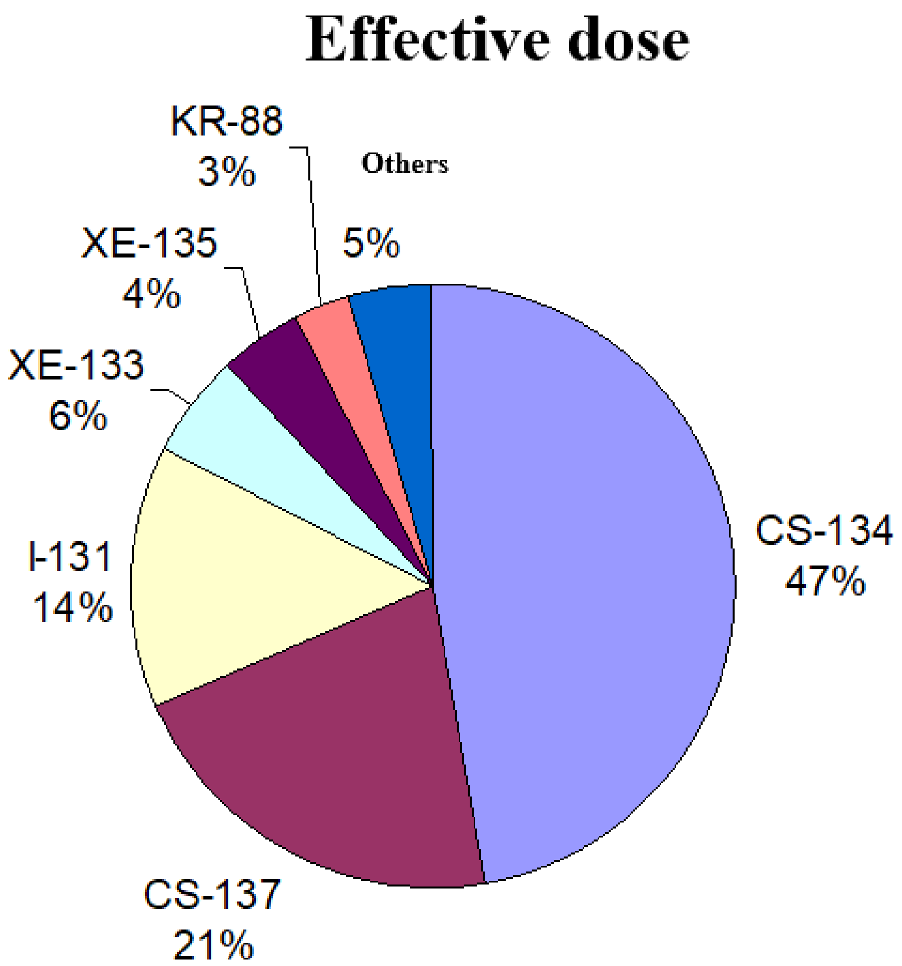


Fig. 3.7 - Relative share of different nuclides in the expected effective dose at a distance of 340 km during the BDBA

As seen from the data in Fig. 3.7, the greatest shares are represented by caesium isotopes: ^{134}Cs - 47 % and ^{137}Cs - 21 %. Inert gases - ^{133}Xe, ^{135}Xe and ^{88}Kr - also make a significant share in the total effective dose. The total share of 29 other nuclides during the BDBA is under 5 %.

Calculations indicate that the dominant share in the total effective dose among various radiation routes is due to food consumption (81 %; see data in Fig. 3.8). Dose from a radiation cloud makes a share of 14 %, dose from soil radiation - 4 %, and radiation by inhalation - 1 %. Other radiation routes can be neglected.

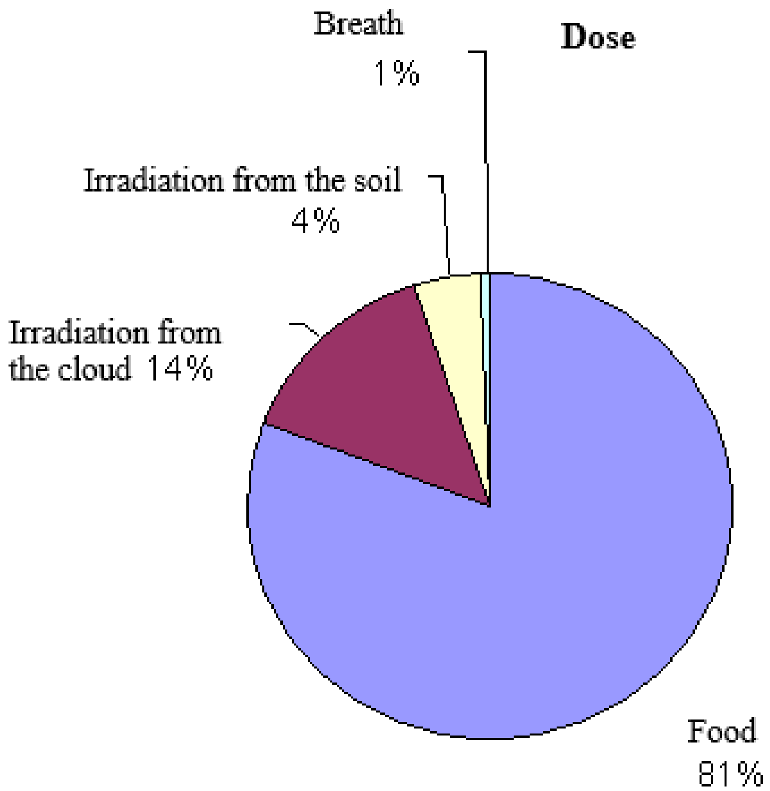


Fig. 3.8 - Relative share of different radiation routes in the expected effective dose at a distance of 340 km from RNPP during the BDBA

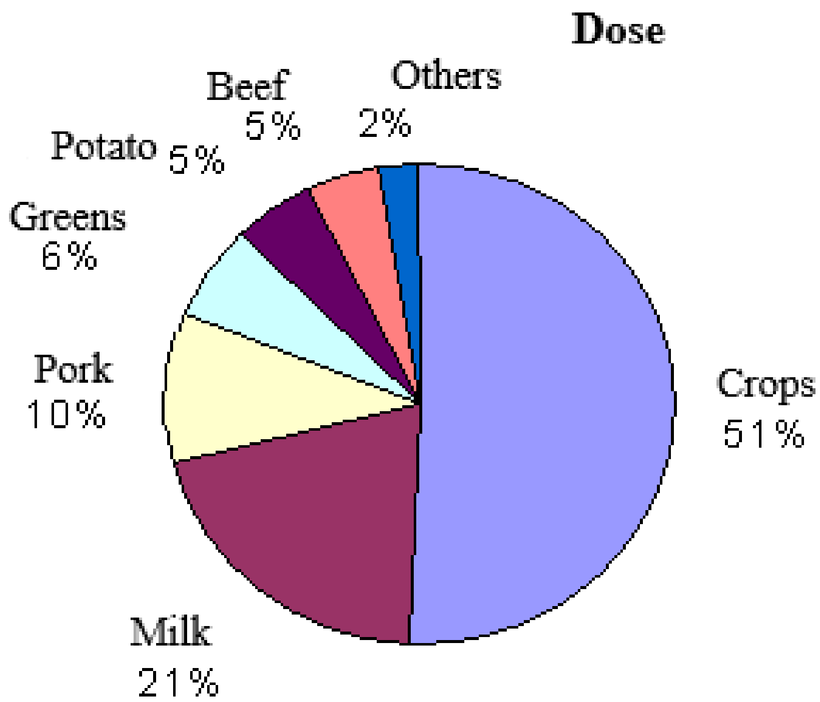


Fig. 3.9 - Relative share of basic food products in the expected effective dose at a distance of 340 km from RNPP during the BDBA

Of all food products, a significant share in the total effective dose is made by cereals, milk/dairy and meat products, vegetables and potatoes (see data in Fig. 3.9).

The total share of other food products is 2 %.

4 Measures to mitigate environmental impact

Environmental releases may be reduced by consistent implementation of in-depth staged protection strategy [15] based on the following:

- system of physical barriers in the way of environmental propagation of ionizing radiation and radioactive substances;
- system of technical and organisational arrangements to secure the physical barriers and keep them effective in order to protect the population and the environment;

The successive barrier system includes:

- fuel matrix;
- FE cladding;
- reactor coolant boundary;
- leak-tight reactor enclosure;
- biological protection.

During normal operation, the above barriers as well as the necessary technical control and protection means shall be operational, and shall be in a state that allows their proper functioning. If this condition is violated, the power unit must be set to safe state in accordance with the operating documentation.

The main purposes of in-depth staged protection strategy implementation include timely detection and elimination of factors that cause abnormal operation, occurrence of emergencies, preventing their development into accident, as well as limiting and elimination of the accident consequences.

5 Description of environmental impact assessment methods

PC CREAM (Consequences of Releases to the Environment: Assessment Methodology) software suite developed for the EU by NRPB (National Radiological Protection Board) (UK) in cooperation with a number of scientific institutions in the EU, was used to model propagation of released radionuclides over distances up to 1,000 km during normal operation of the plant.

5.1 PC CREAM

5.1.1 Brief model description

PC CREAM software suite and its separate modules are described in [17]. The system is designed for calculating radiation impact of continuous (accident-free) air releases and river/sea discharges of radioactive substances. The key features of the software suite are:

- assessment of individual and collective doses from air releases and sea discharges, as well as individual doses from river discharges;
- effective doses (as per ICRP Publication No. 60 [18]) are calculated using dose factors from ICRP Publication No. 72 [19] (ICRP recommendations are also used when developing radiation safety regulations in Ukraine);
- three age groups are considered: infants under 1 YOA, children under 10 YOA and adults;
- reference data include averaged releases and discharges per year;
- the suite allows for choosing from 5 integration times (1, 50, 500, 1000 years and infinity) for collective doses and from 3 integration times (1, 5 and 50 years) for individual doses;
- integration time following the intake of radionuclides by the human body is set to 50 years for adults and 70 years for children;

- dose integrated by n years for 1 year of release and/or discharge is numerically equal to an average dose on n[th] year for continuous release and/or discharge;

- the model covers distances up to 3,000 km;

- air release models take into account all irradiation exposure pathways, while water discharge models do not take into account the possibility of water use for agricultural irrigation.

In PC CREAM, atmospheric dispersion is assessed using Gaussian model, dry deposition using source depletion model, wet deposition using washout factors. The atmospheric dispersion model used accounts for sedimentation of a single daughter product during spot motion. Following deposition, radionuclide transport is represented by separate compartment models for soil and food products [20].

External air radionuclide exposure is calculated in PC CREAM using finite and infinite cloud models for gamma and beta irradiation, respectively.

5.1.2 Mathematical plume dispersal models

Plume dispersal is modelled by modified Gaussian equation [20]:

$$\overline{A}(x,z) = \frac{Q}{(2\pi)^{\frac{3}{2}} x\sigma_z\mu} \sum_{s=0}^{\infty} \exp\left[-\frac{(2sL \pm h_{eff} \pm z)^2}{2\sigma_z^2} \right] \qquad (5.1)$$

where $\overline{A}$ is mean air activity at point (x, z), Bq/m^3;

Q is radionuclide stack emission rate, Bq/s;

x is downwind distance, m;

μ is average wind speed, m/s;

σ_z is vertical dispersion factor, m;

h_{eff} is effective stack height, m;

L is mixing height, m;

s is 0, 1, 2, 3, etc.

PC CREAM uses fixed wind rate and mixing height values for each atmospheric stability class in Table 5.1.

Table 5.1 - Wind rate and mixing height values used in PC CREAM

Pasquill stability class	Wind rate at 10 m, m/s	Mixing height, m	Rain
A	1	1300	No
B	2	900	No
C	5	850	No
D	5	800	No
E	3	400	No
F	2	100	No
C	5	850	Yes
D	5	800	Yes

a. Dispersion factors

Vertical dispersion factor σ_z, which is used to calculate dispersion:

$$\sigma_z = \frac{ax^b}{1 + cx^d} F(z_0, x) \quad (5.2)$$

$F(z_0, x)$ is correction for ruggedness:

$$F(z_0, x) = \ln\left(fx^g \left[1 + \frac{1}{hx^j} \right] \right), \text{ at } z_0 > 0.1 \text{ m}, \quad (5.3)$$

$$F(z_0, x) = \ln\left(fx^g \left[\frac{1}{1 + hx^j} \right] \right), \text{ at } z_0 \le 0.1 \text{ m}, \quad (5.4)$$

where z_0 is soil ruggedness height, m; see values of a, b, c and d factors in equation (5.2) and f, g, h and j in equations (5.3) and (5.4) in Table 5.2.

Table 5.2 - Factors to calculate vertical dispersion factor and factors for ruggedness correction

Pasquill stability class	**a**	**B**	**c**	**d**
A	0.112	1.06	$5.38 \cdot 10^{-4}$	0.815
B	0.130	0.950	$6.52 \cdot 10^{-4}$	0.750
C	0.112	0.920	$9.05 \cdot 10^{-4}$	0.718
D	0.098	0.889	$1.35 \cdot 10^{-3}$	0.688
E	0.0609	0.895	$1.96 \cdot 10^{-3}$	0.684
F	0.0638	0.783	$1.36 \cdot 10^{-3}$	0.672

Soil ruggedness, m	**F**	**G**	**h**	**j**
0.01	1.56	0.0480	$6.25 \cdot 10^{-4}$	0.45
0.04	2.02	0.0269	$7.76 \cdot 10^{-4}$	0.37
0.1	2.72	0	0	0
0.4	5.16	-0.098	18.6	-0.225
1.0	7.37	-0.0957	$4.29 \cdot 10^{3}$	-0.60
4.0	11.7	-0.128	$4.59 \cdot 10^{4}$	-0.78

b Plume depletion

c Dry deposition

Dry deposition model is as follows: $R_{dry} = V_r \cdot A$, where R_{dry} is radionuclide deposition rate per unit area (Bq/(m^2·s)); V_r is deposition rate (m/s); A is concentration of radionuclides in the surface air layer (Bq/m^3).

d Wet deposition

Fraction of radionuclides deposited from the plume with rain or snow is modelled using the following equation:

$$R_{wet} = \frac{\Phi Q'_{wet}(t)}{x \alpha \mu},$$

where R_{wet} is surface deposition rate (Bq/(m^2·s)); Φ is washout factor (s^{-1}); Q'_{wet} is radionuclide activity that remains within the plume when a point under consideration is reached (x (m) from the release point) over the entire time (t) (Bq/m^3):

$$Q'_{wet}(t) = \frac{Q_0 f_{wet}}{m_1 - m_2}\left[(m_1 + \Phi)e^{m_2 t} - (m_2 + \Phi)e^{m_1 t}\right], \tag{5.5}$$

$$2m_1 = -\left(\Phi + P_{dry} + \mathrm{P}_{\mathrm{wet}}\right) - \sqrt{\left(\Phi + P_{dry} + P_{wet}\right)^2 - 4\Phi P_{dry}}\ ,$$

$$2m_2 = -\left(\Phi + P_{dry} + \mathrm{P}_{\mathrm{wet}}\right) + \sqrt{\left(\Phi + P_{dry} + P_{wet}\right)^2 - 4\Phi P_{dry}}\ ,$$

$$f_{wet} = P_{dry}/(P_{dry}+P_{wet}),$$

P_{dry} and P_{wet} are dry and wet weather probabilities, respectively; α is sector angular width, rad; μ is average wind speed.

e Depletion factor

Fraction of radionuclides depleted from the plume:

$$F = F_{wet} \cdot F_{dry} \cdot F_{decay}\ .$$

Fraction of radionuclides depleted with precipitation:

$$F_{dry} = \left[\exp F_{0dry}(x)\right]^{V_z/\mu}$$

where

$$F_{0dry}(\mathrm{x}) = -\sqrt{\frac{2}{\pi}}\int_0^x \frac{1}{\sigma_z}\left\{\exp\left[-\frac{h_{eff}^2}{2\sigma_z^2}\right] + \exp\left[-\frac{\left(h_{eff} + 2L\right)^2}{2\sigma_z^2}\right]\right\}dx$$

at $\sigma_z(x) < L$, and $F_{0dry}(x) = F_{0dry}(x_L)-(x-x_L)/L$ at $\sigma_z(x) \geq L$. x_L here is such that $\sigma_z(x_A) = L$.

$F_{decay} = \exp(-\lambda x/\mu)$. Daughter product concentrations are calculated by substituting Q with QR_d in equation (5.1), where:

$$Rd = \frac{\lambda_d}{\lambda_m - \lambda_d}\left[\exp\left\{-\lambda_\partial \frac{x}{\mu}\right\} - \exp\left\{\lambda_м \frac{x}{\mu}\right\}\right]$$

λ_d, λ_m here are decay constants for daughter and mother radionuclides, respectively.

5.1.3Compartment exponential models

The impurity exchange dynamics within the systems are modelled using first-order differential equations [20]:

$$\frac{dA_i}{dt} = \dot{A}_{0,i} + \sum_n k_{ni}A_n - \sum_j k_{ij}A_i, \qquad (5.6)$$

where A_i is the content of radionuclides within Link i;

$\dot{A}_{0,i}$ is radionuclide intake rate in Link i from outside the system;

k_{ij} is the constant of radionuclide migration from Link i to Link j.

Positive terms of the sum in (5.6) represent the impurity intake rate within Link i from other links, and negative terms represent impurity outflow rate due to removal into other links and radioactive decay. k_{ij} A_i members are the speed of impurity migration from Link i to Link j. Solution of the set of equations (5.6) is a polynomial, in which each component accurate to a coefficient is an exponential series $\exp(-a_i t)$, and a_i are certain constants. The key disadvantage of this model is the assumption that the result does not depend on duration of migration constants k_{ij}, while actual external radionuclide migration often is of a more complex nature.

5.1.4 Migration model for agricultural plants

The migration scheme is shown in Fig. 5.1. Link 1 is topsoil with uniformly distributed activity, Link 2 is aerial parts of plants, which are directly contaminated with radioactive fallout, Link 3 is aerial parts of plants, which are contaminated with soil grains during harvesting, Link 4 is root systems of plants, Link 5 is subsoil layer that contains roots. Constants k_{ij} (s^{-1}) correspond to transitions between links, which are due to the following processes: k_{12} - secondary radioactive fallout; k_{21} - sweeping-away with wind and rainwash; k_{13} - contamination of aerial parts of plants with dirt during harvesting; k_{14} - root absorption; k_{15} - draining out of the root soil layer; k_{22}, k_{33}, k_{44} - periodic harvesting; k_{31}, k_{41} are formal migration constants that provide for nuclides balance within links 1, 3, 4. See values of migration constants in Table 5.3 and Table 5.4.

Table 5.3 - Migration constants for agricultural plants (common for all elements, s^{-1})

Migration constant	Grain crops	Other agricultural plants	Migration constant	Grain crops	Other agricultural plants
k_{12}	7-9	7-9	k_{41}	1	1
k_{21}	2.7-4	2.7-4	k_{15}	2.2-10	2.2-10
k_{13}	8.9-9	4.4-8	k_{22}, k_{33}	3.2-8	3.2-8
k_{31}	1	1	k_{44}	3.2-8	3.2-8

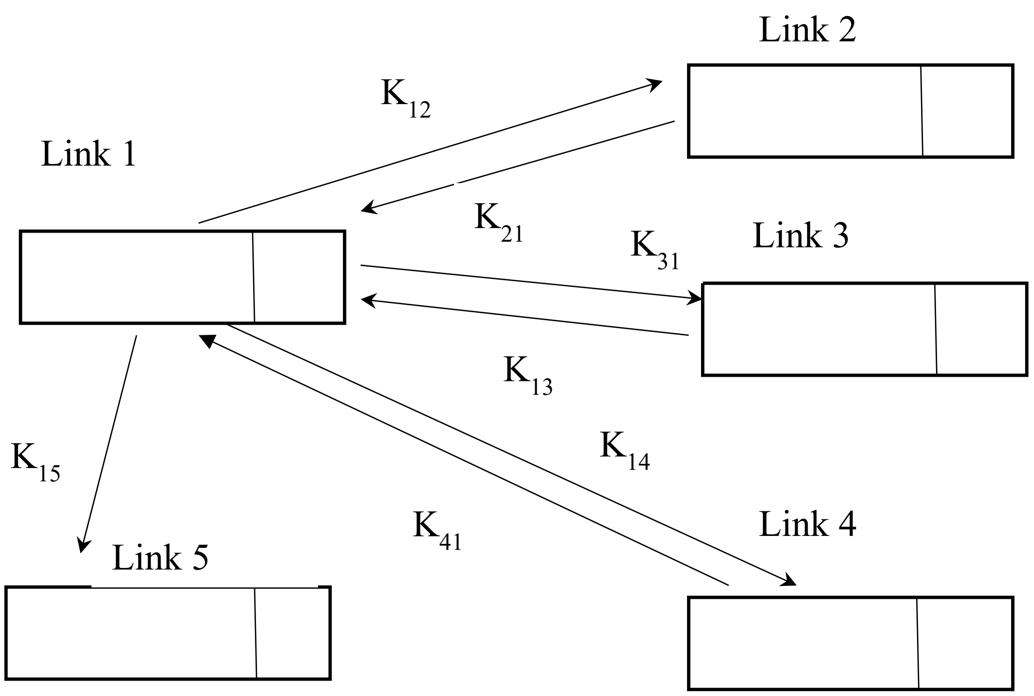


Table 5.4 - Migration constants for agricultural plants (based on chemical elements) k_{14}, s^{-1}

Element	Grain crops	Other agricultural plants	Element	Grain crops	Other agricultural plants
Cr	2.7-7	6.7-7	Ru	5.3-5	8.9-6
Mn	2.7-5	6.7-5	Ag	1.8-4	4.4-4
Fe	3.6-7	4.4-7	Sb	8.9-6	2.2-5
Co	8.9-6	2.2-6	Te	8.9-4	2.2-3
Zn	3.6-4	8.9-4	I	1.8-5	4.4-5
Rb	8.9-5	2.2-4	Cs	5.3-6	4.4-5
Sr	1.8-5	1.6-3	Ba	4.4-6	1.1-5
Y	2.7-6	6.7-6	La	2.7-6	6.7-6
Zr	1.8-7	4.4-7	Ce	2.7-6	1.6-5
Nb	8.9-6	2.2-5	Np, Pu	8.9-10	2.2-7
Mo	8.9-5	2.2-4	Am, Cm	8.9-19	2.2-7
Tc	4.4-2	0.11			

5.1.5. Mathematical models for dose calculation

5.1.5.1 Individual dose calculation based on food chains

Individual doses based on the food exposure route are calculated assuming that only local food products are consumed. This assessment provides for maximum possible radiation levels under the given conditions. These levels nearly always exceed the actual doses, since a certain share of non-local food products is usually present in food ration. For some of these products, like dairy, leaf vegetables or fruits from private garden plots, these estimates may be quite close to actual values. Based on the above assumption, the average rate for individual annual effective dose $\dot{H}$, Sv/s, of uniform fallout $\dot{A}_S$, Bq/(m^2·s), given the steady balance of environmental radionuclide accumulation/depletion processes, is calculated as follows:

$$\dot{H} = \dot{A}_S K_{fi}^{ind} B_{ig},$$

where B_{ig} is a dose factor of internal radiation exposure when radionuclides are ingested with water or food, Sv/Bq; K_{fi}^{ind} is factor that connects fallout intensity when radionuclides are ingested by a separate person with food, m^2:

$$K_{fi}^{ind} = K_{fi}\overline{S}, \quad (5.7)$$

where K_{fi} is a dimensionless factor that characterises loss of radionuclides during migration within the food chain, cooking and storage; $\overline{S}$ is agricultural area required for producing certain food products that are consumed individually, m^2. This parameter is calculated in PC CREAM using the following formulas:

for products of plant origin:

$$\overline{S} = \frac{I_{m,}}{P_y},$$

where P_y is annual yielding capacity of the culture under consideration, kg/m^2; I_m is annual individual consumption of this culture, kg;

for products of animal origin:

$$\overline{S} = \left(\frac{I_m}{P_a}\right)\sum_i \overline{S}_{a,i},$$

where I_m is annual individual consumption of meat or milk, kg (l); P_a is annual productivity of one animal (average annual increase in meat or milk per one animal, kg (l); $\overline{S}_{a,i}$ is area of ith feed crop per one animal. This parameter is calculated using the following formula:

$$\overline{S}_{a,i} = \frac{I_{a,i}}{P_{y,i}},$$

where $P_{y,i}$ is annual yielding capacity of ith feed crop, kg/m^2; $I_{a,i}$ is its annual consumption by one animal, kg.

The values can vary not only for residents of different republics, countries and regions, but for residents of the same village as well. As there is no precise data for the settlements located near NPPs and TPPs in Ukraine, and, besides, it is expedient to use the most similar parameters (without prejudice to the estimates) for comparative analysis of the impact, the average value of this parameter used for the estimates in this paper is derived from statistical data, by dividing the area occupied by this crop by the number of consumers in the country.

Value K_{fi} in (1.7) is a dimensionless factor that characterises loss of radionuclides during migration within the food chain, cooking and storage. When agricultural areas required to produce certain food products are considered, then this factor is a share of that part of the total fallout per given area of radionuclides, which will remain in products until consumed. Values of factor K_{fi} vary for different radionuclides, food products, local weather conditions, soil type, and fallout conditions (short-term or continuous).

5.1.5.2 Individual radiation doses (direct exposure)

Direct exposure means external radiation from photons and β-particles of radionuclides that are found in the air and fall out upon soil, as well as internal radiation by radionuclides that enter the body with air (inhalation route). In these cases individual doses are formed immediately in the release source area.

Photon radiation dose from a radiation cloud

Dispersed radionuclides may be sources of photon radiation. The radiation gas- or aerosol-induced dose in this case largely depends on the physical and chemical form of radionuclides and, naturally, on the radiation type and energy [20].

Source shaped as a semi-infinite space

During continuous release at a variable wind pattern and other weather parameters, a radioactive cloud is simulated by a source shaped as a semi-infinite space with activity A_V, Bq/m^3, uniformly distributed by volume. Effective dose rate, Sv/s, is then calculated using the following formula:

$$\dot{H} = A_V B_{a\gamma}, \quad (5.8)$$

where $B_{a\gamma}$ is a dose factor of internal photon radiation, Sv·m^3/(s·Bq). For radiation 2π-geometry:

$$B_{a\gamma} = \frac{E * 1{,}602 \cdot 10^{-13} r}{2 w \rho}, \quad (5.9)$$

where $E = \sum_i n_i E_i$ is photon energy efficiency, MeV/decay (n_i is absolute efficiency in decay scheme, photon/decay; E_i is i^{th} photon energy, MeV/photon); $1.602 \cdot 10^{-13}$ is energy equivalent, J/MeV; r = 1.09 is a factor of conversion from absorbed air dose into equivalent dose in biological tissue, Sv/Gy; $\rho = 1.293$ is air density under normal conditions, kg/m^3. 2 is a factor that takes into account the 2π-geometry of human radiation. w is Gray's energy equivalent per 1 kg of irradiated medium (in this case, air), w = 1 J/(Gy·kg).

Based on the UOM selected, dose factor (5.9) is represented as follows:

$$B_{a\gamma} = 2.13 \cdot E \ \mu Sv \cdot m^3/(year \cdot Bq)$$

Photon radiation dose from radionuclides that fall out on soil

Correlation between release rate $\dot{Q}$ (Bq/s) and effective dose rate $\dot{H}$ (Sv/s):

$$\dot{H} = \dot{A}_S B_{S\gamma} \tau_{ef}, \quad (5.10)$$

where τ_{ef} is effective period that takes into account radioactive decay and radionuclide soil depletion; it is calculated using the formula $\tau_{ef} = [(T_{1/2}\ T_b)/(T_{1/2} + T_b)]/0{,}693$,

where $T_{1/2}$ and T_b are radioactivity half-life and biological half-life;

$\dot{A}_S$ is contamination intensity, Bq/(s·m^2); dose factor $B_{S\gamma}$, Sv·m^2/(s·Bq) characterises effective dose rate of contaminated soil; it depends on the form of contamination and the type photon contamination distribution.

Dose of external β-radiation

Generalized term β-radiation means the emission of electrons by radioactive nuclei. If they carry a negative charge, they are called β^--particles, if they carry a positive charge β^+-particles, or positrons. The energy spectrum for β-particles is continuous and extends from very low values to 10 MeV, however the main practically significant range is from 10 keV to 5 MeV. In the range of the above energies, electrons, when interacting with a substance, lose their energy due to the inhibition processes. There is a braking power equal to the average energy loss per unit length of the path due to Coulomb collisions with bound electrons of the medium, $S_C\left[-dE/dx\right]$ meV/cm. This process leads to ionization and excitation of atoms. The second process is the energy loss due to the inhibitory (photon) radiation in the electric field of atomic nuclei and electrons is called the radiation braking power S_r, meV/cm. In practice, the mass braking power $S = S/\rho$ is usually applied, where ρ is the density of the medium.

Source: contaminated air

Doses in this case are calculated using the “immersion method”, with a source simulated in a shape of a semi-infinite space. 2π radiation geometry shall be always observed for β-radiation. Equivalent dose rate for exposed (not protected by clothes) biological tissue $\dot{H}$, Sv/s:

$$\dot{H} = A_V B_{a\beta}, \qquad (5.11)$$

where A_V is volumetric activity, Bq/m^3; $B_{a\beta}$ is a dose factor of external β-radiation, Sv·m^3/(s·Bq). See $B_{a\beta}$ values in Table 5.5.

Table 5.5 - Dose factors in basal layer, which are induced by β- particles and electrons from radionuclide conversion, which are found in a semi-infinite radioactive cloud, Sv·m³/(hour·Bq)

Radionuclide name	$B_{a\beta}$	Radionuclide name	$B_{a\beta}$	Radionuclide name	$B_{a\beta}$
^{14}C	2.16×10^{-8}	^{99m}Te	1.78×10^{-8}	^{137}Xe	2.78×10^{-6}
^{41}Ar	7.62×10^{-7}	^{103}Ru	7.18×10^{-8}	^{138}Xe	1.10×10^{-6}
^{51}Cr	9.68×10^{-11}	$^{106}Ru/^{106}Rh$	2.19×10^{-6}	^{137}Cs	2.87×10^{-7}
^{54}Mn	4.04×10^{-10}	^{124}Sb	6.46×10^{-7}	^{135}Cs	5.43×10^{-8}
^{59}Fe	1.77×10^{-7}	^{125}Sb	1.48×10^{-7}	^{136}Cs	1.77×10^{-7}
^{58}Co	5.37×10^{-10}	^{125m}Te	1.06×10^{-7}	^{137}Cs	4.16×10^{-7}
^{60}Co	1.36×10^{-7}	^{127m}Te	6.00×10^{-8}	^{138}Cs	1.91×10^{-6}
^{85m}Kr	4.41×10^{-7}	^{127}Te	4.03×10^{-7}	^{140}Ba	5.05×10^{-7}
^{85}Kr	3.89×10^{-7}	^{129m}Te	4.14×10^{-7}	^{140}La	9.31×10^{-9}
^{87}Kr	2.10×10^{-6}	^{129}Te	9.02×10^{-7}	^{141}Ce	2.83×10^{-7}
^{88}Kr	5.85×10^{-7}	^{131m}Te	2.46×10^{-7}	^{144}Ce	1.19×10^{-7}
^{89}Kr	1.93×10^{-6}	^{132}Te	8.68×10^{-8}	^{144}Pr	1.95×10^{-6}
^{86}Rb	1.07×10^{-6}	^{129}I	1.92×10^{-8}	^{147}Pm	6.30×10^{-8}
^{88}Rb	3.06×10^{-6}	^{131}I	3.44×10^{-7}	^{154}Eu	4.31×10^{-7}
^{89}Rb	1.44×10^{-6}	^{132}I	8.79×10^{-7}	^{155}Eu	2.60×10^{-8}
^{89}Sr	9.32×10^{-7}	^{133}I	7.19×10^{-7}	^{239}Np	3.87×10^{-7}
^{90}Sr	3.02×10^{-7}	^{134}I	1.05×10^{-6}	^{238}Pu	9.81×10^{-11}
^{90}Y	1.49×10^{-6}	^{135}I	6.93×10^{-7}	^{239}Pu	8.70×10^{-9}
^{91}Y	9.85×10^{-7}	^{131m}Xe	1.98×10^{-7}	^{240}Pu	9.81×10^{-11}
^{95}Zr	1.91×10^{-7}	^{133m}Xe	3.19×10^{-7}	^{241}Pu	$3.69\times\cdot10^{-13}$
^{95}Nb	2.62×10^{-8}	^{133}Xe	1.62×10^{-7}	^{242}Pu	7.56×10^{-10}
^{90}Mo	6.73×10^{-7}	^{135m}Xe	1.80×10^{-7}	^{241}Am	3.17×10^{-10}
^{99}Tc	1.14×10^{-7}	^{135}Xe	5.99×10^{-7}	^{242}Cm	1.01×10^{-14}

Source: skin surface contamination

See values of conversion dose factor $B_{S\beta}$, Sv·cm²/(year·Bq), based on the epidermis thickness, in Table 5.6.

Table 5.6 - Dose factor of external basal layer radiation with β-particles and electrons from radionuclide conversion in case of uniform contamination of skin with radioactive substances, $B_{S\beta}$, Sv·cm²/(year·Bq)

Radionuclide name	Epidermis thickness Δx, mg/cm²			Radionuclide name	Epidermis thickness Δx, mg/cm²		
	7	4	40		7	4	40
^{14}C	2.9×10^{-3}	7.9×10^{-3}	0.0	^{135}I	1.8×10^{-2}	2.2×10^{-2}	6.5×10^{-3}
^{32}P	2.1×10^{-2}	2.4×10^{-2}	1.1×10^{-2}	^{134}Cs	1.2×10^{-2}	1.6×10^{-2}	2.7×10^{-3}
^{60}Co	9.9×10^{-3}	1.6×10^{-2}	2.5×10^{-4}	^{137}Cs	1.4×10^{-2}	2.0×10^{-2}	2.3×10^{-3}
^{65}Zn	2.3×10^{-4}	3.3×10^{-4}	1.0×10^{-5}	^{137m}Ba	2.1×10^{-2}	2.4×10^{-3}	1.2×10^{-3}
^{90}Sr	1.6×10^{-2}	2.4×10^{-2}	3.4×10^{-3}	^{140}Ba	1.7×10^{-2}	2.2×10^{-2}	5.0×10^{-3}
^{90}Y	2.1×10^{-2}	2.4×10^{-2}	1.2×10^{-2}	^{140}La	2.0×10^{-2}	2.4×10^{-2}	9.2×0^{-3}
^{95}Zr	1.2×10^{-2}	1.7×10^{-2}	7.4×10^{-4}	^{144}Ce	8.9×10^{-3}	1.5×10^{-2}	1.7×10^{-4}
^{95}Nb	2.3×10^{-3}	6.4×10^{-3}	1.8×10^{-5}	^{144}Pr	2.2×10^{-2}	2.4×10^{-2}	1.3×10^{-2}
^{106}Rh	2.2×10^{-2}	2.5×10^{-2}	1.4×10^{-2}	^{203}Hg	9.6×10^{-3}	1.6×10^{-2}	3.7×10^{-4}
^{131}Te	2.3×10^{-2}	2.8×10^{-2}	1.0×10^{-2}	^{210}Bi	1.9×10^{-2}	2.3×10^{-2}	7.4×10^{-3}
^{132}Te	7.0×10^{-3}	$1.3\cdot\times10^{-2}$	4.7×10^{-5}	^{214}Bi	2.0×10^{-2}	2.3×10^{-2}	9.6×10^{-3}
^{129}I	1.9×10^{-3}	5.7×10^{-3}	0.0	^{235}U	1.1×10^{-3}	3.1×10^{-3}	2.9×10^{-7}
^{131}I	1.5×10^{-2}	2.1×10^{-2}	3.0×10^{-3}	^{237}Np	6.8×10^{-4}	4.3×10^{-3}	0.0
^{132}I	1.9×10^{-2}	2.3×10^{-2}	8.2×10^{-3}	^{238}Np	1.2×10^{-2}	1.8×10^{-2}	3.5×10^{-3}
^{133}I	1.9×10^{-2}	2.3×10^{-2}	7.6×10^{-3}	^{239}Np	2.3×10^{-2}	3.6×10^{-2}	1.2×10^{-3}

Internal radiation dose induced by radioactive gas inhalation

Annual effective doses of internal radiation due to inhalation of contaminated air are calculated using the following formula:

$$\dot{H} = QGVB \tag{5.12}$$

where $\dot{H}$ is the annual effective dose, Sv, Q is release, Bq/year, G is average annual meteorological dilution factor, s/m³, V is inhalation rate, m³/s. The conversion dose factor B, Sv/Bq, characterises the expected effective dose induced by nuclide inhalation with an activity of 1 Bq.

5.1.5.3 Calculation of collective doses

The collective dose assessment is necessary when choosing a site for the construction of radiation-hazardous enterprises, comparing the effectiveness of various measures to protect the population, calculating the radiation hazard from individual links of the nuclear fuel cycle, choosing the type of radiation technology, etc. The collective dose S, man Sv, is determined by the formula:

$$S = \sum_{j} N_i H_i \; ; \qquad (5.13)$$

5.2 Meteorological parameters

PC CREAM software was used for calculation of the transboundary impact under normal operating conditions. This software allows calculating the effect of radionuclide emissions at distances up to 3000 km.

The meteorological file necessary for PC CREAM software is created based on the measured weather data at SS RNPP.

Meteorological observations at the RAES RSCS meteorological station [21] were conducted by the automatic weather station MAWS-301 in Kyiv time.

Day change time:

- 00 hours 00 minutes, Kyiv time;
- 22 hours 00 minutes, Greenwich Mean Time (GMT).
- during the daylight saving time season, the day change time is 21 hours 00 minutes, GMT.

The RAES RSCS meteorological station is registered in the State Hydrometeorological Service of Ukraine since November 2005, valid registration certificate No. 02/10 GM of 28 October 2015.

The meteorological station measures the following meteorological parameters:

- wind direction;
- wind speed;
- air temperature;
- relative air humidity;

- atmospheric pressure;
- surface density of the solar radiation flux;
- radiation balance;
- amount of precipitation;
- intensity of precipitation;
- visibility;
- weather type.

The category of atmospheric stability characterizes conditions for the dispersion of impurities in the atmosphere. It depends on two main factors: turbulent diffusion and wind speed, which, in turn, depend on many meteorological factors.

There are several classification systems. The Pasquill classification scheme used in the report is recommended by the IAEA [22]. The Pasquill classification scheme uses seven categories, which are arranged by increasing the stability degree of the atmosphere from A to G.

5.2.1Meteorological parameters for the years 2006-2017

Wind speed:

- mean value 2.73 m/s;
- the maximum value of 25.6 m/s was recorded on 15.03.14.

The average windrose for 2006-2017 is given in Table 5.7

Table 5.7 - Wind rose for the observation period of 2006-2017, %

Direction	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**
2006-2017	4.73	5.42	5.3	4.24	2.53	4.89	7.84	8.89	6.95
Direction	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**Calm**	**Total**
2006-2017	7.34	9.02	7.81	7.91	5.99	6.11	5.03	7.36	100.0

The average wind speeds depending on directions are shown in Table 5.8.

Table 5.8 - Average wind speed values depending on the wind direction for the period of 2006-2017, m/s

Period	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	For the period
2006	3.21	2.98	2.48	3.07	2.45	3.21	3.11	2.99	2.48	2.33	2.62	3.09	3.13	3.01	2.74	2.97	2.74
2007	3.18	2.95	2.68	3.41	2.96	3.24	3.32	3.10	2.71	2.54	3.11	3.59	3.49	3.40	2.89	3.15	2.90
2008	3.11	3.13	2.55	3.28	2.66	3.12	3.33	3.24	2.90	2.72	3.16	3.79	3.39	3.16	2.95	3.19	2.96
2009	2.83	2.81	2.45	3.10	2.53	3.27	3.14	3.07	2.61	2.55	2.84	3.14	2.95	3.18	2.84	3.02	2.60
2010	2.95	2.57	2.94	3.56	2.88	3.18	3.16	3.25	2.72	2.80	3.24	3.52	3.17	3.18	2.82	3.08	2.76
2011	3.13	2.86	2.65	2.70	2.53	3.21	3.11	3.12	2.65	2.73	2.97	3.34	3.23	3.35	3.15	3.46	2.66
2012	3.00	2.72	2.72	2.94	2.45	2.81	3.26	2.98	2.64	2.68	3.05	3.39	3.16	3.23	3.15	3.48	2.71
2013	3.16	3.00	2.96	3.09	2.63	3.06	2.92	2.94	2.70	2.77	3.03	3.50	3.00	3.11	3.08	3.36	2.71
2014	2.90	2.71	2.76	3.30	2.90	2.97	3.14	3.06	2.66	2.53	2.91	3.33	3.31	3.12	2.75	3.03	2.65
2015	2.92	2.71	2.43	2.93	2.24	2.73	2.71	2.67	2.21	2.22	2.65	3.21	3.09	2.87	2.72	2.88	2.67
2016	2.99	2.79	2.31	2.67	2.21	2.84	3.03	3.19	2.39	2.41	2.62	2.86	2.84	2.69	2.55	2.86	2.67
2017	2.93	2.59	2.44	2.94	2.28	2.41	2.64	2.82	2.39	2.60	3.05	3.00	2.89	2.74	2.65	2.93	2.73
2006-2017	3.03	2.83	2.61	3.11	2.59	3.02	3.08	3.04	2.59	2.56	2.94	3.31	3.13	3.08	2.86	3.13	2.73

Wind speed frequency by intervals is given in Table 5.9.

Table 5.9 - Wind speed frequency by intervals for the period of 2006-2017, %

Wind speed	0.0<=v< 0.4 (no-wind conditions)	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4
2006	4.315	5.024	2.215	27.52	21.08	17.54	2.207	0.168	-	-
2007	7.297	3.385	18.09	26.38	2154	18.45	3.997	0.852	0.009	-
2008	5.866	3.233	17.66	26.33	22.31	20.23	3.789	0.571	0.003	-
2009	10.59	2.600	19.36	28.71	21.61	15.10	1.882	0.141	0.001	-
2010	10.58	1.482	15.74	29.34	22.42	17.75	2.437	0.238	0.001	-
2011	13.18	1.480	15.48	29.51	22.06	15.20	2.565	0.520	0.007	-
2012	10.31	1.907	17.52	29.36	22.07	15.69	2.814	0.329	0.001	-
2013	10.74	1.882	17.55	28.86	21.63	16.27	2.702	0.368	< 0.001	-
2014	10.92	2.547	17.25	29.09	22.04	15.60	2.337	0.220	0.002	< 0.001
2015	1.704	8.766	24.31	26.88	20.28	15.49	2.305	0.275	0.001	-
2016	1.839	8.607	23.57	27.41	20.78	15.50	2.161	0.148	-	-
2017	1.045	6.967	23.95	28.32	21.75	15.66	2.085	0.227	0.002	-
For the period	7.366	3.990	19.39	28.14	21.63	16.54	2.607	0.338	0.003	< 0.001

Air temperature:

- the average value over 12 years is +8.94 ºC;
- the absolute maximum of +35.5 ºC was recorded on 04.08.14 and 11.08.15;
- the warmest day was recorded on 29.07.12, with the average daily temperature of +28.49 ºC;
- the absolute minimum of -29.8 ºC was recorded on 03.02.12;
- the coldest day was recorded on 20.01.06, with the average daily temperature of -23.99 ºC.

Relative humidity:

- the average value over 12 years is 74.5 %
- the absolute minimum of 13.0% was recorded on 05.05.06, 27.04.09, 28.10.14 and 10.08.15.

Atmospheric pressure at the altitude of the meteorological station (altitude of the barometer gauge installation of 172.8 m above the sea level):

- the average value is 995.4 hPa;
- the absolute maximum of 1026.8 hPa was recorded on 23.01.06;
- the absolute minimum of 955.3 hPa was recorded on 29.10.17;
- the maximum pressure drop during a 24-hour period of 30.1 hPa was recorded on 18.01.07.

Total solar radiation:

- the annual average total solar energy is 4136.3 MJ/m^2;
- the annual average sunshine duration is 1961 hours 1 minute;
- the average long-term value of the total solar radiation is 221.1 W/m^2;
- the absolute maximum of one-minute solar irradiance of 1406 W/m^2 was recorded on 07.07.16.

The amount of precipitation:

- RG-13H average annual precipitation is 577.75 mm;
- PWD-11 average annual precipitation is 549.83 mm;
- the average annual snowfall height is 901.67 mm;
- the average intensity is 0.59 mm/h;

- the maximum precipitation rate of 2.45 mm/min was recorded on 14.07.08;

- the maximum amount of precipitation during a 24-hour period measured by PWD - 43.3 mm, recorded on 15.07.06;

- the maximum amount of precipitation during a 24-hour period measured by RG-13H - 51.4 mm, recorded on 13.08.12;

- the maximum amount of precipitation over a month is 161.53 mm (July 2008);

- the minimum amount of precipitation over a month is 1.6 mm (August 2015);

- the maximum fallen snow height during a 24-hour period is 183 mm (24.01.07);

- the maximum time of continuous precipitation is 46 hours and45 minutes (15.12.12 to 17.12.12), with precipitation in the form of mild and moderate snow;

- precipitation was observed 2683 days from 4377 days (61%); average annual number of days with precipitation - 224.

Average annual number of days with fog of 32.2 days was observed over the period of 2006-2017. The number of days with fog by months is presented in Table 5.10.

Table 5.10 - Number of days with fog

Month, year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2006	0	2	7	2	2	3	0	1	4	5	11	0	37
2007	0	4	3	1	1	0	1	1	2	1	4	3	21
2008	5	1	3	3	2	1	3	2	2	5	8	4	39
2009	6	3	6	1	0	4	2	2	5	2	8	4	43
2010	2	6	1	2	3	3	3	2	1	1	7	4	35
2011	6	0	1	1	1	2	1	2	4	1	5	2	26
2012	3	0	2	2	4	0	0	1	3	8	7	3	33
2013	2	1	2	3	3	2	0	2	6	8	3	4	36
2014	1	5	2	5	1	2	2	2	1	4	4	3	32
2015	4	3	1	0	0	0	1	0	6	4	5	9	33
2016	4	2	1	1	2	1	0	1	4	3	1	6	26
2017	4	6	0	4	0	0	2	0	0	2	3	4	25
For the period	37	33	29	25	19	18	15	16	38	44	66	46	386
Yearly average	3.1	2.8	2.4	2.1	1.6	1.5	1.3	1.3	3.2	3.7	5.5	3.8	32.2

The average annual values for the main meteorological parameters are summarized in Table 5.11.

Table 5.11 - Average values of meteorological parameters for the period of observations, years

No.	Parameter	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	For the period
1.	Prevailing wind direction	SSE	SW	SSE	SSE	SE	SW	SW	SSE	SE	SW	SW	SW	SW
2.	Maximum wind speed, *m/s*	18.3	24.0	24.3	18.8	18.8	22.1	19.0	18.8	25.6	21.2	16.9	21.0	25.6
3.	Average wind speed, m/s;	2.74	2.90	2.96	2.60	2.76	2.66	2.71	2.71	2.65	2.67	2.67	2.73	2.73
4.	Frequency of no-wind conditions, %	4.32	7.30	5.87	10.60	10.58	13.18	10.31	10.74	10.92	1.70	1.84	1.04	7.36
5.	Maximum air temperature, °C	32.2	34.7	34.7	32.3	34.5	33.7	35.4	34.0	35.5	35.5	33.7	34.0	35.5
6.	Average air temperature, °C	8.18	9.23	9.24	8.48	8.17	8.85	841	8.94	9.35	10.01	9.29	9.12	8.94
7.	Minimum air temperature, °C	-27.0	-16.6	-15.7	-22.5	-25.8	-16.8	-29.8	-19.3	-22.8	-18.7	-18.9	-21.5	-29.8
8.	Maximum air humidity, %	104	104	100	110	110	99	97	97	97	96	99	98.9	110
9.	Average humidity, %	77.2	75.9	76.4	76.8	76.8	73.4	74.1	74.5	71.1	68.9	72.6	76.1	74.5
10.	Minimum air humidity, %	13	14	17	13	17	16	15	15	13	13	19	17.6	13
11.	Maximum atmospheric pressure, hPa	1026.8	1017.9	1021.6	1013.3	1019.2	1018.9	1022.3	1018.0	1018.3	1023.4	1017.9	1020.5	1026.8
12.	Average atmospheric pressure, hPa	996.4	994.7	995.1	994.5	993.3	997.0	995.2	994.8	996.4	997.1	995.6	995.1	995.4
13.	Minimum atmospheric pressure, hPa	968.7	957.2	957.6	963.4	968.3	966.1	964.5	962.8	968.7	956.2	964.0	955.3	955.3
14.	Maximum atmospheric pressure adjusted to sea level, hPa	1051.4	1040.4	1045.1	1035.5	1043.6	1041.7	1046.1	1040.9	1042.0	1046.3	1040.2	1043.5	1051.4
15.	Average atmospheric pressure adjusted to sea level, hPa	1017.5	1015.7	1016.1	1015.6	1014.4	1018 .1	1016.3	1015.9	1017.5	1018.2	1016.7	1016.2	1016.5
16.	Minimum atmospheric pressure adjusted to sea level, hPa	989.8	977.4	978.0	984.1	988.7	987.0	985.5	984.2	989.5	976.6	984.8	975.6	975.6
17.	Maximum solar irradiance W/m^2	1352	1259	1292	1343	1263	1282	1286	1286	1324	1403	1406	1324	1406

18.	Average solar irradiance, W/m^2	218.7	215.4	207.8	220.8	218.9	233.6	226.2	220.1	231.5	230.0	220.1	212.3	221.3
19.	Total solar Energy, MJ/m^2	3992.1	4032.1	3898.3	4138.9	4052.5	4316.7	4234.5	4120.8	4311.0	4329.8	4186.9	4022.7	49636.4
20.	Sunshine duration	80 d., 20:34	78 d., 17:05	77 d., 10:06	81 d., 00:03	80 d., 10:22	86 d., 22:46	83 d., 07:10	81 d., 10:15	85 d., 05:24	86 d., 10:24	80 d., 12:38	78 d., 05:27	2 yr. 250 d., 12:14
21.	Maximum radiation balance, W/m^2	858	874	925	887	863	836	863	906	904	1053	1017	952	1053
22.	Average radiation balance, W/m^2	35.9	39.1	36.6	38.5	38.4	38.1	39.9	40.2	45.2	49.8	48.3	48.2	41.5
23.	Minimum radiation balance, W/m^2	-500	-458	-418	-398	-199	-198	-198	-198	-199	-199	-199	-199	-500
24.	Total radiation balance, MJ/m^2	1116.1	1231.9	1158.7	1209.8	1200.2	1196.2	1260.4	1265.3	1424.4	1570.6	1525.6	1517.8	15677.1
25.	Amount of precipitation (RG-13H), mm	568.8	527.6	695.0	600.6	583.8	485.8	681.4	554.8	525.0	511.6	494.6	654.0	6933
26.	Amount of precipitation (PWD-11), mm	578.59	521.42	701.01	580.64	527.49	481.42	627.86	535.39	437.20	460.30	478.13	668.50	6597.96
27.	Average precipitation rate (PWD-11), mm/h	0.62	0.62	0.68	0.55	0.50	0.58	0.63	0.56	0.55	0.61	0.52	0.65	0.59
28.	Maximum precipitation intensity (PWD-11), mm/min	1.015	1.559	2.453	1.011	0.943	1.677	1.166	1.918	0.721	1.630	1.484	1.476	2.453
29.	Height of fallen snow, mm	1093	814	594	1013	1291	620	1277	1463	437	283	852	1083	10820
30.	Duration of precipitation	38 d., 17:30	34 d., 19:22	43 d., 00:59	43 d., 21:10	44 d., 06:41	34 d., 15:17	41 d., 10:27	39 d., 13:20	33 d., 10:06	31 d., 07:14	38 d., 03:04	43 d., 00:17	1 yr 101 d., 05:27
31.	Maximum duration of continuous precipitation	18:35	20:46	16:52	24:00	17:52	14:30	24:00	24:00	14:22	10:45	15:14	16:35	24:00:00
32.	Minimum visibility, m	35	30	87	83	25	60	66	40	88	95	54	66	25
33.	Duration of reduced-visibility conditions	14 d., 04:13	6 d., 17:51	8 d., 07:08	10 d., 22:57	11 d., 18:37	8 d., 08:10	9 d., 17:37	11 d., 17:44	7 d., 07:06	8 d., 10:04	5 d., 23:54	8 d., 15:37	112 d., 02:58

34.	"No precipitation" weather conditions, min	293 d., 19:02	315 d., 14:03	307 d., 21:43	303 d., 06:25	300 d., 08:47	314 d., 14:15	307 d., 20:43	308 d., 11:27	318 d., 02:27	321 d., 01:21	315 d., 11:02	307 d., 05:35	10yr. 63 d., 16:50
35.	"Mist (V > 1 km)" weather conditions, min	00:19	-	-	-	-	-			00:03	-	-	-	00:22
36.	"Haze" weather conditions, min	4 d., 02:34	20:56	1 d., 01:10	1 d., 11:14	1 d., 20:19	1 d., 21:07	1 d., 06:03	2 d., 04:18	1 d., 11:09	2 d., 00:32	1 d., 05:01	1 d., 13:22	20 d., 21:45
37.	"Fog" weather conditions, min	5 d., 17:11	2 d., 08:10	3 d.,13:13	3 d., 16:27	3 d., 23:19	2 d., 04:40	3d; 01:53	3 d., 02:59	2 d., 13:07	2 d., 21:39	2 d., 02:59	2 d., 23:12	38 d., 04:49
38.	"Drizzle " weather conditions, min	3 d., 04:37	2 d., 10:53	5 d., 17:06	3 d., 10:23	1 d., 17:20	4 d., 02:56	1 d., 07:15	2 d., 08:09	2 d., 05:32	4 d., 08:40	2 d., 16:24	2 d., 10:57	36 d., 00:12
39.	"Rain" weather conditions, min	21 d., 13:24	26 d., 00:33	33 d., 21:12	28 d., 03:01	23 d., 18:47	21 d., 23:19	24 d., 17:06	22 d., 04:59	25 d., 16:28	28 d., 01:44	28 d., 14:23	34 d., 12:09	319 d., 03:05
40.	"Snow" weather conditions, min	28 d., 20:09	16 d., 23:46	13 d., 03:00	23 d., 05:14	30 d., 08:37	18 d., 15:57	27 d., 16:53	25 d., 14:12	14d , 07:10	6 d., 10:07	15 d., 20:27	16 d., 02:18	237 d., 03:50
41.	Meteorological station operation time	359 d., 07:35	364 d., 08:51	365 d., 07:58	363 d., 07:42	362 d., 01:11	363 d., 11:00	365 d., 22:03	364 d., 05:03	364 d., 18:35	364 d., 20:16	365 d., 22:27	364 d., 21:19	11y 353 d., 16:36

Table 5.12 for the distribution of atmospheric stability categories is given below.

Table 5.12 - Frequency of stability categories, depending on wind direction and speed for 2006-2017,%

Category	**Speed**	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**Total**
		N	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	
A	**0.0<=v<0.4**	0.006	0.006	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.006	0.008	0.007	0.007	0.006	0.006	0.006	**0.087**
	0.4<=v<1.0	0.014	0.012	0.012	0.010	0.008	0.009	0.009	0.010	0.011	0.012	0.013	0.014	0.013	0.014	0.015	0.013	**0.190**

	1.0<=v<2.0	0.069	0.059	0.054	0.042	0.038	0.043	0.055	0.057	0.065	0.069	0.084	0.072	0.073	0.073	0.081	0.072	**1.007**
	2.0<=v<3.0	0.083	0.075	0.066	0.045	0.040	0.056	0.094	0.097	0.087	0.086	0.100	0.075	0.085	0.098	0.117	0.102	**1.306**
	3.0<=v<4.0	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.001**
	4.0<=v<6.0	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	-	-	-	<0.001
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.171	0.152	0.136	0.100	0.090	0.111	0.163	0.168	0.169	0.173	0.206	0.168	0.179	0.191	0.220	0.193	**2.592**
B	**0.0<=v<0.4**	0.018	0.017	0.014	0.008	0.006	0.006	0.009	0.010	0.016	0.028	0.043	0.029	0.020	0.017	0.020	0.016	**0.278**
	0.4<=v<1.0	0.016	0.014	0.012	0.008	0.007	0.007	0.009	0.010	0.014	0.021	0.032	0.023	0.016	0.015	0.018	0.016	**0.238**
	1.0<=v<2.0	0.073	0.080	0.083	0.043	0.036	0.044	0.064	0.078	0.097	0.109	0.116	0.083	0.082	0.083	0.090	0.079	**1.239**
	2.0<=v<3.0	0.143	0.157	0.144	0.080	0.063	0.093	0.206	0.247	0.204	0.189	0.213	0.141	0.161	0.171	0.185	0.168	**2.566**
	3.0<=v<4.0	0.202	0.172	0.150	0.109	0.077	0.127	0.298	0.317	0.229	0.220	0.263	0.165	0.211	0.228	0.259	0.251	**3.278**
	4.0<=v<6.0	0.133	0.106	0.091	0.066	0.029	0.052	0.143	0.166	0.119	0.123	0.149	0.101	0.134	0.118	0.133	0.138	**1.803**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.583	0.546	0.493	0.315	0.220	0.329	0.729	0.828	0.678	0.691	0.815	0.542	0.624	0.631	0.707	0.669	**9.402**
C	**0.0<=v<0.4**	0.024	0.026	0.027	0.012	0.007	0.008	0.010	0.012	0.021	0.042	0.061	0.039	0.032	0.023	0.025	0.019	**0.388**
	0.4<=v<1.0	0.011	0.013	0.014	0.008	0.007	0.007	0.008	0.009	0.015	0.021	0.034	0.025	0.019	0.015	0.015	0.011	**0.232**
	1.0<=v<2.0	0.061	0.081	0.091	0.047	0.042	0.045	0.059	0.071	0.098	0.112	0.121	0.096	0.102	0.093	0.098	0.067	**1.285**
	2.0<=v<3.0	0.182	0.205	0.178	0.101	0.084	0.122	0.221	0.250	0.241	0.221	0.270	0.185	0.208	0214	0.231	0.193	**3.106**
	3.0<=v<4.0	0.205	0.187	0.154	0.123	0.075	0.126	0.290	0.315	0.197	0.209	0.309	0.217	0.262	0.239	0.249	0.230	**3.388**
	4.0<=v<6.0	0.212	0.185	0.145	0.150	0.054	0.107	0.278	0.312	0.170	0.207	0.332	0.274	0.349	0.249	0.231	0.235	**3.490**

	6.0<=v<8.0	0.026	0.026	0.018	0.020	0.004	0.005	0.019	0.032	0.020	0.027	0.041	0.038	0.043	0.025	0.019	0.025	**0.390**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.721	0.723	0.626	0.462	0.274	0.419	0.886	1.001	0.762	0.839	1.168	0.875	1.015	0.857	0.869	0.781	**12.279**
D	**0.0<=v<0.4**	0.077	0.095	0.137	0.084	0.071	0.059	0.061	0.070	0.126	0.203	0.242	0.163	0.142	0.083	0.076	0.052	**1.740**
	0.4<=v<1.0	0.037	0.051	0.065	0.042	0.043	0.041	0.041	0.045	0.068	0.103	0.139	0.117	0.100	0.063	0.051	0.035	**1.042**
	1.0<=v<2.0	0.236	0.399	0.403	0.232	0.221	0.282	0.325	0.388	0.488	0.572	0.556	0.397	0.474	0.358	0.412	0.242	**5.986**
	2.0<=v<3.0	0.471	0.604	0.502	0.325	0.237	0.469	0.660	0.817	0.741	0.647	0.765	0.582	0.631	0.535	0.619	0.447	**9.054**
	3.0<=v<4.0	0.374	0.400	0.338	0.327	0.154	0.392	0.641	0.787	0.438	0.361	0.589	0.564	0.572	0.444	0.433	0.390	**7.205**
	4.0<=v<6.0	0.343	0.343	0.296	0.481	0.124	0.410	0.556	0.604	0.235	0.291	0.651	0.856	0.749	0.519	0.372	0.386	**7.216**
	6.0<=v<8.0	0.082	0.083	0.050	0.118	0.026	0.070	0.102	0.091	0.021	0.091	0.275	0.467	0.332	0.198	0.105	0.110	**2.220**
	8.0<=v<12.0	0.008	0.014	0.002	0.007	0.001	0.003	0.006	0.004	0.002	0.012	0.048	0.106	0.060	0.037	0.014	0.015	**0.339**
	12.0<=v<25.0	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	**0.002**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	1.629	1.989	1.793	1.616	0.878	1.726	2.391	2.807	2.120	2.281	3.265	3.252	3.061	2.238	2.083	1.676	**34.805**
E	**0.0<=v<0.4**	0.012	0.014	0.012	0.007	0.010	0.009	0.009	0.013	0.015	0.031	0.031	0.024	0.022	0.014	0.010	0.006	**0.238**
	0.4<=v<1.0	0.006	0.008	0.007	0.007	0.012	0.014	0.013	0.011	0.013	0.015	0.016	0.013	0.016	0.011	0.009	0.005	**0.177**
	1.0<=v<2.0	0.053	0.079	0.055	0.040	0.050	0.069	0.079	0.091	0.093	0.107	0.113	0.090	0.116	0.087	0.091	0.046	**1.259**
	2.0<=v<3.0	0.141	0.182	0.126	0.108	0.083	0.158	0.209	0.251	0.216	0.158	0.199	0.157	0.178	0.147	0.157	0.125	**2.597**
	3.0<=v<4.0	0.091	0.115	0.108	0.110	0.047	0.156	0.192	0.229	0.144	0.084	0.147	0.133	0.145	0.122	0.110	0.113	**2.048**
	4.0<=v<6.0	0.091	0.096	0.088	0.146	0.044	0.144	0.176	0.185	0.066	0.111	0.233	0.301	0.241	0.160	0.113	0.146	**2.343**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.395	0.493	0.396	0.420	0.246	0.551	0.679	0.781	0.547	0.507	0.739	0.719	0.718	0.540	0.491	0.441	**8.662**

F	**0.0<=v<0.4**	0.005	0.007	0.005	0.004	0.003	0.004	0.005	0.006	0.008	0.016	0.016	0.010	0.009	0.006	0.004	0.002	**0.109**
	0.4<=v<1.0	0.003	0.003	0.003	0.002	0.004	0.003	0.003	0.003	0.005	0.008	0.010	0.008	0.009	0.006	0.004	0.002	**0.076**
	1.0<=v<2.0	0.017	0.028	0.023	0.016	0.022	0.023	0.021	0.029	0.041	0.043	0.045	0.033	0.039	0.032	0.035	0.014	**0.462**
	2.0<=v<3.0	0.055	0.076	0.054	0.042	0.031	0.053	0.072	0.083	0.078	0.079	0.089	0.074	0.075	0.063	0.073	0.055	**1.052**
	3.0<=v<4.0	0.077	0.087	0.070	0.071	0.035	0.076	0.103	0.117	0.084	0.076	0.124	0.119	0.118	0.087	0.091	0.088	**1.420**
	4.0<=v<6.0	0.021	0.021	0.019	0.040	0.014	0.038	0.053	0.055	0.025	0.040	0.078	0.089	0.064	0.042	0.032	0.034	**0.668**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	-	-	-	**<0.001**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.177	0.223	0.173	0.175	0.109	0.197	0.257	0.293	0.242	0.262	0.362	0.333	0.314	0.236	0.239	0.197	**3.788**
G	**.0<=v<0.4**	0.142	0.210	0.332	0.219	0.166	0.097	0.131	0.157	0.331	0.600	0.800	0.494	0.401	0.191	0.156	0.096	**4.522**
	0.4<=v<1.0	0.052	0.088	0.125	0.085	0.065	0.041	0.047	0.077	0.140	0.242	0.345	0.265	0.218	0.123	0.081	0.042	**2.037**
	1.0<=v<2.0	0.222	0.439	0.760	0.360	0.258	0.245	0.373	0.441	0.735	1.101	0.786	0.559	0.689	0.433	0.489	0.241	**8.131**
	2.0<=v<3.0	0.380	0.392	0.493	0.298	0.193	0.500	1.002	1.063	0.899	0.741	0.625	0.420	0.434	0.258	0.428	0.324	**8.450**
	3.0<=v<4.0	0.166	0.124	0.106	0.176	0.094	0.394	0.676	0.738	0.311	0.228	0.337	0.269	0.222	0.138	0.162	0.164	**4.301**
	4.0<=v<6.0	0.032	0.021	0.012	0.045	0.022	0.110	0.153	0.147	0.033	0.061	0.092	0.097	0.081	0.053	0.035	0.038	**1.030**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.994	1.274	1.828	1.183	0.797	1.387	2.383	2.622	2.449	2.972	2.984	2.105	2.046	1.194	1.350	0.904	**28.471**
All categories	**0.0<=v<0.4**	0.284	0.375	0.530	0.337	0.266	0.187	0.229	0.272	0.523	0.925	1.200	0.765	0.633	0.339	0.299	0.198	**7.360**
	0.4<=v<1.0	0.140	0.189	0.237	0.163	0.146	0.123	0.130	0.165	0.267	0.423	0.589	0.465	0.393	0.246	0.193	0.125	**3.990**
	1.0<=v<2.0	0.730	1.170	1.470	0.781	0.667	0.750	0.978	1.160	1.620	2.110	1.820	1.330	1.570	1.160	1.300	0.761	**19.400**
	2.0<=v<3.0	1.450	1.690	1.560	1.000	0.732	1.450	2.460	2.810	2.470	2.120	2.260	1.640	1.770	1.490	1.810	1.410	**28.100**
	3.0<=v<4.0	1.110	1.080	0.926	0.916	0.483	1.270	2.200	2.500	1.400	1.180	1.770	1.470	1.530	1.260	1.300	1.240	**21.600**

	4.0<=v<6.0	0.832	0.772	0.651	0.929	0.288	0.862	1.360	1.470	0.649	0.833	1.540	1.720	1.620	1.140	0.917	0.976	**16.600**
	6.0<=v<8.0	0.108	0.109	0.068	0.138	0.030	0.075	0.121	0.122	0.041	0.118	0.316	0.505	0.375	0.223	0.124	0.135	**2.610**
	8.0<=v<12.0	0.008	0.014	0.002	0.007	0.001	0.003	0.006	0.004	0.002	0.012	0.048	0.106	0.060	0.037	0.014	0.016	**0.339**
	12.0<=v<25.0	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	**0.002**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	**4.670**	**5.400**	**5.450**	**4.270**	**2.610**	**4.720**	**7.490**	**8.500**	**6.970**	**7.720**	**9.540**	**7.990**	**7.960**	**5.890**	**5.960**	**4.860**	**100.00**

Data on the distribution for the sustainability categories for the period of 2006-2017 are given in Table 5.13.

Table 5.13 - Distribution of the sustainability categories for the period of 2006-2017

Category	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Total**
Probability	2.6	9.4	12.3	34.8	8.7	3.8	28.4	100

5.3 PC COSYMA

Modelling of atmospheric propagation of radioactive substances and formation of radiation doses dependent on radionuclide releases during accidents was carried out using software suite PC COSYMA by National Radiological Protection Board (UK).

PC COSYMA (Code System for MARIA) is a software suite used to model impact of accidental air release of radioactive substances. PC COSYMA was developed by joint efforts of National Radiological Protection Board (UK) and Forschungszentrum Karlsruhe (Germany) within the framework of MARIA (Methods for Accidental Radiation Impact Assessment) project of the European Commission for EU.

PC COSYMA suite and its separate modules are described in [23].

The system allows assessing the following parameters and impacts:

– integral surface air volumetric activity of radionuclides and activity of radionuclides deposited on the ground surface at certain points within the area;

– expected individual and collective doses within the selected periods;

– number of people covered by countermeasures (shelter, evacuation, dispensing of stable iodine tablets, relocation, deactivation, restricted use of agricultural products), and area on which countermeasures are taken;

– amount of agricultural products prohibited for use;

– number of latent and non-latent diseases;

– economic cost of countermeasures and treatment.

The system may be used for deterministic and probabilistic assessment. Deterministic assessment allows calculating the impact for a single user-specified set of weather conditions, while probabilistic assessment takes into account probable variations of weather conditions as may occur during the accident.

Impurities air transport models are built in MUSEMET module. This module utilises a model of segmented Gaussian spot that takes into account hourly wind speed and direction changes, atmospheric stability classes and amounts of precipitation, which impact the released substances. The model assumes that weather conditions in the entire area affected are identical. Hourly changes in weather conditions are only taken into account in probabilistic assessment. Deterministic assessment assumes that weather conditions (wind speed and direction, atmospheric stability class and amount of precipitation) remain unchanged throughout the period of time under consideration. MUSEMET utilises the mixing layer height as well as horizontal and vertical dispersion factors, which are functions of atmospheric stability. Dispersion factors have two parameter values for smooth (agricultural areas) and rugged (cities) ground surfaces.

6 Monitoring and environmental impact management program

The main document defining the scope of control during normal operation of power units and in excess of allowable releases and discharges, types, objects, frequency, methods, technical means of radiation control, list of controlled parameters, is “Regulations on radiation control at Rivne NPP. 132-1-Р-ЦРБ” [24]. When the “Emergency Plan” is put into effect, the amount and frequency of control is determined by the headquarters of the head of emergency operations at the site.

The regulation establishes the following types of control:

- on condition of protective barriers;
- radiation technological control;
- radiation dosimetric control;

- radiation control of the environment;

- radiation control over non-propagation of radioactive contamination;

- radiation control under conditions other than normal operation;

- radiation control of environments that are heated due to heat released from the NPP.

6.1 Control for the main technological environments

The radiation control system (RCS) is a complex of technical means and organizational measures designed to control the main technological environments, radiation situation in premises of the nuclear power plant and its surrounding territory. The system is aimed at ensuring compliance with the radiation safety norms and defining parameters characterizing the radiation safety for the NPP operation.

RCS solves the following tasks:

- radiation control of the status of protective barriers for the spread of radioactive substances and ionizing radiation;

- radiation control over technological environments;

- dosimetric control of internal and external irradiation of the personnel and population;

- radiation environmental control;

- radiation control for scheduled releases and discharges;

- detection of leaks in the technological equipment;

- performing accounting and reporting documents on radiation conditions at the NPP and radiation exposure of personnel.

The following provisions are suggested for the solution of the above tasks:

- automatic remote (continuous or periodic) monitoring using the permanently installed local means;

- monitoring using portable devices;

- monitoring by sampling of the media to be controlled with subsequent processing and measurement;

- monitoring using mobile express labs.

In organizational terms, the RCS consists of four subsystems:

- radiation technological control (RTC);
- radiation dosimetric control (RDC);
- individual dosimetric control (IDC);
- radiation environmental control (REC).

6.2Monitoring of the NPP impact on population and environment

Sanitary protection zone

SPZ is set around radiation hazard nuclear facilities. Dimensions of the SPZ are determined taking into account the prognostic estimates of the radiation situation in the vicinity of the NPP during its long-term operation and are defined in the project.

Initially, the SPZ was set at a radius of 3 km. However later on, given that the size of the zone should be specified more precisely taking into account the dominant wind directions, calculations were made and in agreement with the Chief Sanitary Inspector of the USSR V. D. Turovskyi (letter of August 1984 No. 32-014/324) the size of the SPZ for RNPP was reduced to a radius of 2.5 km.

Currently, there are no residents or institutions, enterprises or facilities, except those that are a part of the NPP, within the SPZ. Only the buildings and constructions intended for auxiliary needs and serving of the NPP are located in the SPZ.

Cultivation of crops and grazing of cattle with the obligatory control over the radionuclides content in the produced agricultural products is permitted on the territory of the SPZ.

Radiation control is carried out in the SPZ.

Observation zone

According to NRBU [8], the observation zone includes the monitored area in which the radioactive releases and emissions from the radiation nuclear facility (NPP) are likely to happened. Currently, an observation zone with a radius of 30 km is set for SS RNPP. Existing boundaries of the OZ in accordance with the requirements of [24] were confirmed by calculations.

Controlled parameters, frequency and methods

The purpose of the REC is to monitor releases of radioactive substances in the environment, radiation situation in SS RNPP area and radioactive contamination of the natural environment locations [25-26]. RC of the environment is ensured by measurements given in Tables 6.1 to 6.7.

Table 6.1 - Activity and radionuclide composition of the scheduled releases of radioactive aerosols, iodine radionuclides, IRG and tritium

Name of the radiation parameter	Frequency	Measurement method
Release rate of IRG, radioactive aerosols and iodine radionuclides	Continuously	Channels of ARSMS, SPB GAR, RSCS
Activity of LLN release, radionuclides of iodine and tritium	Regularly	Laboratory control
Radionuclide composition and activity of LLN release	Once a month	Laboratory control

Table Ошибка! Текст указанного стиля в документе отсутствует.**.2 - VA and radionuclide composition of liquid discharge into the environment**

Name of the radiation parameter	**Frequency**	**Measurement method**
VA and radionuclide composition of the water in RWMT after RAWT	Regularly, after filling	Laboratory control
VA in the pits of WP, ISC1	Continuously (when discharged into the environment)	Channels of ARCS, RSCS
VA and radionuclide composition of liquid discharges of radioactive substances, including tritium	Regularly	Laboratory control
VA and radionuclide composition of LRW	Regularly	Laboratory control

Table 6.3 - Activity and radionuclide composition of SRW

Name of the radiation parameter	**Frequency**	**Measurement method**
VA and radionuclide composition of SRW	Regularly, at the DD request	Laboratory control
SRW activity in primary packaging	Regularly, with accumulation at the waste collection sites	SEG-001m spectrometer

Table 6.4 - Activity and radionuclide composition of radioactive leakages from SRWS, LRWS, RR, spray pools

Name of the radiation parameter	**Frequency**	**Measurement method**
VA and radionuclide composition of water samples from observation wells	Regularly	Laboratory control

Table 6.5 - EDR in the territory of the SPZ and OZ

Name of the radiation parameter	**Frequency**	**Measurement method**
Integral dose in the SPZ and OZ area	Regularly	TLD

Name of the radiation parameter	Frequency	Measurement method
EDR in the in the SPZ and OZ area (at the locations of RSCS CS)	Continuously	RSCS
EDR control in the SPZ and OZ, including settlements	Once a year (when replacing TLD)	Portable devices
EDR control at industrial facilities	Regularly (once a month)	Portable devices

Table 6.6 - Volumetric activity of radioactive aerosols in the air in the vicinity of the NPP

Name of the radiation parameter	Frequency	Measurement method
VA of radioactive aerosols in the air in the vicinity of the NPP	Regularly	Laboratory control

Table 6.7 - Activity in the natural environment locations

Name of the radiation parameter	Frequency	Measurement method
Samples from natural environment locations	Regularly	Laboratory control

6.3Management of environmental impact

The environment management strategy is implemented on five levels [16].

Level 1. Preventing violations of normal operation.

The main instruments for achieving the above objective are:

- selection of the NPP site in accordance with the requirements of regulatory documents;

- conservative approach to project development with maximum use of the safe-secure properties of the RU;

- ensuring the required quality of structures, systems and elements of the NPP, works on its construction, operation and modernization;

- availability of automatic technical means preventing the violation of normal operation conditions;

- operation of the power unit in accordance with the requirements of regulatory documents, technological regulations for safe operation and operational manuals;

- maintaining operating condition of safety-critical structures, systems and elements by timely detection of defects and adoption of preventive measures against their occurrence, replacement of equipment with expired lifetime, organization of high-performance control system for the structures, systems and elements, their maintenance, repair and modernization, documentation of the results for the above works;

- selection and training of personnel, ensuring the required personnel skill level;

- formation and development of the safety culture.

Level 2. Ensuring safety in case of violations of normal operation and prevention of emergencies.

The main instruments for achieving the above objective are:

- timely detection and correction of deviations from normal operation;

- availability of automatic protection and interlocks preventing transformation of deviations from normal operation into emergencies;

- actions of personnel in accordance with the requirements of instructions and technological regulations for safe operation, continuous improvement, taking into account the expertise gained and new scientific and technical data;

- training of personnel regarding actions in case of violations in normal operation.

Level 3. Accidents prevention and elimination.

The main instruments for achieving the above objective are:

- availability of safety systems (protective, localizing, supporting and controlling) designed to prevent emergencies and design accidents, eliminate their consequences and prevent their transformation into beyond design basis accidents;

- the use of normal operation systems for preventing emergencies and design basis accidents, as well as for containment of emergencies and accidents;

- availability and use of emergency operating procedures, and appropriate actions of personnel in accordance with their requirements;

- training of personnel with the use on full-scale simulators for actions in case of accidents.

Level 4. Management of beyond design basis accidents.

The main instruments for achieving the above objective are:

- the use of normal operation systems and safety systems to prevent the development of beyond design basis accidents, limit their consequences, as well as to restore the controlled state of the RU;
- availability and use of instructions on management of beyond design basis accidents aimed at stopping the fission chain reaction, efficient cooling of nuclear fuel and keeping radioactive substances within the established limits, as well as containment of serious accidents, including protection of the hermetic envelope against destruction;
- availability and use of instructions for the management of severe accidents aimed at preventing the outflow of the active zone melt from the reactor shell and violation of the hermetic envelope integrity, limiting the radiation exposure to personnel, the population and the environment, as well as creating conditions for the timely implementation of plans on protection of personnel and population;
- actions of personnel in accordance with the instructions for managing beyond design basis accidents;
- training of personnel on managing beyond design basis accidents.

Level 5. Emergency readiness and response.

The following is provided tt this level:

- establishment of the sanitary protection zone and surveillance zone around the NPP;
- availability of emergency plans, emergency response plans, which efficiency and readiness for implementation should be checked at regular intervals during emergency training and exercises;
- construction of radiation shelters and crisis centres.

CONCLUSIONS

Radiation action of gas-aerosol releases of RNPP during normal operation is much lower than the specified dose limits for the population in adjacent countries (these limits are within the range of 0.2-0.3 mSv/year for different countries). The annual individual effective dose does not exceed the value of 1.5 nSv/year at the border of the nearest country - the Republic of Belarus.

The main criterion for limiting the exposure the population in Europe due to anthropogenic sources is the limit of the individual effective dose (due to all radiation routes), which is set at 1 mSv/year. The assessment has shown that the expected total effective dose for 50 years at the border of the nearest country - the Republic of Belarus - does not exceed the value of 13 mSv in any of the accidents considered.

Under normal operating conditions of RNPP, as well as in the event of accidents, the environmental impact in a transboundary context, that is, in the territory of adjacent countries, does not arise, as the regulatory requirements for air contamination and dose limits for the population are not exceeded, and already are at a level below the limits at a distance of 60 km from RNPP.

Thus, it has been justified that planned activities have no major transboundary impact, and there is no affected party in terms of the Convention on Environmental Impact Assessment in a Transboundary Context. In execution of para. 8 Article 3 of Convention on Access to Public Information, posting the information on environmental impact of the planned activities in a transboundary context at common access Internet resources, e. g. on websites of the Ministry of Ecology and Natural Resources of Ukraine and SS NNEGC Energoatom, will suffice.

LIST OF REFERENCES

1. Ривненская АЭС. Энергоблок № 3. Отчет по анализу безопасности. Дополнительные материалы по анализу безопасности. Раздел 3. Влияние АЭС на окружающую среду. Киев. 2014, -128 с.

2. Ровенская АЭС. Энергоблок № 4. Оценка воздействий на окружающую среду. Том 3. Общая характеристика энергоблока и хозяйственной деятельности в зоне его влияния. Книга 1. -208 с.

3. Отчет по радиационной безопасности Ривненской АЭС за 2013 год. 132-05-НР-14-ЦРБ. -111 с.

4. Отчет по радиационной безопасности Ривненской АЭС за 2014 год. 132-05-НР-15-ЦРБ. -117с.

5. Отчет по радиационной безопасности Ривненской АЭС за 2015 год. 132-05-ОЧ-16-ЦРБ. -125 с.

6. Отчет по радиационной безопасности Ривненской АЭС за 2016 год. 132-05-ОЧ-17-ЦРБ. -123 с.

7. Отчет по радиационной безопасности Ривненской АЭС за 2017 год. 132-05-ОЧ-18-ЦРБ. -126 с.

8. Нормы радиационной безопасности Украины (НРБУ-97). Государственные гигиенические нормативы. – Киев: 1998. – 134 с.

9. Санитарно-эпидемиологические правила и нормативы СанПин 2.6.1.24-03 «Санитарные правила проектирования и эксплуатации атомных станций», Министерство Здравоохранения Российской Федерации. М, 2003, 36 с.

10. Accident Source Terms for Light-Water Nuclear Power Plants. Final Report. NUREG-1465, 1995, 30 p.

11. D.A. Powers, M.T. Leonard, R.O. Gauntt, R.Y. Lee, and M. Salay/ Accident Source Terms for Light-Water Nuclear Power Plants Using High-Burnup or MOX Fuel.- SANDIA REPORT SAND2011-0128 Unlimited Release January 2011, 60 p.

12. Новий ядерний блок на території Ясловське Богуніце. Звіт про оцінку транскордонного впливу запланованої діяльності на навколишнє середовище. Jadrová energetická spoločnosť Slovenska, a. s.,Tomášikova 22, 821 02 Bratislava, Словацька Республіка.

13. JZJB_EIA_CP02_DOK_AMEC_JESS_0043_0FINAL.

14. Ривненская АЭС. Энергоблок №3. Отчет по периодической переоценке безопасности. Этап 2.4. Актуализация материалов АЗПА. Глава 5. Анализ запроектных аварий. Часть 1. Дополнительные расчетные обоснования и разработка финальных отчетов по АЗПА. Книга 4. Рекомендации по противоаварийным действиям персонала. Итоговый перечень ЗПА. КИЕВ. 2014, -428 с.

15. Sources and effects of ionizing radiation. UNSCEAR, UN, N.Y., 1993, 922 pp.

16. Общие положения безопасности атомных станций. НП 306.2.141-2008. Киев. 2008, 62 с.

17. PC-CREAM 97. Installing and Using the PC System for Assessing the Radiological Impact of Routine Releases / A. Mayall, T. Cabianca, C. Attwood et al. - NRPB, 1997. - 172 p.

18. Radiation Protection. ICRP Publication 60. 1990 Recommendations of the International Commission on Radiological Protection (ICRP). - N.Y.: Pergamum Press, 1991. - 197 p

19. *ICRP72* International Commission on Radiological Protection, “Age Dependent Doses to Members of the Public from Intake of Radionuclides, Part 5. Compilation of Ingestion and Inhalation Dose Coefficients” ICRP Publication 72, Pergamum Press, Oxford, 1996.

20. Simmonds J.R., Lawson G., Mayall A. Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment. Radiation Protection. - NRPB, 1995. - 353 p.

21. Річний звіт про результати метеорологічних спостережень у 2017 році в районі розташування Рівненської АЕС. 132-09-ЗВ-18-ЦРБ. Вараш. 2018, -206 с.

22. Руководство по расчету индивидуальных и коллективных доз облучения населения от выбросов радионуклидов, поступающих в атмосферу при эксплуатации АЭС. Сборник правил и норм по радиационной безопасности в атомной энергетике. М: 1989, т. 3, с.19-315

23. J. A. Jones, P. A. Mansfield, S. M. Haywood et al. PC COSYMA (Version 2): An accident consequence assessment package for use on a PC. − Luxemburg: Office for Official Publications of the European Communities, 1996. − 59 pp.

24. НП 306.2.173-2011 «Вимоги щодо визначення розмірів і меж зони спостереження атомної електричної станції».

25. 132-1-Р-ЦРБ. Регламент радиационного контроля Ривненской АЭС.

26. Ривненская АЭС. Энергоблоки № 3, 4. Отчет по периодической переоценке безопасности. Глава 5. Влияние на окружающую среду. 22.3,4.133.ОППБ.05. АТ03-14.564.ОД.1. Киев. 2015, -82 с.

NON-TECHNICAL SUMMARY

OF SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

2018

CONTENTS

LIST OF LEGENDS, SYMBOLS,
UNITS OF MEASUREMENT, ABBREVIATIONS AND TERMS

Abbreviation	Name
BDBA	Beyond design basis accident
ChNPP	Chornobyl Nuclear Power Plant
CSFSF	Centralized spent fuel storage facility
CUF	Capacity utilization factor
EIA	Environmental impact assessment
ERS	Emergency preparedness and response system
HLW	High-level waste
IAEA	The International Atomic Energy Agency
LRW	Liquid radioactive waste
LWR	Light water reactor
MDBA	Maximum design basis accident
MPC	Maximum permissible concentration
MSK-64	Earthquake repetition scale
NPP	Nuclear Power Plant
NRBU-97	Norms of Radiation Safety of Ukraine, 1997
RNPP	Rivne Nuclear Power Plant
RW	Radioactive waste
SE NNEGC “Energoatom”	State Enterprise “National Nuclear Energy Generating Company Energoatom”
SF	Safety Factors
SNF	Spend nuclear fuel
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SPZ	Sanitary protection zone
SRW	Solid radioactive waste
SRW CT	Comprehensive treatment of solid radioactive waste
SS Rivne NPP	Separated Subdivision Rivne Nuclear Power Plant
SWP	Special water purification system
VVER-440	Water-water power reactor with a rated power output of 440 MW
VVER-1000	Water-water power reactor with a rated power output of 1000 MW

1 INFORMATION ABOUT THE DOCUMENTS WHICH ARE THE BASIS FOR ENVIRONMENTAL IMPACT ASSESSMENT DEVELOPMENT

Non-technical summary is a review document, it does not contain original assessments or independent conclusions and based entirely on the information given in the text.

The report on the environmental impact assessment of Rivne NPP site was developed in accordance with the Law of Ukraine “On Environmental Impact Assessment”.

The basis for development of materials is the Energy strategy of Ukraine for the period to 2030, approved by the Order of the Cabinet of Ministers of Ukraine No. 1071-r, dated July 24, 2013, which defines the operation of Ukrainian nuclear power plant units, Strategic plan of the State Enterprise “National Nuclear Energy Generating Company “Energoatom” development for 2017-2021, the Decision VI/2 of the 6th meeting of the Parties to the Convention on the Environmental Impact Assessment in a Transboundary Context (Espoo Convention) etc.,

Facility, which activity has been assessed in terms of impact on the environment, includes operating power units, facilities and structures integrated into technological complex located at SS Rivne NPP site, as well as other facilities within the power complex in the vicinity of NPP (Sanitary Protection Zone (SPZ) and Observation Zone (OZ).

To provide reliable protection of the personnel, public and environment from the effect of ionizing radiation and maximum possible reduction of the impact of anthropogenic factors on the environment a number of general measures have been established by SS Rivne NPP of SE “NNEGC “Energoatom”:

– fulfilling the requirements of the Environmental legislation of Ukraine, international agreements of Ukraine, standards and regulations in the area of the use of nuclear energy, environmental management and environmental protection;

– planning of work in the area of environmental protection and monitoring of observance of environmental impact standards;

– environmental support of NPP power units operation;

– development and implementation of environmental protection management system;

– compliance with the technological parameters of SS Rivne NPP operation;

– consideration of quantitative and qualitative indicators of releases to atmoaphere, discharges to water, waste management for the rational use of natural resources;

– implementation of environmental policy by way of organization of environmental training of the personnel, enhancement of environmental training level;

– constructive interaction with supervisory authorities, public organizations on environmental safety issues.

In the course of Rivne NPP economic activity SE “NNEGC “Energoatom” prepares annual reports on radiation safety, non-radiation factors of environmental impact, implementation of environmental actions etc.

Radiation safety issues are monitored in compliance with corresponding instructions and specifications developed and approved for each structural department of SE “NNEGC “Energoatom” in accordance with current legislation in this area.

Emergency response issues are defined by the Emergency plans developed and put into effect in compliance with par 10.13.1 of НП 306.2.141-2008 “General Provisions for Safety of Nuclear Power Plants” for each plant, including Rivne NPP.

In order to determine the environmental substantiation and effectiveness of SS Rivne NPP power units operation, the compliance of the operation with the requirements of environmental protection legislation, in 2015 the environmental audit has been carried out, that meets the requirements of the Law of Ukraine “On the Environmental Audit” No. 1862-IV, dated June 24, 2004.

In addition to this, the Reports on Safety Review are periodically developed (in compliance with the regulatory requirements).

Power unit Periodic Safety Review Reports contain the analysis of 14 Safety Factors (SF):

– SF-1 “Power unit design”;
– SF -2 “Current state of power unit systems, structures and components”;
– SF -3 “Equipment qualification”;
– SF -4 “Structures, systems and components ageing”;
– SF -5 “Deterministic safety analysis”;
– SF -6 “Probabilistic safety analysis”;
– SF -7 “Analysis of internal and external impacts”;
– SF -8 “Operational safety”;
– SF -9 “Use of other NPP experience and scientific research results”;
– SF -10 “Organization and management”;
– SF -11 “Operating documentation”;
– SF -12 “Human factor”;
– SF -13 “Emergency preparedness and planning”;
– SF -14 “Impact of NPP operation on the environment”.

The mandatory element of all Ukrainian NPPs operation is the “Complex (Consolidated) Safety Upgrade Program for Power Units of Nuclear Power Plants”, approved by the Resolution of the Cabinet of Ministers of Ukraine No. 1270, dated December 07, 2011.

In the reporting materials on Environmental Impact Assessment there is a description of the elements of activity of SS Rivne NPP, as well as an assessment of the environmental impact in accordance with the requirements of Article 6 of the Law of Ukraine “On Environmental Impact Assessment”.

2 GENERAL DESCRIPTION OF THE SS RIVNE NPP

2.1 General Information

SS Rivne NPP is a separate subdivision (unit) of the State Enterprise "National Nuclear Energy Generating Company Energoatom. SE NNEGC "Energoatom" carries out activities in accordance with its Articles of Association and is subordinate of the Ministry of Fuel and Energy of Ukraine, which forms the state policy in the field. In accordance with the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" adopted by the Resolution No. 1268 of the Cabinet of Ministers of Ukraine dated 17 October 1996 "On the Establishment of the National Nuclear Power Generating Company Energoatom" SE NNEGC "Energoatom" is assigned with functions of an operating organization responsible for the safety of all nuclear power plants in the country.

Rivne NPP is located in western Polissya, in the north-west of the Rivne Region, near the Stir River. The site choice was preconditioned by several reasons: low fertility of sandy land and great distance from densely populated areas. In 1973, the density of population in this territory was 55 persons/km^2, while today's population in Varash is 3,684 persons/km^2.

According to SNiP P-7-81 "Construction in Seismic Areas", the industrial area of SS Rivne NPP is located in the P3-5, MR3-6 zone. NPP was designed taking into account two levels of seismicity (P3) - magnitude 5 and the maximum estimated earthquake - magnitude 6. The recurrence of earthquakes according to the MSK-64 scale is 1 time in 5000 years.

SS Rivne NPP industrial site is located in a moderate climate zone characterized by mild and humid winters, relatively cold and rainy summer, wet autumn and unstable weather during the season transitions.

The terrain is even and open to the wind, which provides good ventilation of the site. Power delivery to the power system is carried out via:

- power lines -750 kV;
- power lines - 330 kV lines;
- power lines - 110 kV lines.

NPP process water supply is of circulating type, feeding from the Styr River. The Rivne NPP power units cooling system does not include cooling ponds. The entire power units cooling system is designed to use six cooling towers and spray pools. Heat is removed from circulating water via 6 cooling towers with a productivity of 100,000 m^3/h each. Spray pools are used to remove heat from critical consumers.

Each year, SS Rivne NPP generates about 13 % of the total electricity amount generated in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Varash town and Zabolottia village. The design CUF capacity utilization factor is 74.2 %.

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:

- protection safety systems;
- localizing safety systems;
- auxiliary safety systems;
- control safety systems.

SS Rivne NPP power units have been designed, built and installed in accordance with the regulative documents that were in force at that time.

In 1971, the West Ukrainian NPP subsequently renamed in Rivne NPP has entered the design stage. The power plant is designed to cover electrical loads in the western part of the country.

SS Rivne NPP is the first nuclear power plant in Ukraine based on a VVER-440 water-water power reactor. The power plant construction was commenced in 1973. The first two units with VVER- 440/213 reactors were put into operation in 1980-1981, and the third power unit, 1000 MW VVER-1000/320 - in 1986.

The construction of the fourth Rivne NPP unit was commenced in 1984, with commissioning scheduled for 1991. However, due to the introduction of the moratorium on the construction of nuclear facilities on the territory of Ukraine by the Verkhovna Rada, the works were suspended at 85 % of the unit's readiness.

Construction was resumed in 1993. Following the withdrawal of the moratorium, Unit 4 was inspected, and a program for its modernization and a completion project dossier were prepared. Power Unit No. 4 at SS Rivne NPP was commissioned on 16 October 2004.

SS Rivne NPP is located at the address:34400, city of Varash of the Rivne Region.

Mr. Pavlyshin Pavlo Yaremovich, General Director of the Rivne NPP, fulfills the overall management of the facility with the functions authorized by the President of NNEGC "Energoatom".

The general view of Rivne NPP is presented on Figure 2.1.

Figure 2.1. General view of Pivne NPP site

Technical characteristics of the power units of Rivne NPP are provided in Table 2.1.

Table 2.1. Key performance indicators of Rivne NPP

Indicators	Power unit No. 1	Power unit No. 2	Power unit No. 3	Power unit No. 4	NPP
Electric energy generated per current day, mln kW·h	4.5	4.5	n/a	10.8	19.9
Electric energy generated per current month, mln kW·h	182.5	183.3	n/a	437.6	803.4
Electric energy generated per previous month, mln kW·h	309.5	308.6	n/a	736.9	1355
Electric energy generated year-to-date, mln kW·h	1346.8	1292.6	0	4061.9	6701.4
Capacity utilization factor (CUF) per current month, %	98	99.6	n/a	98.6	63.9
Capacity utilization factor (CUF) per previous month, %	99	99.9	n/a	99	64.2
Capacity utilization factor (CUF) year-to-date, %	78.9	76.6	0	99.9	58.1

2.2 The Operation Time for Rivne NPP Power Units

The operation time for Rivne NPP power units is presented in Table 2.2.

Table 2.2. Information on the power units of Rivne NPP.

Power unit	Type of reactor facility	Series of reactor facility	Date of unit connection to the grid	Date of putting the unit into commercial operation	Date of design lifetime	Date of lifetime extension
RNPP-1	VVER-440	B-213	22.12.1980	22.09.1981	22.12.2010	2030
RNPP-2	VVER-440	B-213	22.12.1981	29.07.1982	22.12.2011	2031
RNPP-3	VVER-1000	B-320	21.12.1986	11.12.1987	11.12.2017	2037
RNPP-4	VVER-1000	B-320	10.10.2004	07.06.2005	07.06.2035	-

2.3 Brief Description of Products of Rivne NPP

SS Rivne NPP produces heat and electricity. Electricity production is accomplished at four power units with VVER-440 reactor and VVER-1000 reactor, with total installed capacity of 2835 MWt. The capacity factor is 74.2%.

Production of the electrical energy by the power units of Rivne NPP started from 1981. Figure 2.2 provides information on the amount of milliards of kWt×year of the produced electricity as per years of operation.

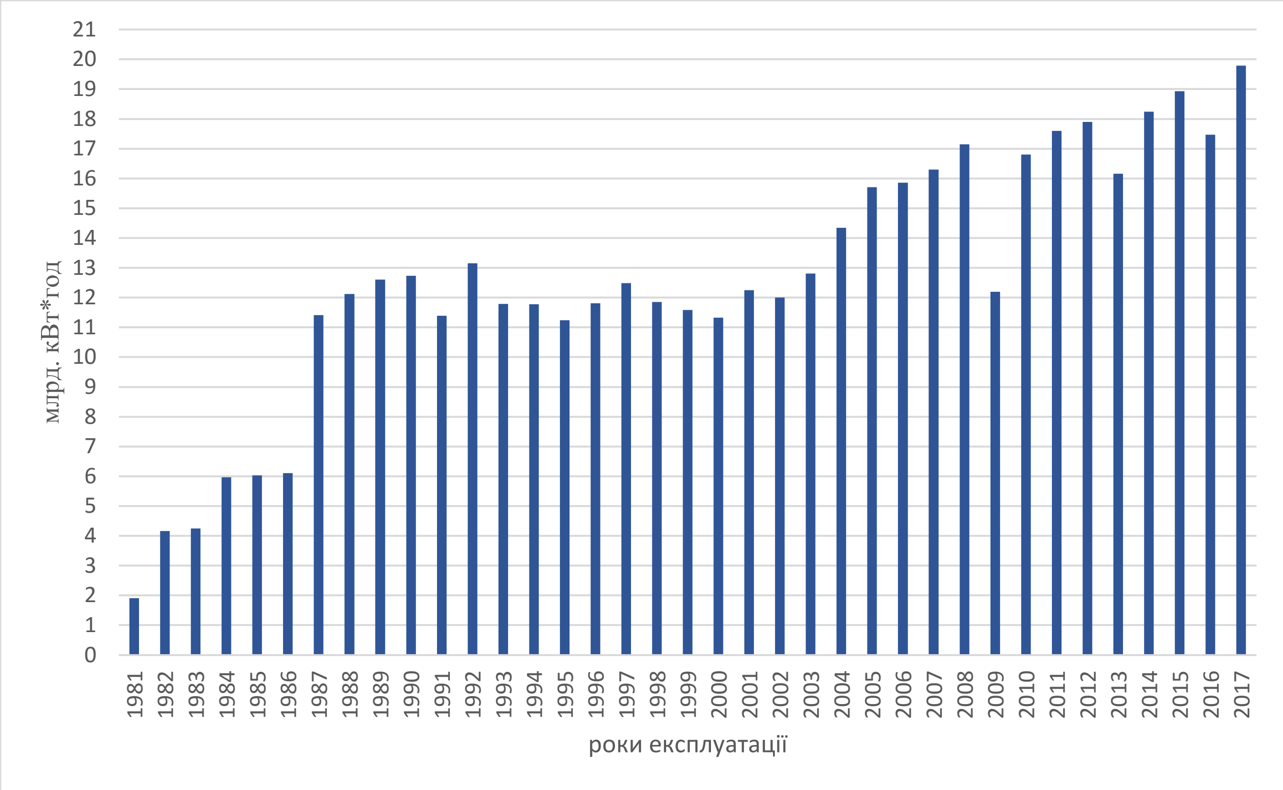


Figure 2.2. Annual electricity produced by Rivne NPP

2.4 Data on Raw Materials, Land, Water, Energy and Other Used Resources

SS Rivne NPP uses the following resources for the production needs:
- NPP territory and industrial site;
- circulating water use, evaporation of water for cooling purposes;
- auxiliary electric power.

The land plot with an area of 217.895 ha, which is intended for usage by the facilities of electricity production and distribution, is assigned for the permanent use by NNEGC "Energoatom" and certified with the state act on the right of continuous management of the land plot - series ЯЯ №252110 as of 01.07.2006, issued upon the Decision № 433 as of 28.04.2005 by the Kuznetsovsk Town Council.

In addition to the land plot used by Rivne NPP power units, NNEGC "Energoatom" also holds the right of continuous use of the land plots for servicing the production and social objects with the total area of 262,3 ha on the territory of Varash town council and Volodymyrets and Manevytskiy regions.

Preservation and rational use of the land resources is ensured by the maximum effective use of the assigned territory. The territory is arranged, the land plot used for the power units has a developed infrastructure and landscape. No additional land allocation for extended lifetime of Rivne NPP power units operation is required.

Rivne NPP includes main, auxiliary and warehouse buildings and structures. The technological process of producing electricity is characterized by stability. The main and auxiliary workshops with their characteristic sites are located on the industrial site to ensure the operation of power units at the industrial site.

In the process of production activity, the fuel materials (fuel oil, anthracite, diesel fuel, gasoline), the welding materials for repair (welding electrodes, propane-butane mixture), lubricating and cooling liquids, paint and varnish materials, chemical reagents (sulfuric acid, ammonia, nitric acid, hydrazine hydrate, monoethanolamine) are used at SS Rivne NPP. As the fuel in start-up boiler-house, the fuel oil of M-100 grade is used.

A part of the electric and thermal energy produced at Rivne NPP is used for its own needs. Other resources (inventories, works and services) for the needs of Rivne NPP are purchased from other entities.

2.5 Brief Description of Rivne NPP Power Units and Technological Processes

As of 2018, four power units are in operation at SS Rivne NPP:
- power unit I (VVER-440) with a capacity of 420 MW since 1980;
- power unit II (VVER-440) with a capacity of 415 MW since 1981;
- power unit III (VVER-1000) with a capacity of 1000 MW since 1986;
- power unit IV (VVER-1000) with a capacity of 1000 MW since 2004.

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008) and World Association of Nuclear Operators (WANO) (1988, 1989, 1993, 1995, 1997, 2001, 2003, 2005, 2012, 2014, 2015, 2016, 2018 years).

Each year, SS Rivne NPP generates about 13 % of the total electricity amount generated in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Varash town and Zabolottia village. The design CUF capacity utilization factor is 74.2 %.

SS Rivne NPP power units include the following equipment:
- VVER-440 (B-213) reactor - units 1, 2 and VVER-1000 (B 320) - units 3, 4;
- K-220-44 turbine - units 1, 2 (2 pcs per unit) and K-1000-60/3000 - units 3, 4;
- TVV-220 turbogenerator - units 1, 2 (2 pcs per unit) and TVV-1000 - units 3, 4.

Each power unit is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

Table 2.4 provides specifications of SS Rivne NPP power units.

Table 2.4. Specifications of SS Rivne NPP power units

Parameter	Value	
	VVER-440	VVER-1000
Reactor capacity, MW	137527	3000
Pressure at 1 k (at active zone discharge) kgf/cm^2 (MPA)	125±1.2 (12.25±0.1)	160±3 (15.7±0.29)
Temperature of coolant at the reactor discharge, °C	300	320
Coolant heating in the reactor, °C	30.3	30.3
Average consumption of coolant for active zone cooling, t/h	42700400	84800^{+400}_{-480}
Steam production for all SG, t/h	2700	5880
Humidity of steam at SG discharge, %	0.25	0.2

The process of economic operations, including all environmental impact factors and technical solutions, is intended to eliminate or reduce harmful releases, discharges, leaks and radiation in the environment.

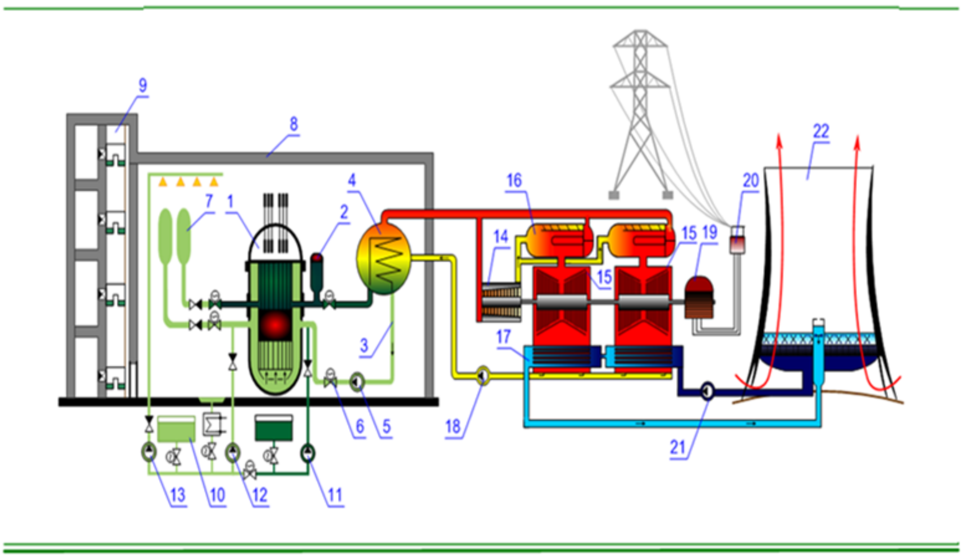
VVER-440 and VVER-1000 reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel.

2.5.1 Flow Chart of the Power Unit With VVER-440 Reactor Type

The power units of Rivne NPP have a water-cooled water-moderated power reactor (VVER). The power units with VVER reactor type have a two-circuit system, primary and secondary circuits that do not mix with each other.

Rivne NPP is special for introduction of power units operated with the reactors of VVER-440 type. Two reactors of this type are operated at the plant, specifically reactor 1 and reactor 2.

Flow chart of the power units with VVER-440 reactor type is presented on the Figure 2.3 below.



1. Reactor
2. Pressurizer
3. Main circulation circuit
4. Steam generator
5. Main circulation pump
6. Main loop isolation valve
7. Hydroaccumulators
8. Containment
9. Accident localization vault
10. Boron concentration storage tank
11. Emergency feedwater pump
12. Core cooling pump
13. Spray pump
14. Turbine high pressure cylinder
15. Turbine low pressure cylinder
16. Moisture separator reheater
17. Condencer
18. Feedwater pump
19. Generator
20. Main transformer
21. Circulating pump
22. Cooling tower

Figure 2.3. The flow chart of the power unit with VVER-440 reactor type.

The reactor primary circuit includes:
- reactor,
- steam generator,
- main circulation pumps,
- pressurizer,
- main loop isolation valves.

All components of the primary circuit are installed in the leak-tight boxes.

The coolant and neutron moderator is demineralized water.

The coolant removes heat generated during uranium fission in the operating reactor, and then it is pumped through the reactor core by the main circulation pumps and transfers heat to water of the secondary circuit in the steam generators.

The reactor core consists of hexagonal fuel assemblies, which contain fuel elements.

A fuel element is a rod made of zirconium alloy and filled with fuel pallets with uranium dioxide.

The water in the primary side heats up to 300 °C in the reactor, but it does not boil, since the pressure that is maintained by the pressurizer is 12 MPa for VVER-440 and 16 MPa for VVER-1000. The secondary circuit is nonradioactive, it includes:
- steam generators,
- steamlines,

- steam turbines,
- moisture separator reheaters,
- feedwater pipelines with feedwater pumps, deaerators and regenerating heaters.

The saturated heat generated in the steam generators is supplied to the turbine, which activates electrical generator.

The electrical energy produced by RNPP is transmitted to the unified grid of Ukraine via the open switchgears of electrical transmission lines 110, 330 and 750 kV.

2.5.2 Flow Chart of the Power Unit With VVER-1000 Reactor Type

Rivne NPP has two power units of VVER-1000 reactor type – Units 3 and 4.

VVER-1000 is a water-cooled and water-moderated reactor, where pressurized water is used as coolant and moderator. This is a second-generation light water reactor with high capacity. The electrical power is 1000 MWt, the thermal power is 3000 MWt. Nuclear reactors of this type are operated at Zaporizhzhya, Rivne, Khmelnitskiy, South Ukraine NPPs, as well as at the NPPs of Russia, Bulgaria, Check Republic and China.

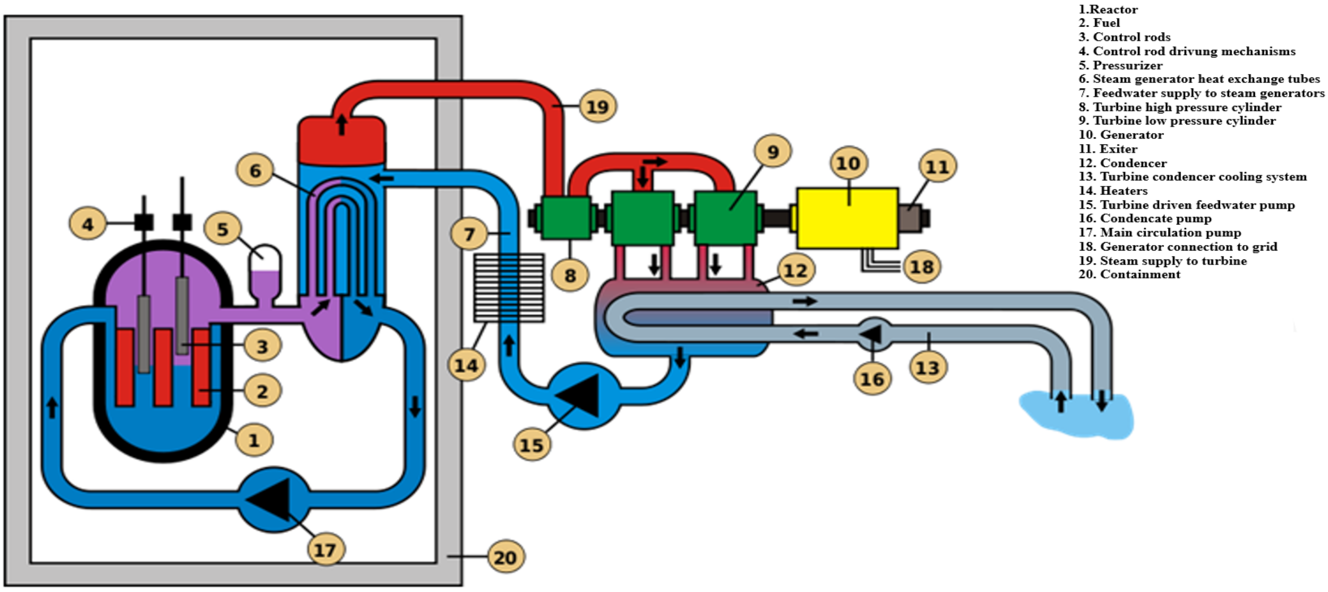


Figure 2.4 The flow chart of the power unit with VVER-1000 reactor type.

The regular demineralized water (heterogeneous reactor) is used as a neutron moderator and coolant in the energy reactors of VVER vessel-type. The core is placed in one common vessel, with water circulating through it. Two-circuit principle is applied to remove the heat. In the vessel-type unboiling reactor, the core is located in the high-strength, thick-walls steel vessel. The diameter of the core is 3.12 m, the height is 3.5 m, loading with natural uranium is 66 t, ^{235}U enrichment is 3-4%.

The reactor vessel is one of the most important structural elements and must ensure total reliability and complete leak-tightness both in normal operation conditions and in case of possible emergencies. The vessel is completely filled with pressurized water (15.7 MPa and greater).

The primary side of the reactor is fully isolated from the secondary side, which reduces radioactive releases into atmosphere. Water is pumped by the circulation pumps through the reactor and heat exchanger (the circulation pumps take suction from the turbine). Water of the reactor radioactive circuit is at the high pressure, thus regardless of its high temperature (320°C at the reactor exit, 289°C at the core inlet) it does not boil.

Water of the secondary side is at operating pressure of 6.4 MPa, that is why it is converted into steam at operating temperature of 280 °C in the heat exchanger (steam generator). In the heat exchanger – steam generator the coolant that circulates in the primary circuit transfers heat to the secondary circuit. The steam, generating in the steam generator, goes to the turbines via the main steamlines of the secondary side and gives away part of its energy to rotation of the turbine, and after that, it gets to the condenser. The condenser, which is cooled with water of the circulation circuit (so to say, the third circuit), ensures collection and condensation of the steam. The condensate, after going through the heaters system, goes back to the heat exchanger and the cycle repeats again.

For convenience of reloading and transportation, the fuel elements of the reactor are collected in the special assemblies – fuel assemblies (FAs). The assemblies have the hexagonal shape. The reactor consists of 163 fuel assemblies, which are located in the middle of the core with a pitch of 20-25 cm. All FAs in the core are assembled in the reactor core barrel (RCB). The bottom end of FAs is placed in the RCB's support tubes, and the top end (head) is supported by the guide tubes. The RCB's support tubes, the baffle and guide tubes hold the fuel assemblies in the required position.

Power units operate in a two-loop cycle: first (hot) loop is a water circuit with direct heat extraction from the reactor; second (cold) loop is a steam circuit with heat energy extracted from the first loop and converted into mechanical energy of turbine rotation, and then into electrical energy in a turbine generator.

The main building with 4 operating power units (two VVER-440 and two VVER-1000 units) includes a reactor room.

Turbine island with adjacent deaerator bay and auxiliary switchgear room.

Main process equipment of reactor unit:

- reactor;
- steam generators;
- main circulation pumps;
- pressurizer;
- emergency core cooling tank;
- connecting pipelines arranged under the containment in boxes with solid walls of heavy concrete or reinforced concrete.

2.6 Main Sources of Radiation Hazard

Radiation impact of the power complex is possible in connection with the release of radioactive substances produced during the NPP production cycle into environment.

Main types of the possible radiation impact are caused by:

- radioactive gaseous releases into atmosphere;
- solid radioactive wastes (SRW);
- liquid radioactive wastes (LRW).

Radioactive gaseous releases are produced due to release of radioactive gases and aerosols from liquid radioactive media. Radioactive gases are released into atmosphere under normal power unit operation by special ventilation systems through vent stacks of reactor compartments and auxiliary buildings.

Solid radioactive wastes produced during operation are collected, sorted, conditioned and temporarily stored in the solid radioactive waste storage facilities. Solid radioactive wastes are collected in the place of their formation, sorted according to the activity categories and technological properties.

By the relative activity level solid radioactive wastes are divided into three categories:

I – low-level;

II – medium-level;

III – high-level.

There is a general solid radioactive storage facility for power units 3 and 4 of SS "Rivne NPP", wastes from power units 1 and 2 are stored separately. Solid radioactive wastes are mainly generated in the form of:

- contaminated dismantled equipment;
- dismantled pipelines and valves;

- contaminated tools and devices;
- spent filters and filtering materials of special ventilation system;
- dismantled fragments of thermal insulation materials;
- immobilized liquid radioactive wastes;
- materials used for wiping;
- used overalls and additional personal protective equipment not subject to decontamination.

LRW are mainly produced in the process of water purification systems operation and contamination of oil pump systems of reactor compartment.

LRW includes:

- non-controlled primary circuit leaks;
- radiation contaminated oil;
- water used for decontamination;
- laundry and hot shower drain water;
- water from hydraulic filters;
- evaporator sludge of evaporation plants;
- spent filtering materials of water purification system filters;
- sludge.

Minimization of radioactive releases and discharges and their impact on the environment and the public is provided by the following main engineering solutions:

- decontamination of air which is removed and which contains radioactive isotopes using aerosol and iodine filters;

- decontamination of process vent on filters-absorbers, where gas is held up in order to reduce relative activity (radioactive decay of the major part of inert noble gases isotopes (xenon (Xe), Krypton (Kr);

- air releases from the premises of reactor compartment controlled access area and auxiliary building through vent stacks of 150 m high, that provides necessary dispersion of radioactive substances in atmosphere;

- establishment of barriers to prevent propagation of radioactive substances by way of the reactor compartment containment, lining of the premises with LWR sources by corrosion resistant steel;

- implementation of closed process and component cooling systems to prevent discharges of liquid substances containing radioactivity;

- implementation of special system for SRW collecting, as well as SRW and LRW storage;

- prevention of non-controlled releases and discharges;

- arrangement of NPP’s SPZ;

- organization of continuous technological dosimetry monitoring of discharges and releases, air, soil, vegetation, water contamination monitoring in the SPZ and OZ.

2.7 Main Sources of Danger of Non-radiation Origin

2.7.1 Chemical Impact

Chemical impact on the elements of the environment can be made by chemical elements and substances that are part of releases and discharges. The permissible amount of harmful components contained in releases and discharges to the environment is regulated by the sanitary norms and rules depending on the degree of their impact.

During SS Rivne NPP operation the non-radioactive solid wastes are produced which can cause chemical pollution of the environment.

Waste management at SS Rivne NPP is carried out in compliance with the requirements of laws and sanitary and hygienic standards of Ukraine. Solid domestic wastes are transferred to the public utility landfill of town of Varash. In compliance with the “Provision on the Interrelations of SS “Warehouse” with SS NPP, SS “AtomKomplekt”, SS “AtomProjectEngineering” and the Directorate for Organization of Internal Inspection of SE “NNEGC “Energoatom” ПЛ-Д.0.45.551-13, the wastes of spent luminescent lamps, monitors, batteries, spent and worn buses were transferred to the specialized enterprises for further disposal through RV VP SG.

Spent oils and lubricants (motor, turbine, industrial, transformer), spent storage batteries, broken glass, waste metal and paper (except for technical documentation, accounting and other documents to be destructed) have been transferred to Rivne department of SS “Warehouse” as raw-materials.

The major amount of wastes produced at SS Rivne NPP is located at MVV, namely: at the moisture proof sludge collector and at the landfill of industrial and construction waste in designated areas. Environmental monitoring near the sludge collector and landfill of industrial and construction waste is carried out according to the approved schedule.

The sources of non-radioactive impact are both main production facilities (main building, auxiliary buildings) and auxiliary facilities and structures.

The sources of chemical impact on atmosphere under normal operation and emergency situations are gas releases during process equipment operation through the ventilation systems and smoke stacks.

It shall be noted that operation of the above mentioned installations is periodic and has almost no impact on the environment.

The main harmful elements released into atmosphere, the amount of which does not exceed the regulatory limits established for concentration and gross indicators, are: nitrogen dioxide, sulfur dioxide, carbon monoxide, soot, dust, vapors of oil products.

Chemical and chemical and biological impact on the water environment is possible due to discharges of industrial and rain drain water to the Styr river.

Chemical impact on soil and vegetation can take place due to precipitation of chemical elements and compounds from atmosphere.

The amount of chemical (non-radioactive) releases of harmful substances from SS Rivne NPP sources and their concentration in the atmosphere are currently limited by the following documents:

- boundary gross release – “Project standards for maximum permissible releases from stationary sources of Rivne nuclear power plant”.
- concentration of harmful substances in the atmosphere – “State Sanitary Rules for Protection of Atmospheric Air of Populated Areas (from chemical and biological contamination) ДСП-201-97, approved by the Order of the Ministry of Health of Ukraine No. 201, dated July 09, 1997 and State Environmental Safety Administration in Rivne oblast, dated April 09, 1999.
- “The list of harmful substances released into atmosphere and those subject to monitoring in the area of environmental protection” approved by the Resolution of the Cabinet of Ministers of Ukraine No. 343, dated March 09, 1999.

Main chemical pollutants are carbon monoxide, nitrogen dioxide, hydrocarbons, sulfur dioxide, substances in the form of suspended solids. In addition, ventilation emissions can contain non-methane volatile organic compounds, gasoline, acids, hydrazine etc.

Discharge of domestic waste water from NPP into public water bodies is not carried out.

2.7.2 Physical Impact

Physical impact of SS Rivne NPP site on the environment is characterized by:

- thermal impact on the air environment associated with operation of NPP process equipment cooling systems (spray cooling ponds and cooling towers);
- increased humidity due to the evaporation of water into the atmosphere from spray cooling ponds and cooling towers;
- thermal impact on the water environment associated with the discharge of blowdown water from the main cooling system;

- impact on the water environment (the Styr river) associated with the irretrievable water consumption;

- impact of the electric field of 330/750 kVt transmission lines;

- noise during equipment operation and traffic.

The complex of planning, technical, technological (process), organizational measures and decisions regarding the limitation of negative impact is aimed at providing regulatory indicators for environmental protection.

Table 2.5 presents the values of heat releases of Rivne NPP into atmosphere.

Table 2.5. Amount of heat removed by the cooling water from the plant components and released into atmosphere.

Plant equipment	Heat release, Gcal/year
Circulation systems of service water supply	5220
Group A service water supply system	60
Group B service water supply system	100

The existing regulatory documents do not have requirements to the allowed limits of heat releases. Monitoring of heat releases is performed by measuring the consumed water, which is collected from the River Styr for service needs and consumed water that returns to the river.

Taking into account that impact of the plant cooling systems is quite insignificant on the climate parameters, and that impact of the cooling towers and spray ponds is practically implicit on the microclimate and environment outside the sanitary protection zone within the radius of 2.5 km, no special activities are foreseen with regard to limitation of these influences during NPP operation.

2.8 Scheme for Spent Nuclear Fuel Treatment

In the process cycle of the nuclear power plant, one of the most important elements is the spent nuclear fuel (SNF), which generates as a result of the energy produced in the nuclear reactors.

The time of using the nuclear fuel in the reactors is defined by the value of allowed burn-up of the fissionable isotopes. After the planned burn-up is achieved, the nuclear fuel is unloaded from the reactor and considered to be spent fuel, since it cannot be used any longer for energy generation.

After unloaded from the reactor, the spent nuclear fuel is loaded to the near-reactor spent fuel pit (SFP). The SNF is stored in the pits for the limited time, necessary for reduction of energy release, due to decay of fission products, to the allowed values. After SNF storage in the SFP during limited time, the spent fuel assemblies (SFAs) should be transported from the power unit and shipped for storage (disposal) or processing. This is done because the capacity of SFP is limited and it should always have free volume for loading of the nuclear fuel from the reactor core or periodic inspections of the reactor vessel and in-vessel internals of VVER reactors.

During SNF management, it is also necessary to consider the factors, which relate to the specifics of this material: high radioactivity level and presence of valuable elements in SNF (uranium, plutonium, germanium, erbium, palladium, zirconium etc.), which in the perspective can be used in other fuel cycles (nuclear fuel for the fast-neutron reactors, MOX-fuel for light-water reactors). Taking into account the above mentioned, the SNF does not refer to radioactive waste.

The current state of the nuclear energy field in the world shows that, given the modern level of technologies, the final conclusions cannot be made as for the economic viability of SNF processing or disposal, i.e. the final phase of the nuclear fuel cycle (NFC). In light of this, Ukraine like most other countries that develop nuclear energy, took for themselves the so-called “deferred decision”, which implies long-term storage of the spent nuclear fuel. The “deferred decision” allows the country to take a decision later on the final phase of NFC, considering the technologies development in the world and economic benefit for the country.

At present, Ukraine has two storage facilities in operation, designed for temporary storage of the spent nuclear fuel: wet type interim spent fuel storage facility at Chernobyl NPP and dry-type spent fuel storage facility at Zaporizhzhya NPP. Besides, Ukraine is constructing two more storage facilities: ISF-2 at Chernobyl NPP and Centralized spent fuel storage facility (CSFSF) for the SNF of VVER reactors.

SNF from Rivne, Khmelnitskiy and South Ukraine nuclear power plants is currently transported to the Russian Federation. SNF from VVER-1000 reactors is shipped for storage, and SNF from VVER-440 (power units 1, 2 of Rivne NPP) is shipped for reprocessing.

To accomplish "Action Plan for 2006-2010 with regard to implementation of the Energy Strategy of Ukraine for the period up to 2030" (approved by the Decree of the Cabinet of Ministers of Ukraine № 427 as of July 27, 2006), the operator SE "NNEGC "Energoatom"" signed the contract with the American Company "Holtec International" for construction of the CSFSF in Ukraine. The SCFSF will be used for storing the spent nuclear fuel of Rivne, Khmelnitskiy and South Ukraine NPPs based on the dry-type storage technology applied at Zaporizhzhya NPP.

In accordance with the legislative provisions, the operator NNEGC "Energoatom" developed "Feasibility Study for construction of the CSFSF for VVER reactors types". Following the complex state expert review, the document was approved by the Cabinet of Ministers with the Decree № 131-p as of 04.02.2009.

The specified Feasibility Study justified the economic viability for the long-term storage of SNF in Ukraine, compared to SNF shipment to the Russian Federation, and construction of one centralized storage facility was substantiated compared to any other option of SNF storage.

The CSFSF is designed to store 12500 SFAs (spent fuel assemblies) from VVER-1000 reactors and 4000 SFAs from VVER-440 reactors for the period of 100 years.

On 09.02.2012 by the Law of Ukraine № 4383-VI "On Spent Nuclear Fuel Handling with regard to Location, Design and Construction of the Centralized Spent Fuel Storage Facility for VVER reactors", the Verkhovna Rada of Ukraine took a decision with regard to CSFSF siting on the territory of the Exclusion Zone, as well as CSFSF design and construction.

On 30.04.2013, the State Nuclear Regulatory Committee of Ukraine agreed the document of NNEGC "Energoatom" "Task Order for modification of the SNF shipment technology from VVER-1000 reactor (B-320) to ensure its transportation to the CSFSF".

On 23.04.2014, with the Decree №399-p of the Cabinet of Ministers, NNEGC "Energoatom" received a permission for development of the land survey project with regard to siting of lands with the total area of 45.2 ha, located between the former villages Stara Krasnytsya, Buryakivka, Chystogolivka and Stechanka of Kyiv Oblast in the exclusion Zone, that were contaminated due to the Chernobyl catastrophe. The lands shall be allocated to the specified enterprise for the permanent usage and the target application will be changed for construction of the CSFSF and railway access road.

On 22.07.2015, the State Nuclear Regulatory Committee of Ukraine agreed the updated "Licensing plan for establishment of the centralized spent nuclear fuel storage facility" (PN-Д.0.46.527-15), developed to replace PN-Д.0.46.527-11.

On 23.07.2015, the State Nuclear Regulatory Committee of Ukraine agreed the proposals of the operating company with regard to the content and scope of the Explanatory Note "Construction Plan for the Centralized Spent Fuel Storage Facility for VVER reactors of Ukrainian NPPs" and provided recommendations as for the CSFSF construction.

On 12.10.2015, with the Order № 926 of NNEGC "Energoatom", the Steering Committee was established with regard to implementation of the Holtec technology for SNF handling at Rivne, Khmelnitskiy and South Ukraine nuclear power plants, which included the representative from the State Nuclear Regulatory Committee of Ukraine and State Scientific and Technical Center.

On 05.10.2016, by the Directive № 721-p of the Cabinet of Ministers, the land plot with the area of 45.2 ha was extracted from the permanent use of the State Agency on Exclusion Zone Management and assigned to the permanent use by NNEGC "Energoatom" for construction and operation of the Centralized Spent Fuel Storage Facility.

On 03.11.2016, by the Directive №08 of the SNRIU Board, the Conclusion was agreed with regard to the state review of the preliminary safety analysis report for CSFSF.

On 07.12.2016, NNEGC "Energoatom" received registration of declaration № ІУ030163421149 for beginning of preliminary works.

On 07.06.2017, the Cabinet of Ministers by Decree №380-р approved the project "Construction of the centralized storage facility for spent nuclear fuel of VVER reactor type".

On 29.06.2017, the State Nuclear Regulatory Inspectorate of Ukraine issued NNEGC "Energoatom" with the license for implementation of activity at the phases of lifecycle of "construction and commissioning of the nuclear facility (centralized spent fuel storage facility for VVER reactor type)".

On 09.11.2017, the special ceremony was held with regard to the beginning of CSFSF construction in the urban-type village Buryakivka (Exclusion Zone)

In addition, the following tasks were accomplished by SNRIU in 2017:

- review of 15 packages of the technical specifications for safety important equipment, with the preliminary comments provided to "Energoatom";
- preliminary agreement was made, following the state review of nuclear and radiation safety of three technical specifications;
- state review and submittal of the preliminary comments to three programs on acceptance tests at the manufacturer's factory;
- review of series of Technical Solutions related to the Holtec technology on SNF preparation for storage in CSFSF to be implemented at the Ukrainian NPPs;
- participation in the meetings of the Steering Committee with regard to the Holtec technology on SNF preparation for storage in CSFSF to be implemented at the power units of Rivne, Khmelnitskiy, South Ukraine NPPs.

2.8.1 Treatment of High-level Waste of Radioactivity Formed After Processing of Spent Nuclear Fuel of SS Rivne NPP

According to the Agreement between the Government of Ukraine and the Government of the Russian Federation on the scientific and economic cooperation in the nuclear energy field as of 14.01.1993 and contractual obligations of NNEGC "Energoatom", the spent nuclear fuel of VVER reactors is transported for the technological storage and reprocessing to the entities of the Russian Federation (Federal State Unitary Enterprise (FSUE)"Mayak Production Association and Federal State Unitary Enterprise "Mining and Chemical Plant"). To Ukraine, the products of reprocessing are expected to be returned in the form of vetrified high-level waste (HLW)[1], obtained after SNF reprocessing. The waste will be returned to Ukraine in compliance with the conditions and terms specified in the relevant contracts between the entities of the Parties.

Starting from 1993, the SNF of Rivne NPP VVER-440 is transported to the FSUE "Mayak" for storage and reprocessing.

Amount of the vetrified HLW that returns to Ukraine is calculated on the agreement by the regulatory authorities of Ukraine and Russia in accordance with the document СОУ-Н ЯЕК 1.027:2010 "Methodology for calculation of high level radioactive waste that returns to Ukraine after storage and reprocessing of SFAs of VVER-440" (put into effect by the Order of the Ministry of Fuel and Energy of Ukraine as of 25.08.2010 № 332).

[1] After reprocessing of the SNF from the VVERs, the valuable products of processing also have to be returned (oxides of uranium, plutonium and neptunium), solid HLW (structural elements of SFAs, residues of cladding of heavy and light fraction) and cemented intermediate-level waste.

At present, the parties are in the process of agreement of the Technical Conditions for the vitrified HLW from the reprocessed SNF of Rivne NPP VVER-440, that will be returned to Ukraine, and the passportization procedure and Quality Assurance Program for SNF processing.

Construction of the storage facility at the site of “Vector” Complex, for interim long-term storage (100 years) of the vetrified HLW from the reprocessed SNF of VVER-440, is planned in Task 3 of “National Target Environmental Program on Radioactive Waste Management” approved by the Law of Ukraine № 516-VI as of 17.09.2008.

In 2012, the Feasibility Study (FS) was developed with regard to construction of the storage facility for the interim storage of the vetrified HLW that are returned from the Russian Federation after processing of the spent nuclear fuel from VVER-400 reactors of the Ukrainian NPPs. The FS received a positive expert report after the State Construction Review. The state review showed that the Technical Solutions accepted in the FS are in compliance with the current construction norms and design rules applied in Ukraine, as well as in compliance with the requirements to the nuclear and radiation safety. Since the FS, due to some objective reasons, was not approved in the corresponding ministries and government departments, the activities are being performed now with respect to its repeated state review.

In addition, a full package of the design and estimates documentation (“draft” stage) was developed, which is also submitted for the state construction review.

According to the design, the lifetime of the storage facility is 15 years for the mode of acceptance and HLW preparation to storage and 100 years for the mode of interim storage and off-loading of HLW (for disposal). The capability of reverse HLW uploading is considered when the interim storage finishes in the facility.

The construction will be conducted in two queues (it is planned to have two commissioning complexes, the first one for 350 m^3, and the second one for 200 m^3).

The decision on locating the HLW at the site of “Vector” Complex has several advantages:

- a closely situated operating railway;
- a quite developed network of roads;
- availability of labor resources;
- possibility to use an existing infrastructure of the first queue of the “Vector” Complex, engineering and telecommunication systems, systems of radiation control and environmental monitoring.

The spent nucler fuel of Khmelnitskiy, Rivne and South Ukraine NPPs with VVER-1000 (until 2001 Zaporizhzhya NPP as well) is transported for the temporary storage with further reprocessing to the Federal State Unitary Enterprise "Mining and Chemical Plant” (Krasnoyarsk, Russian Federation). At present, reprocessing of the SNF from VVER-1000 of Ukrainian NPPs is not performed in the Russian Federation. Returning of the products of reprocessing to Ukraine, including HLW, can start from 2025.

Two documents agreed and approved by the Russian Federation and Ukraine must define the amount and nomenclature of the products after reprocessing of SFAs from VVER-1000. They are Methodology for defining the amount of high-level waste and products of reprocessing, which return to Ukraine after technological storage and reprocessing of the batch of SFAs from VVER-1000, and Technical Conditions for products after reprocessing of SFAs from VVER-1000.

The radioactive waste after reprocessing of SNF from VVER-1000 has to be shipped to the facilities for interim storage with further transition for disposal in the deep geological formations. At present, such facilities in the infrastructure of the operating RW management entities is absent in Ukraine.

Construction of the modern high-technology, centralized spent nuclear fuel storage facility, designed for storage of the SNF from South Ukraine, Rivne and Khmelnitskiy NPPs, will enable to resolve the problem with the spent nuclear fuel handling in the long-term perspective. This is confirmed by the positive experience of the dry spent nuclear fuel storage at Zaporizhzhya NPP.

The government of Ukraine issued the Directive №399-р as of 23.04.2014 on giving the permission to NNEGC "Energoatom" for development of the land survey project as for allocation of the land plot for storage of the spent nuclear fuel from the nuclear power plants of Ukraine. NNEGC "Energoatom" is assigned as the operator of the nuclear facility - centralized facility for storage of the spent nuclear fuel from VVER reactors of Ukrainian NPP (which is part of the complex for spent nuclear fuel handling at the specialized entity "Chernobyl NPP").

According to the estimations, the expenses for construction and operation of the CSFSF will be almost four times less than the total costs spent by Ukraine today for transportation of SNF to Russia; investments into the CSFSF will be compensated in less than four years of the facility operation.

Design, production and supply of the SNF handling equipment will be accomplished in line with the contract with "Holtec International".

Commissioning of the CSFSF will be performed by the stages, starting from 2018. This will allow Ukraine to refuse from the SNF shipment to the Russian Federation, which will significantly increase the energy safety of Ukraine and eliminate risks of shutting the power units down due to overloading of the spent fuel pits.

2.9 Project Decisions on Radioactive Waste Treatment

During the plant operation, it is inevitable to have the production waste: solid, liquid and gaseous.

Production of the electricity at the nuclear power plants comes along with generation of radioactive waste in the course of the main technological process, as well as during routine and maintenance operations. The stable development of the nuclear energy field in the country requires safe management of the radioactive waste at all phases of waste formation and existence. The RW management system is an important component in the entire safety systems while using nuclear energy.

The main principles of the RW management at the NPP is minimization of waste formation and interaction between all phases – from formation to disposal.

The strategy on RW management in Ukraine, approved by the Cabinet of Ministers of Ukraine and National Target Environmental Program for Radioactive Waste Management approved by the Law of Ukraine, specifies withdrawal and processing of radioactive waste accumulated during plant operation. It should be done through establishment of the infrastructure for radioactive waste specification, conditioning and packaging using the method applicable for its further transportation for storage and/or disposal.

Radioactive waste management at Rivne NPP is accomplished in line with:

- Law of Ukraine "On radioative Waste Management", dated 30.06.1995 № 256/95 –ВР;
- Law of Ukraine "On Usage of Nuclear Energy and Radiation Safety" as of 08.02.1995 № 40/95 – ВР;
- Law of Ukraine "On National Target Environmental Program for Radioactive Waste Management" as of 17.09.2008 №516-VI;
- Radioactive Waste Management Strategy in Ukraine, approved by the directive of the Cabinet of Ministers of Ukraine, as of 08.2009 № 516- VI;
- Integrated Program for Radioactive Waste Management in NNEGC "Energoatom" ПМ-Д.0.18.174-16, put into force with the order as of 12.10.2016 №927-р.

The national regulatory authorities for radioactive waste management are the State Nuclear Regulatory Inspectorate of Ukraine and the Ministry of Health Protection of Ukraine, the national governing body is the Ministry of Energy and Coal Industry of Ukraine.

The State Special Enterprise "Central Radioactive Waste Management Enterprise" (CRWME), the storage facilities operator, within the State Agency of Ukraine on Exclusion Zone Management (SAUMEZ) is responsible for acceptance and storage (if required, long-term storage) of the conditioned

RW. Currently, NPP RW shipping for the long-term storage or disposal at the facilities is not accomplished, but activities were initiated on RW preparation for shipping to the special enterprise.

Planning of the activities on radioactive waste management at RNPP is accomplished in accordance with “Integrated Program for Radioactive Waste Management in NNEGC “Energoatom” ПМ-Д.0.18.174-16. The program specifies main areas and a list of activities related to radioactive waste management in NNEGC “Energoatom”. These activities are: minimization of RW generation, improvement of the current RW management systems at NPPs sites, construction of complex lines on RW processing for its preparation to transference to the ownership of the state, provision the plant with the equipment for RW storage, harmonization and improvement of the regulatory framework in the area of RW management.

During planning the activities in the field of radioactive waste management, NNEGC “Energoatom” applies the following main principles:

– ensure corresponding safety level in the field of radioactive waste management;

– minimization of generated RW volumes during plant operation;

– selection of optimal RW treatment technologies considering such factors as:

- ✓ individual and collective radiation doses of the personnel;
- ✓ cost of RW processing;
- ✓ amount of generated RW;
- ✓ duration and cost of short-term RW storage;
- ✓ requirements to the end product accepted for disposal;
- ✓ capability of using selected methods of RW processing both during plant operation and its decommissioning;

- ensure capability of processing, immobilization, and temporary storage of RW generated during extended lifetime of the plant;

- application of the advanced technologies during RW processing and immobilization to provide for RW safe transportation and disposal;

- ensure quality of all processes and works related to the radioactive waste management at the plant.

The main activity on improvement of the radioactive waste management system at Rivne NPP is construction of a complex for the radioactive waste processing (CRWP). The Program ПМ- Д.0.18.174-16 indicates commissioning of CRWP in 2018. A separate permission was obtained from the SNRIU for operation of the new facility of the infrastructure - radioactive waste processing complex.

SNRIU ensured regulatory follow-up of the activity, review and agreement of the complex testing programs and corresponding technical solutions regarding putting of CRWP into trial operaiton at Rivne NPP within other process facilities:

- extraction of SRW from the SRW storage compartments;
- SRW sorting and fragmentation;
- SRW supepressing;
- SRW cementation;
- SRW activity measurement;
- metal decontamination;
- spent oil treatment.

Implementation of the RW complex will allow for:

- reduce the amount of accumulated SRW and waste generated during operation;
- condition the SRW to ensure its safe long-term storage and disposal;
- obtain additional free volumes in the existing storage facilities for the short-term storage of the containers with SRW under the ownership of the state.

RW management at Rivne NPP is accomplished like at any other operating NPP in compliance with the principle flow chart presented below at Figure 2.5.

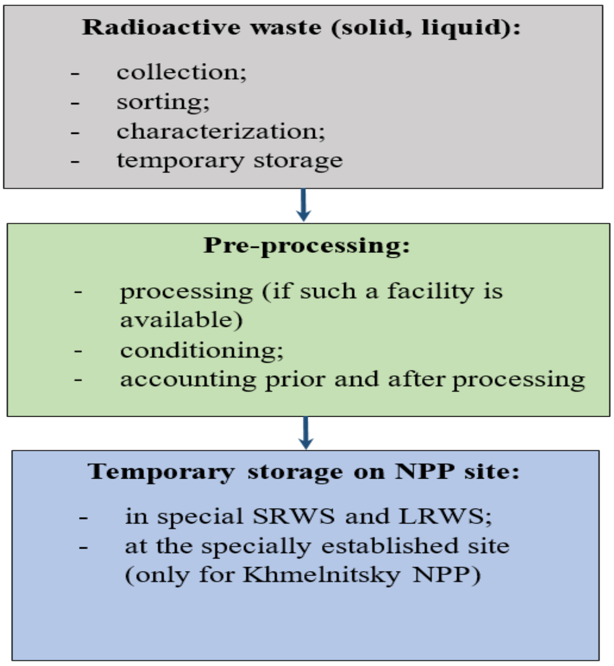


Figure 2.5 Principal flow chart for radioactive waste management at NPP

The condition of RW management at Ukrainian NPPs is characterized with absence of completed technological cycle from the processing to obtaining of the end-product, acceptable for further long-term storage or disposal.

At present, due to unreadiness of the Operator of CRWME storages, which is under subordination to the State Agency of Ukraine for the of Exclusion Zone Management, with regard to receiving the NPP RW for its long-term storage and disposal, RW transfer to this specialized enterprise is not accomplished.

2.9.1 Solid Radioactive Waste Treatment During Plant Operation

The solid radioactive waste (SRW) generates in the process of normal plant operation, during maintenance and repair activities and during accidents.

The main source of SRW generation is maintenance and repair activities at the power units, which include:

- operation of the plant components, buildings and facilities;
- reconstruction and modernization of equipment;
- decommissioning of components, including replacement of steam generators;
- decontamination of equipment, rooms, buildings and facilities of NPP;
- equipment maintenance and repair;
- activities on mounting, dismantling and replacement of thermal insulation;
- construction and reconstruction works;
- replacement of worn and spent part of equipment, consumables;
- replacement of worn work clothes, personnel protection means;
- implementation of sanitary and health protection measures in the Sanitary protection zone.

<u>The solid radioactive waste usually is</u>:

- metal formed during replacement of the equipment and as a result of maintenance activities;
- woodware (stage, spacer, scaffolding);
- used individual protection means;
- rubber technical goods, cable products;

- filters of ventilation systems in auxiliary building and reactor hall;
- thermal insulation materials;
- construction waste (concrete chips, plaster);
- wipers, dusters;
- ash after RW processing at the burning facility;
- reactor internal devices and elements of reactor hall systems.

Transportation of SRW containers to the SRW storage located in the special building of Rivne NPP site is performed using special transport, as shown on Figure 2.6.

Figure 2.6. Special vehicle OT-20 on the chassis ISUZU

SRW distribution by types of treatment is presented on Figure 2.7.

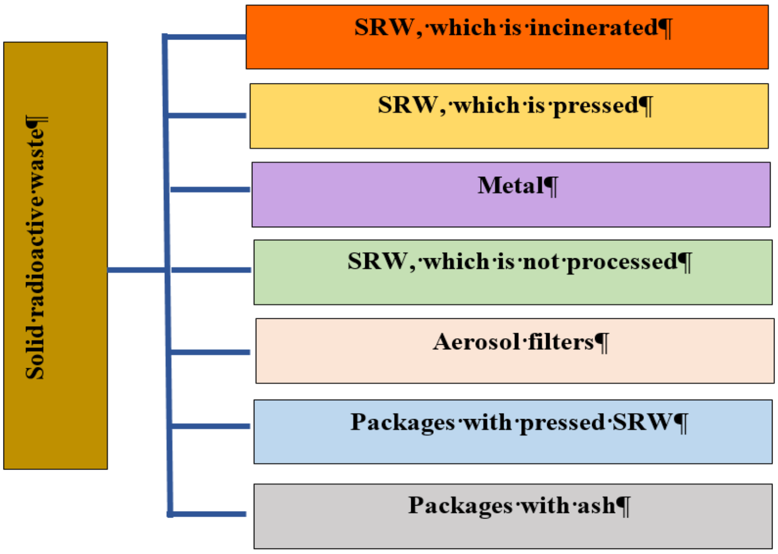


Figure 2.7. SRW distribution by types of treatment

Solid RW are classified by the following types:
- Short-lived ($T_{1/2}$ – to 10 years);
- Medium-lived ($T_{1/2}$ - to 100 years);
- Long-lived ($T_{1/2}$ – over 100 years).

SRW management at RNPP includes:
- waste collection into plastic bags at the places of waste formation;

- primary sorting of waste with fragmentation (is necessary);
- waste transportation from the places of temporary collection;
- SRW sorting by its activity to low-level, intermediate-level and high-level activity;
- SRW transportation by special vehicle OT-20 from the places of temporary collection into special building № 2 (for power units 3, 4);
- SRW acceptance by the personnel of the decontamination and RW processing departments for temporary storage;
- SRW loading by the personnel of the decontamination and RW processing departments into cells of special building №1 of SRW storage (for power units 1, 2) and special building № 2 of SRW storage (for power units 3, 4).

According to all SRW, sorted by types and classification, are allocated for temporary storage in the SRW storage in the special building at Rivne NPP site.

The diagram of the SRW management at Rivne NPP is provided on Figure 2.8.

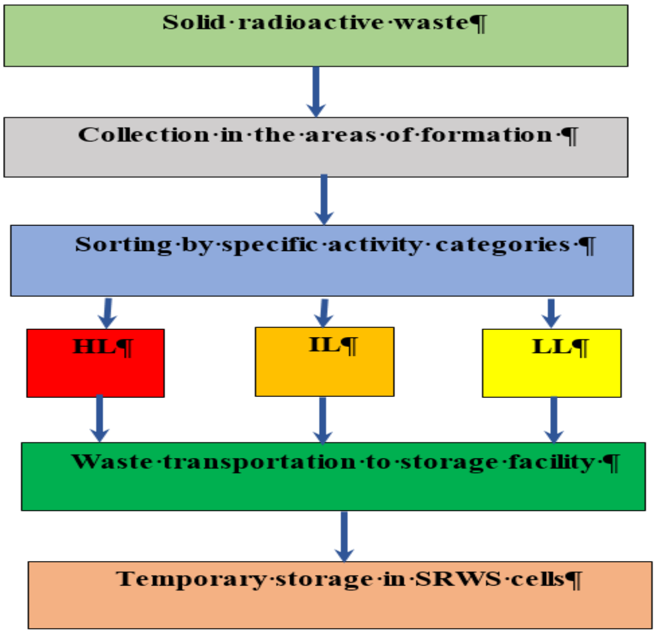


Figure 2.8. Diagram of the SRW management at Rivne NPP

All SRW, sorted by types and classified by activity, are allocated for temporary storage in the SRW storages in the special building at Rivne NPP site.

At the RNPP's Complex for radioactive waste processing (CRWP), which was jointly constructed with the European Commission under the framework of TACIS International Technical Assistance Program, the first phase of complex testing has been completed. Next in turn is the second phase, so called "hot" tests with the actual radioactive waste. The successful completion of these tests will become the beginning of operation of the first RW processing complex at the operating nuclear power plants of Ukraine.

This complex consists of seven installations. Four of them: extraction (ONET, France); SRD sorting and fragmentation (Nukem, Germany); superpressing Megane 15 (Nukem, Germany) and activity measurement HS 541 (Envinet, Check Republic) were provided within the TACIS project. The rest three installations: cementing (Envitek, Ukraine), oil purification and metal decontamination (Consortium Specenergetikos, Lithuania-Ukraine) were implemented by NNEGC "Energoatom"'s funds. In May, 2018 "cold" tests were successfully conducted on the RW simulators at CRWP.

Figure 2.9. Exterior of CRWP building

Implementation of the CRWP will increase the safety level at Rivne NPP by application of the advanced innovative technologies on radioactive waste treatment, thus promoting the RW management system of Rivne NPP to the new, modern international level.

Figure 2.10. CRWP equipment

In February of this year, the first stage of complex (“cold”) tests of the additional systems and all seven installations of CRWP were completed at Rivne NPP. The tests were conducted with participation of the plant personnel and representatives of the SNRIU. The testing results were documented in the report, which was submitted to the SNRIU. In addition, the Special Permit was obtained for the second phase of “hot” tests.

The successful results of “hot” tests will transfer the facility gradually to the commercial operation. “The complex is intended for processing of “historical” low-level RW, which accumulated in the solid RW storage at the Rivne NPP site”, the current waste, which formed during plant operation and the waste, which will accumulate during decommissioning of the power units of the NPP. The end product of processing will comply with the requirements of waste acceptance for disposal at the special RW treatment facilities.

Before the radioactive waste was shipped to the CRWP, the Rivne NPP personnel and guests had a chance to see the unique installation, its process line, obtain answers from the experts who will further operate the equipment of the RW processing complex.

The modern process equipment meets the high European standards. The activity implemented at CRWP of Rivne NPP will allow not only reduce the volumes of waste generated during plant operation but also increase safety and environmental compatibility of the nuclear power industry in general and preserve the environment.

The permission was issued on June 1, 2018 with duration period until the end of the lifetime of “Power Unit 4 of Rivne NPP”. The decision on its issuing was taken by SNRIU based on the results of the state expert review of the safety justification documents related to implementation of the declared activity, and inspection conducted by SNRIU commission to study the capability of the operator (NNEGC “Energoatom”) to accomplish works related to commissioning of the Complex for RW processing at Rivne NPP.

2.9.2 Liquid Radioactive Waste Treatment During Plant Operation

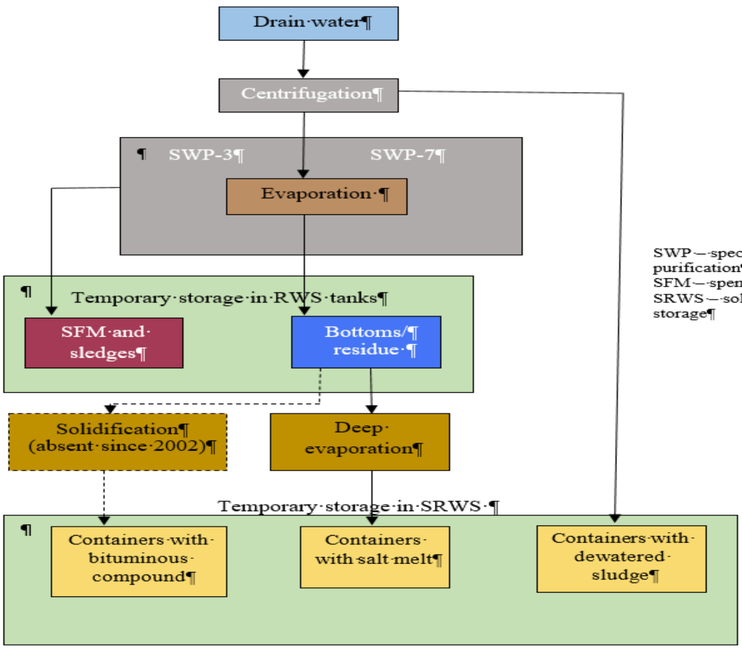
During plant operation, the liquid radioactive waste are generated in the process systems of the reactor department and auxiliary building as a result of the contact of water with fuel elements, contamination of oil systems, and operation of special water purification systems.

LRW are mainly met in the form:

- primary coolant uncontrolled leakages;
- contaminated oils;
- spent ion-exchange resins of the SWP system;
- waters that generate after decontamination;
- sewage waters from laundry hot shower drains;
- waters from hydraulic discharge of the filters;
- bottoms/residue;
- spent filtering materials of SWP system;
- SWP sludge.

Rivne NPP operates the transport bridge, which allows transmission of the drain waters and decantate of bottoms/residue from the auxiliary building 1 into auxiliary building 2. The spent filtering materials (SFM) are transported by the hydro-transportation system into the tanks of RW storage (RWS), where they are stored under the layer of water.

The diagram of LRW management system is presented on Figure 2.11.



SWP – special water purification
SFM – spent filtering materials
SRWS – solid radioactive waste storage

Figure 2.11. Diagram of LRW management system at Rivne NPP.

The analysis of the sources and amount of generated drains was conducted. Based on the analysis results, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, “Measures on minimization of liquid radioactive waste at Rivne NPP” were developed, which result in significant reduction of drain waters.

According to ДСП 6.177-2005-09-02 the liquid radioactive waste include:

- solutions of non-organic substances;
- pulps of filter materials;
- salt melt;
- organic liquids (oils, solvents), which have the following radiation characteristics:

- content of particular radionuclides that exceeds the allowed concentration established for water consumed by the population for drinking and household;

- content of radionuclide mixture is such that the total of ratio of specific activity of each individual radionuclide to the corresponding value is greater than one.

During normal plant operation, the equipment is collected and stored in the special tanks of contaminated environment (effluents) – drain waters. Radioactive liquids and drains are obtained from the equipment of the reactor departments, and are generated as a result of operation of the special water purification system (SWP), decontamination of equipment and special protection clothes, sanitary and household discharge, laboratory discharge etc.

Following the procedure of treatment and evaporation at the SWP drain water evaporators, the liquid concentrate of salts is generated – evaporator residue/bottoms. The residue is stored in the special storage of liquid radioactive waste in the metal leak-tight tanks made on corrosion resistant steel, equipped with automated system indicating the LRW level and alarm system in case of a leakage. To exclude accidental LRW leakage into the environment, all tanks are placed in the reinforced-concrete rooms, encased with the sheets made of corrosion resistant steel up to the elevation of accidental spillage of tanks.

From the RWS the residue/bottom is sent to the deep evaporation facility for processing, where more concentrated product is formed, which is placed to the container (with volume of 200 dm^3) and it gets into a solid phase during the cooling process. The containers with the salt melt (the product of the residue processing at the deep evaporation facility) is transported for the temporary storage to the solid radioactive waste storage facility.

The photo of 200-litre containers with the salt melt SM is presented on Figure 2.12.

Figure 2.12. Containers with the salt melt

The analysis of the sources and amount of generated drains was conducted. Based on the analysis results, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, “Measures on minimization of liquid radioactive waste at Rivne NPP” were developed, which result in significant reduction of drain waters.

The general diagram of the drain water and LRW treatment is presented on Figure 2.13.

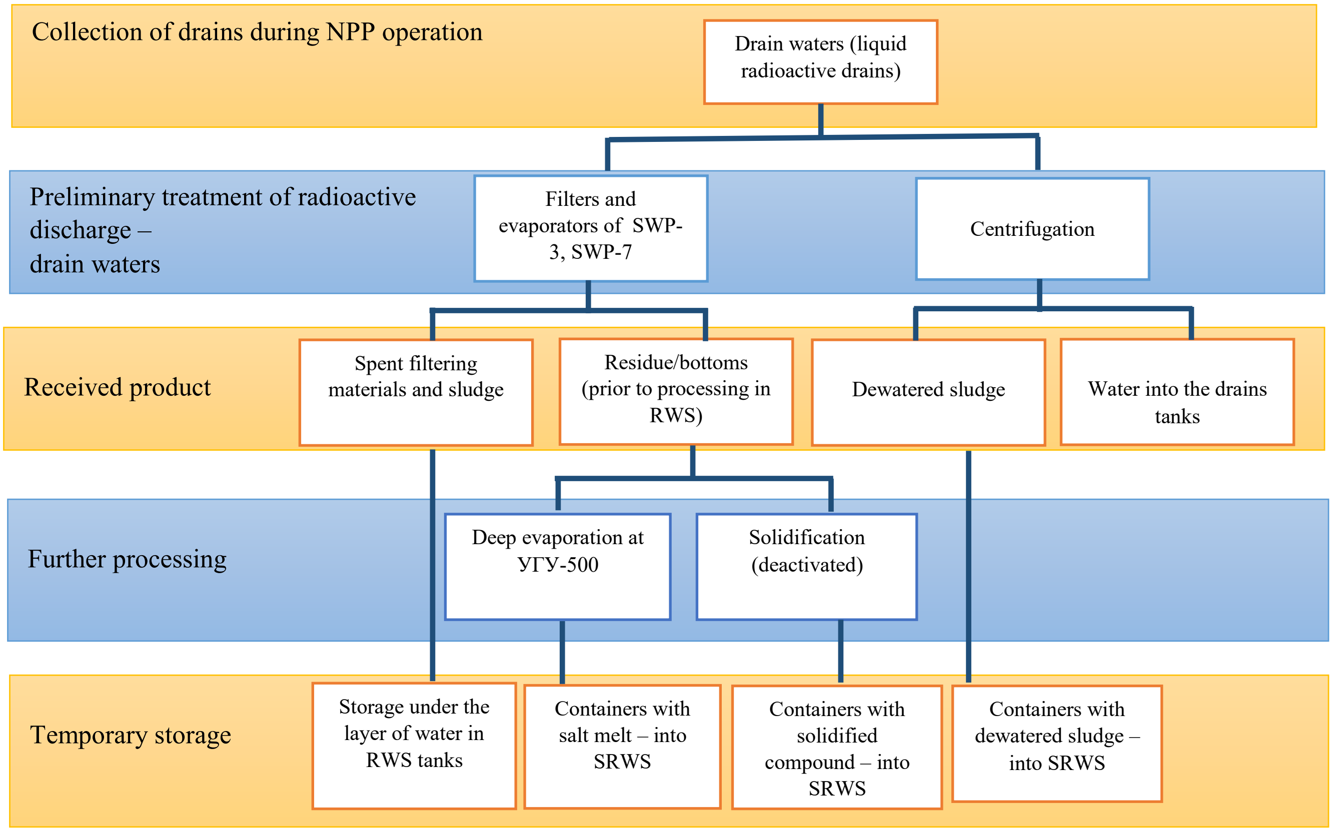


Figure 2.13. Diagram of drain waters and LRW treatment at Rivne NPP

List of available facilities/installations for LRW treatment at Rivne NPP are presented in Table 2.6.

Table 2.6. LRW treatment facilities at Rivne NPP.

Facility/installation	Main function	Design capacity
Evaporators of the drains treatment system of SWP-3, 7	Evaporation of drain waters	6 m^3/year
Deep evaporation facility (УГУ1-500М)	Deep evaporation of drain waters	500 dm^3/year
Solidification facility (with rotor film solidifier РБ-800)	Solidification of residue/bottoms	150 dm^3/year
Centrifugation facility	Purification of drain waters from mechanic residues	1.5 – 7 m^3/year

Accumulation of the liquid radioactive waste in the storage facilities at Rivne NPP as of 31.12.2017 is presented on Figure 2.14.

During 2017, the following volumes were accumulated at Rivne NPP:
- 380 m^3 residue/bottoms;
- 3.6 m^3 of spent filtering materials;
- 5.0 m^3 of dewatered sludge (25 containers);

- 77. 6 m^3 of salt melt (388 containers).

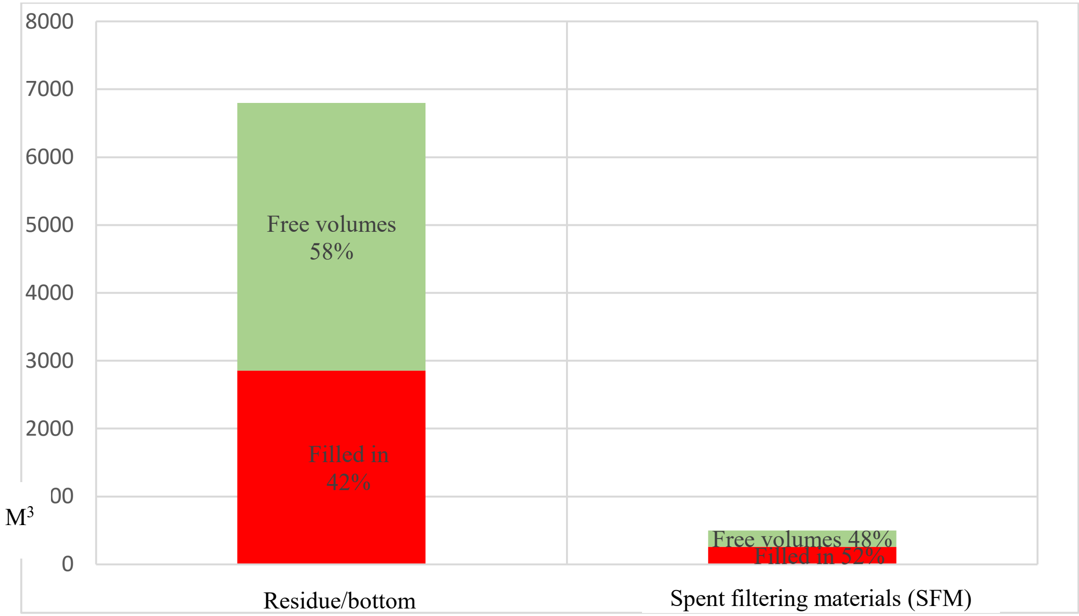


Figure 2.14. LRW accumulation in RWS at Rivne NPP

The radioactive waste management at Ukrainian NPPs is characterized with absence of the completed technological cycle from the RW processing to receiving of the end-product, suitable for further long-term storage or disposal. For this reason, the interdepartmental working group was created for solving the issues on RW optimization strategy in Ukraine, which included the representatives from NNEGC "Energoatom", NPPs, STC, SNRIU, Ministry of Energy and Coal Industry of Ukraine, KIEP, Ministry of Health Protection of Ukraine, SAUMEZ, ChNPP (Directive by NNEGC "Energoatom" as of 21.01.2015 № 60-р. It was agreed that at the first phase of the working group's work it is reasonable to focus efforts on the improvement of the radioactive waste management system in Ukraine. To resolve the existing issues, the group developed "Extended Plan on Primary Actions for NPP RW Optimization System" and got its approval on 09.03.2016. The issues related to further treatment of the SFM, salt melt, dewatered sludge are resolved with the efforts of the specified working group.

The following measures are in place: control of meeting the LRW formation and drain waters controlled levels, established in "Technical Specifications for radioactive waste formation and shipment to the storage facilities of Rivne NPP" 175-7-Р-ЦД, continuous control of LRW shipment to RWS, implementation of the minimization measures related to residue/bottoms accumulation, that reduce due to residue processing at the deep evaporation facilities. Implementation and development of the SRW management system at Rivne NPP.

Having stable operation of the deep evaporation facilities and activities implemented as per the schedule of "Comprehensive program for radioactive waste management at NNEGC "Energoatom" ПМ-Д.0.18.174-16, there will be sufficient free volumes in the RWS to ensure safe operation of power units of Rivne NPP, both during design and extended lifetime of the plant.

2.10 Non-radioactive Waste Treatment

The information, received from all the plant divisions with regard to volumes and types of non-radioactive waste to be transmitted to the specialized utilization (extraction) facility, was provided to SE "Storage Facilities" (SE SF) of NNEGC "Energoatom" for development of the plans. Transportation of the secondary material to SE SF during the reporting period was made on the basis of "Provisions on arrangement of work with the secondary material" ПЛ-Д.045.541-15.

In 2017, the ecological and chemical laboratory of the environmental protection service of Rivne NPP (according to the registration certificate № R-4/11-57-5 as of 30.05.2018) performed monitoring of the state of groundwaters and soils in the waste extraction locations. Monitoring was performed in line with the approved schedule of analytical control of the environmental state around the sludge collector and landfill of industrial and construction waste.

The facility has “Instruction on non-radioactive waste management at Rivne NPP” 083-1-I-COHC. The persons, responsible for waste management issues, were designated in the order № 436 as of 31.05.2017.

On a yearly basis, according to the paragraph 15 of “Procedure for keeping records on the locations of waste formation, treatment and utilization” approved by the Directive of the Cabinet of Ministers № 1360 as of 31.08.1998, the information is submitted to the Rivne Oblast Administration with regard to the changes in the registration card and changes in the passports of waste extraction locations: sludge collector and landfill of industrial and construction waste.

According to the paragraph 19 of “Procedure for keeping records on the waste extraction locations” approved by the Directive of the Cabinet of Ministers № 1216 as of 03.08.1998, based on the results of surveillance and control measurements, the passports of the sludge collector and landfill of industrial and construction waste are reviewed annually. To control the waste extraction location (WEL) at Rivne NPP, the State entity “Rivne Oblast Laboratory Center” of the Ministry of Health Protection of Ukraine conducted the instrumentation and laboratory measurements of the atmospheric air pollution in the third quarter of 2017 in the waste extraction locations. The analysis of water, soil and air indicators show that WEC operation is performed in accordance with the requirements of the environmental legislation and does not cause damage to the environment.

Changes in the passports are agreed with the Department of Ecology and Natural Resources of Rivne Oblast Administration, which are recorded in the relevant documentation.

Waste management is accomplished by the entity in compliance with the regulatory documents and production instructions.

The solid household waste was transferred to the landfill of the municipal company of the town. In accordance with the document ПЛ-Д.0.45.551-13 “Provision on interrelation of SE “Storage Facility” with NPPs, SE “Atom Complekt”, SE “Atomproerkengineering” and In-service Inspection Department of NNEGC “Energoatom””, the waste of used luminescent lamps, monitors, used batteries and tires were transmitted through SE SF to other specialized entities.

The used oils and lubricants (motor, turbine, industrial, transformer), used storage batteries, broken glass, metal scrap and waste paper (except for the technical documentation, accounting and other documents that must be destructed/shredded) were transmitted to Rivne department of SE “Storage Facility”, as secondary materials.

Due to putting into force the law of Ukraine № 1193-VII “On introducing changes into some legal acts of Ukraine regarding reduction of number of documents of permissive character” as of 09.04.2014, issuing of permits for activities and operations in the waste management field shall be accomplished in accordance with the requirements of associated Orders (Directives) following their approval by the Cabinet of Ministers of Ukraine. Currently, the corresponding Order has not been approved (clarification letter of the Department of Ecology and Natural Resources of Rivne Oblast Administration №2560/02/2-07/15 as of 09.12.2015).

The dynamics of the non-radioactive waste accumulation in the sludge collector and polygon/landfill of Rivne NPP is presented in Table 2.7.

Table 2.7. Dynamics of the non-radioactive waste accumulation in the sludge collector and polygon/landfill of Rivne NPP

	2011	2012	2013	2014	2015	2016	2017
Sludge collector, thous. tons	139.154	161.746	184.227	161.683	132.664	116.978	133.636
Polygon/landfill, thous. tons	14.164	19.727	25.133	29.113	32.794	36.789	42.193

2.11 Sanitary Protection Zone and Observation Zone of SS Rivne NPP

SS Rivne NPPoperation is regulated by the environmental and sanitary and epidemiological constraints stipulated by regulatory documents on the environmental safety.

The boundary values of the following main criteria are established at the plant:

- Size of Sanitary protection zone;
- Internal and external exposure of the personnel and the public;
- Maximum boundary values of radioactive and non-radioactive substances releases and discharges into environment;
- Level of open ionizing radiation sources impact;
- Ways of disposal and storage facilities of solid and liquid wastes shall comply with regulatory requirements and approval documents.

Observation Zone is an area which can possibly be affected by NPP discharges and releases and which is subject to radiological monitoring including measurement of radionuclides content in the environmental objects, food etc.

Sanitary protection zone SPZ is an area around NPP where the level of the public exposure can exceed the dose limit quota for category C.

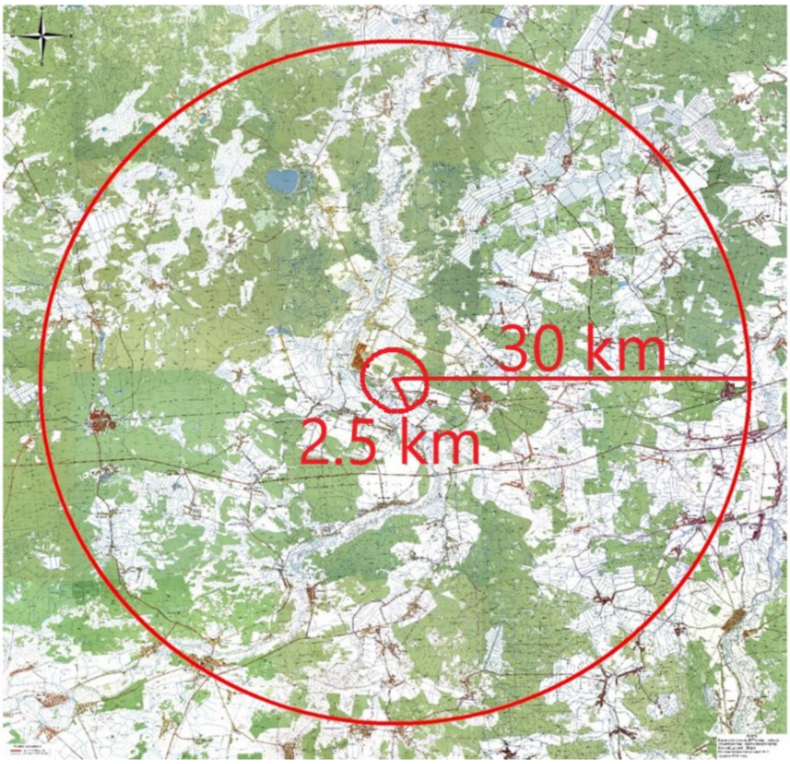


Figure 2.15 Sanitary protection zone and Observation Zone of Rivne NPP

Within the Sanitary protection zone it is prohibited to live, the restrictions on production activity not related to NPP are established, and radiation monitoring is carried out.

The size of SS Rivne NPPSPZ is 2.5 km, and OZ area is 30 km.

The size of SPZ and OZ are officially introduced in accordance with SS Rivne NPP document, namely the “Decision on the size and boundaries of Sanitary protection zone and Observation Zone of Rivne NPP” No. 132-1-P-11-ЦРБ.

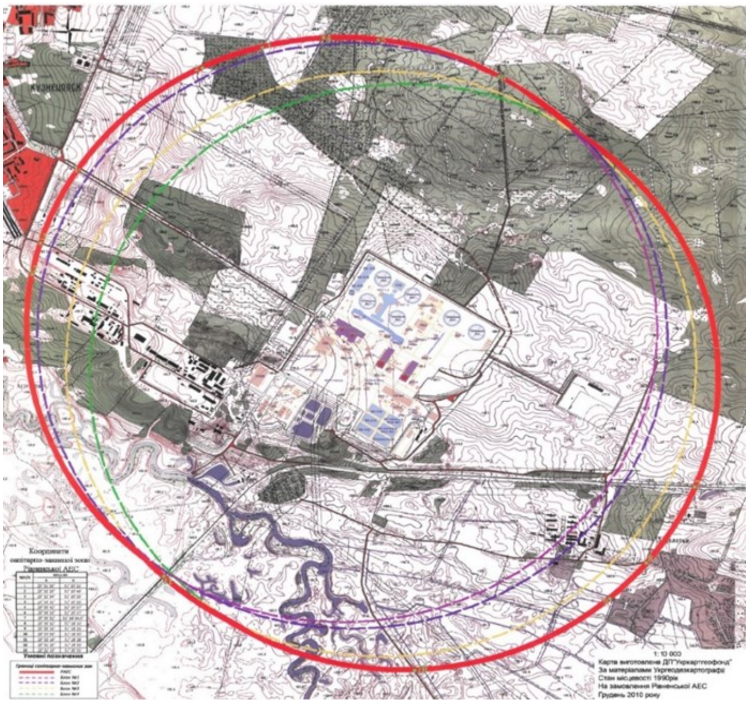


Figure 2.16. The boundary of SS Rivne NPP SPZ and the boundaries of SPZ of power units 1, 2, 3, and 4.

The boundaries of SPZ and OZ are established based on the following criteria:
- Internal and external exposure of the personnel and the public;
- Maximum permissible amount of releases and discharges of radioactive substances into environment.

The boundaries of Sanitary protection zones are established around each power unit. Figure 2.16 shows the boundaries of Sanitary protection zones of power units 1, 2, 3, 4 and the boundary of Rivne NPP Sanitary protection zone.

2.12 Radiation State of Rivne NPP Location During the Pre-commissioning Period

From 1976 to 1979, the radiation state of the environment was studied in the area of the construction activities for Rivne NPP prior to the plant commissioning. This refers to as studying of "zero background". The results of this research were used for assessment of the radiological impact of RNPP power units onto the environment during the entire period of plant operation.

According to the data of "zero background":
- specific activity of aerosols in the atmospheric air was in the range:
  ^{137}Cs – 1.11E-05÷5.92E-05 Bq/m^3; ^{90}Sr – 1.48E-05÷1.11E-04 Bq/m^3;
- total beta-activity of the atmospheric precipitations was in the range:
  7.4E+00÷3.29E+02 (Bq/m^3)/month;
- content of ^{137}Cs in the pines was in the range:
  7.2E+00÷1.7E+01 Bq/kg; ^{90}Sr – 2.96E+01÷1.05E+02 Bq/kg;
- content of ^{137}Cs in the plants was in the range:
  2.55E+00÷9.55E+01 Bq/kg;
- ground surface contamination with ^{137}Cs prior to RNPP commissioning was in the range:
  4.44E+02÷5.07E+03 Bq/m^2; ^{90}Sr – 1.85E+02÷2.92E+03 Bq/m^2;
- specific activity of ^{137}Cs in the milk prior to RNPP commissioning was in the range:
  6.3E-01÷6.6E+00 Bq/l;
- specific activity of ^{137}Cs in the vegetables prior to RNPP commissioning was in the range:
  1.5E-02÷2.0E+00 Bq/kg;
- specific activity of ^{137}Cs in the grain crops prior to RNPP commissioning was in the range:
  8.1E-01÷1.18E+00 Bq/kg.

3 IMPACT ON ENVIRONMENT OF SS RIVNE NPP SITE

3.1 Impact on Surface and Ground Waters

3.1.1 Radiation Impact on Surface and Ground Waters

Three points are established to conduct monitoring of impact of liquid discharges from Rivne NPP into the Styr River:

- Mayunychi Village – 10 km up the river stream;
- below the drain point of industrial and storm sewage system;
- Sopachiv village – 10 km down the river stream.

The sampling is performed once per a decade and then the specific activity of natural and man-made radionuclides is determined using semi-conductive γ-spectrometers. The tritium activity is determined by the liquid scintillation radiometer Tri-Carb 3170 TR/SL.

The concentration of radionuclides is thousand times lower in the Styr River than the allowed radionuclides concentration in portable water.

The bottom sediments, weed and fish of the Styr River are sampled in August every year. The samples go through preliminary verification and γ-spectrometric analysis. The objects of the Styr River have no man-made radionuclides except for ^{137}Cs of Chernobyl origin. The specific activity of ^{137}Cs in the fresh fish is 100 times less than the established allowed level.

To control non-spreading of the radioactive materials into the ground waters, the radiation monitoring of underground waters is conducted on the territory of Rivne NPP site. To control the underground water supply sources, the content of radionuclides is measured in the artesian wellholes.

There are 35 check-wellholes, and water is sampled from the bottom layer at a depth of 10÷14 meters from the surface. The frequency of water sampling from the check and artesian wellholes is once per quarter. Each sample is measured in terms of Σβ-activity using α/β radiometer MPC-9604 and specific activity of tritium is measured using liquid scintillational radiometer Tri-Carb 3170 TR/SL. The samples of check-wellholes are averaged and are subject to γ-spectrometeric analysis. The activity of man-made isotopes in the groundwaters is thousand times less than the level of allowed concentration in the portable water.

The network of artesian well-holes consists of nine wells, organized on the territory of the water withdrawal point "Ostriv". The samples of water are taken from the special collector, and go through γ-spectrometry and measurement of tritium activity. The water of artesian wellholes has no isotopes of manmade nature.

3.1.2 Non-radiation Impact on Surface and Ground Water

The water from the cooling system returns back continuously to the river through one discharge point of the industrial storm water sewerage system, which is located 30 m below the river stream from the river (additional) water intake facility. The industrial storm sewerage system receives the blowdown water from the circulation systems continuously and other debalancing waters from the power unit sites periodically after calculation of non-exceedance of normative effluents of contaminating substances. In accordance with the permission on special water use, the allowed effluents are in the volume of up to 18409.0 thousand m^3 of water for a year ($0.7m^3/sec$).

Monitoring of the chemical composition of sewerage water and river water discharged to the water intake station of Rivne NPP and after the discharge point is conduced by the certified laboratories of the NPP. The laboratory of chemical department take samples and performs analysis of the discharge water not less than six times a day (oil products and pH).

The ecological and chemical laboratory of environmental protection service (EPS) performs analysis of the surface and sewerage (discharge) waters three times a week using 25 indicators. The analysis of monitored indicators prove that the values of the maximum allowed effluents (in tons) were not exceeded, the sewerage water is within the purity limits, and contains the same natural impurities like the source river water, and operation of Rivne NPP does not input the significant changes into the quality of surface waters.

The hydrogeological analysis includes the following activities:

- measurement of water level and temperature in the drill holes;
- measurement of water temperature along the entire length of the shaft in the drill holes - temperature log;
- water pumping from the drill holes;
- sampling of water from the drill holes for determination of the chemical composition of the groundwaters.

The Sanitary protection zone of the first ring of the Artesian wells of the village Ostriv are subtracted and enclosed. The analysis is conducted by the ecological and chemical laboratory certified for making measurements of chemical composition of groundwaters (drill holes/wells) in the area of sludge collector and landfill for construction and industrial waste from Rivne NPP. The analysis of monitored characteristics prove that Rivne NPP operation does not input significant changes into the quality of ground waters.

3.2 Air Protection

Emissions of pollutants into the air from stationary sources are based on the permits issued by regional representatives of the Ministry of Environmental Protection of Ukraine No. 5620881201-1 and permits issued by the Department of Ecology and Natural Resources of the Rivne Regional State Administration No. 5610700000-8 dated 23.09.2013 (valid for 5 years), 5610700000-11 dated 27.12.13 (valid for 5 years), 5610700000-12, 5610700000-13 dated 24.10.2014 (unlimited validity), 5610700000-14 dated 24.10.2014 (valid for 10 years) and permit No 5610700000-16 dated 24.10.2014 (without limitation as to period of validity).

SS Rivne NPP has 164 stationary sources of pollutant emission into the atmospheric air, 14 of them outfitted with gas treatment modules. The largest sources of air pollution of SS Rivne NPP are auxiliary facilities: Start-up and standby boiler house, diesel generators, as well as transportation means. SS Rivne NPP owns 142 diesel and 148 gasoline vehicles, as well as 4 diesel locomotives, 1 rail crane, 1 gasoline locomotive and 1 motor trolley. The transport shop has a diagnostic station for measuring the toxicity and smoke content in the exhaust gases. Diagnostics is conducted quarterly with corresponding records made in accounting journals.

Data on emission of pollutants into the atmosphere from stationary sources for 2016 according to the statistical reporting form No. 2-TP (air) are given in Table 3.1. Total emissions from stationary sources in 2017 amounted to 34.785 t.

Table 3.1. Emissions of pollutants into the atmosphere from stationary sources

Contaminant, greenhouse gas and group code	Contaminants	Emissions from the beginning of the year, t
00000	Total for the enterprise (excluding carbon dioxide)	34.785
01000	Metals and their compounds	0.203
03000	Substances in a form of suspended solid particles (micro particles and fibres)	2.237
04000	Nitrogen compounds	8.582
05000	Dioxide and other sulphur compounds	1.510
06000	Carbon monoxide	3.356
11000	Non-metallic volatile organic compounds	18.810

Contaminant, greenhouse gas and group code	Contaminants	Emissions from the beginning of the year, t
12000	Methane	0.004
15000	Chlorine	0.012
16000	Fluorine and its compounds (expressed in fluorine)	0.034
18000	Freons	0.037
07000	Carbon dioxide, additionally	109.691

To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for emissions into the air by stationary sources has been developed and approved. According to the concluded agreement with the state institution Rivne Regional Laboratory Centre of the Ministry of Health of Ukraine, measurement of the pollutant contents in the scheduled emissions from stationary sources during the reporting period was carried out at the SS Rivne NPP (Record No. 45 dated 07.06.2016)

In 2017, mobile sources of SS Rivne NPP utilized 507.072 t of diesel fuel and 397.989 t of unleaded petrol.

3.2.1 Condition of Radiation Pollution of Atmospheric Air

Sampling and monitoring of the radionuclides content in the surface air are carried out in accordance with the radiation control regulations in force at Rivne NPP once every 10 days at 16 control stations. The volumetric activity of anthropogenic radionuclides in atmospheric air over 37 years of observations did not exceed the standard values as per NRBU-97. The volumetric activity for ^{90}Sr and ^{137}Cs is within the “zero background”.

Air pollutant emissions from the NPP are 2-3 thousand times less than that from a coal-fired TPP with a similar installed capacity.

Gas-aerosol emissions of radioactive substances released to the atmosphere through ventilation pipes are dissipated in the atmosphere and form a so-called “cloud of emissions”. Aerosol particles fall out of the cloud and settle on the ground, migrating into elements of ecological systems adjacent to NPPs.

Laboratory of external radiation control uses stainless steel pans with an area of 0.25 m^2 to collect atmospheric precipitations. The tray bottom is lined with a filter paper in accordance with DST 12026-76.

The pans are located at 22 monitoring points in accordance with the history of long-term pre-launch meteorological observations at the construction site of SS Rivne NPP (according to the Windrose diagram), mainly in settlements within the OZ. In accordance with the Regulation, atmospheric precipitation sampling frequency is 1 time per month.

Long-term observation results indicate that the total β-activity of precipitations and content of ^{90}Sr and ^{137}Cs during the observation period are within the “zero background” and do not depend on the distance from an observation point to SS Rivne NPP.

The assessments have shown that the major share of gas-aerosol release within the dose during operation of power units of SS Rivne NPP will be by inert gases through irradiation from the cloud. The maximum annual average concentrations of these radionuclides in the air were obtained in the east direction at a distance of about 1.5 km from the plant. They made: 1.351×10^{-11} Ci/m^3 (0.5 Bq/m^3) for ^{133}Xe; 2.703×10^{-13} Ci/m^3 (0.01 Bq/m^3) for ^{85}Kr; 5.406×10^{-14} Ci/m^3 (0.002 Bq/m^3) for ^{41}Ar.

Non-exceedance of the effective dose of 100 mrem/year (1 mSv/year) per population (Category B) is possible when maximum air concentrations of these radionuclides are as follows: 26.489×10^{-8} Ci/m^3 (9.8 kBq/m^3) for ^{133}Xe; 54.06×10^{-8} Ci/m^3 (20 kBq/m^3) for ^{85}Kr; 0.973×10^{-8} Ci/m^3 (0.36 kBq/m^3) for ^{41}Ar, which is 10^3-10^6 times higher than the maximum design concentrations of radioactive noble gases (RNG) during normal operation of the power units.

3.3 Impact on Soils

Pollution of observation zone of Rivne NPP consists of a superposition of global falls, falls as a result of Chernobyl accident and overshoots due to aerosol emissions from the working units of SS Rivne NPP. The last source of pollution is so insignificant that virtually its eduction from total pollution is impossible and it is confirmed by spatial distribution of radiocesium contamination around the NPP, which does not correlate with the windrose of the region.

Soil contamination is determined by the hazard class of some toxicants. Malignity classes are included:

I-class - arsenic, cadmium, mercury, selenium, lead, zinc, fluorine, benz(a)pyrene;

II-class – boron, cobalt, nickel, copper, molybdenum, antimony, chromium;

III-class – barium, vanadium, tungsten (wolfram), manganese, strontium.

Their content in soils can be estimated in both gross and moving forms of elements.

The results of chemical analysis are compared with maximum permissible concentrations (MPC). The level of contamination by hazardous substances for which MPC concentrations are not established are estimated in comparison with background values of these substances in soil; it gives the opportunity to objectively evaluate the degree of soil pollution in a zone of influence of industrial activity of SS Rivne NPP and, if necessary, to take remedial measures.

The list of chemically parameters of soils and muds for control is given in Table 3.4.

Table 3.4. Chemical parameters of soils and muds for control.

No	Name	Physical units	MPC
1	Ammonium nitrogen	mg/kg	not standardized
2	Aluminium exchange	mg/kg	not standardized
3	Bicarbonate ion	Mmol/ 100 g soil	not standardized
4	Hydrogen index	unit pH	not standardized
5	Iron (mobile forms)	mg/kg	not standardized
6	Potassium	mg/kg	not standardized
7	Calcium	mg/kg	not standardized
8	Cobalt (mobile forms)	mg/kg	5.00
9	Magnesium	mg/kg	not standardized
10	Manganese	mg/kg	1500.0
11	Cooper (mobile form)	mg/kg	3.0
12	Sodium	mg/kg	not standardized
13	Petroleum products	mg/kg	not standardized
14	Nickel (mobile form)	mg/kg	4.0
15	Nitrates	mg/kg	130.0
16	Lead (mobile forms)	mg/kg	20.0
17	Sulphates	mg/kg	160.0
18	Specific electrical conductivity	mSm/cm	not standardized
19	Phosphorus (mobile forms)	mg/kg	not standardized
20	Chlorides	mg/kg	not standardized
21	Zinc	mg/kg	23.0

One of the direction of environmental monitoring of SS Rivne NPP is the laboratory control of soil conditions in the area of waste disposal sites – sludge collectors and landfills for construction and industrial wastes.

The results of ecological monitoring give the opportunity to objectively assess the degree of influence of industrial activity of SS Rivne NPP on the state of soil in the vicinity of the NPP. The analysis of long-term observations of chemical composition and properties of soil cover has shown that according to the moving forms of chemical elements, which are the most environmentally significant (as they are responsible for the speed of migration in food chains), the exceedances of MPC were not detected. In case of absence of MPC of the substance, the comparison is performed with a natural background concentration.

SS Rivne NPP has little influenced on the change of water-physical properties of adjacent soils due to changes in the level of groundwater during its construction. It is possible to talk about the joint influence of SS Rivne NPP and land-use only in case of overshooting of SS Rivne NPP emissions to agricultural soils, when, as a result of agrochemical treatment, pollutants penetrate down the soil profile to the depth of plow sole and evenly mix. In fact, there is an acceleration of the migration process of those small amounts of pollutants which can settle on soil due to the emissions from a nuclear power plant.

3.3.1 Radiation Impact on Soils and Vegetation

The samples of soil from 0÷5 cm layer were selected for controlling the surface contamination of the ground with radionuclides in the territory of location of SS Rivne NPP.

The analysis in sites of sludge collector and landfill for construction and industrial wastes of SS Rivne NPP is carried out by ecological and chemical laboratory, which is authorized to perform the measurements of chemical composition of soils. The analysis of monitored parameters confirms that operation of SS Rivne NPP does not make significant changes to quality of soils.

According to "zero background", the surface contamination of soil ^{137}Cs prior to commissioning of SS Rivne NPP was in range of 0.44 ÷ 5.07 kBq/m^2; ^{90}Sr - 0.19 ÷2.92 kBq/m^2.

The soil samples were taken in the adjacent territory of SS Rivne NPP to control the possible surface contamination of soil with radionuclides in accordance with the requirements of current radiation control regulations.

Sampling is carried out annually in April-May and research is conducted on γ-spectrometers.

Table 3.5 provides data on specific soil contamination during the period from 2004 to 2016. The average values of activity are shown for each year.

Table 3.5. Specific soil contamination during the period from 2004 to 2016.

Year	^{7}Be, Bq/m^2	^{40}K, Bq/m^2	^{60}Co, Bq/m^2	^{131}I, Bq/m^2	^{134}Cs, Bq/m^2	^{137}Cs, Bq/m^2
2004	4.11E+02	9.87E+03	<2.10E+01	<1.90E+02	4.96E+01	1.12E+04
2005	3.21E+02	9.97E+03	1.78E+01	<7.40E+02	3.53E+01	1.11E+04
2006	4.40E+02	9.20E+03	<2.50E+01	<1.90E+02	2.81E+01	7.99E+03
2007	2.00E+02	7.96E+03	<7.90E+00	<4.70E+01	1.47E+01	8.16E+03
2008	2.31E+02	8.98E+03	<9.60E+00	<7.90E+01	<1.40E+01	5.20E+03
2009	4.32E+02	1.06E+04	<2.10E+01	<1.0E+02	<3.20E+01	5.92E+03
2010	3.29E+02	9.53E+03	1.70E+01	<7.10E+01	<2.40E+01	4.95E+03
2011	1.56E+02	8.27E+03	<7.42E+00	<3.70E+01	<1.08E+01	3.47E+03
2012	2.02E+02	1.06E+04	<8.40E+00	<5.90E+01	<1.42E+01	5.72E+03
2013	2.62E+02	9.84E+03	<1.1E+01	<1.1E+02	<1.8E+01	4.67E+03

Year	^{7}Be, Bq/m^2	^{40}K, Bq/m^2	^{60}Co, Bq/m^2	^{131}I, Bq/m^2	^{134}Cs, Bq/m^2	^{137}Cs, Bq/m^2
2014	1.48E+02	8.19E+03	<9.00E+00	<2.40E+01	<1.30E+01	4.19E+03
2015	9.20E+01	8.18E+03	<3.9E+00	<2.2E+01	<6.80E+00	3.43E+03
2016	1,15E+02	8.91E+03	<4.2E+00	<2.4E+01	<7.20E+00	3.33E+03

During the reporting period, the maximum contribution to the specific activity of the soil is due to the presence of ^{137}Cs isotope that over all reporting years exceeds the "zero background", but this contamination is explained by the consequences of Chernobyl accident.

The ratio of the maximum activity of ^{137}Cs to the minimum observed in the zone of location of SS Rivne NPP during considered period reached several dozen times (21.2 in 2016), which indicates a significant heterogeneity of soil contamination.

Table 3.6 shows the coefficients of the pair correlation and the ratio of activities ^{137}Cs and ^{134}Cs, which is calculated for the samples with activity of ^{134}Cs higher than MPC. The mix age is determined by taking into account the initial $^{137}Cs/^{134}Cs$ activity ratio of 1.6:1. The data indicate that soil contamination in the monitoring zone is due to the fallout of fission products after Chornobyl catastrophe.

Table 3.6. Chornobyl ratio of activity $^{137}Cs/^{134}Cs$ in soil

Year	Coefficient of pair correlation	Ratio of activity	Estimated age of the mixture
1994	0.98	21.1	8.2
1995	0.91	30.5	9.4
1996	0.96	42.8	10.5
1997	0.97	57.0	11.4
1998	0.96	74.1	12.2
1999	0.97	93.5	13.0
2000	0.98	128	14.0
2001	0.99	186	15.2
2002	0.89	180	15.1
2003	0.83	226	15.8
2004	0.74	267	16.4
2005	0.81	314	16.9
2006	0.54	284	16.5
2007	0.14	1280	21.4

Since 2002, there has been a decline in tendency of activity ratio of ^{137}Cs and ^{134}Cs to the isotope associated with the decay of ^{134}Cs ($T_{1/2}$ = 2,064 years) and biochemical processes in soil.

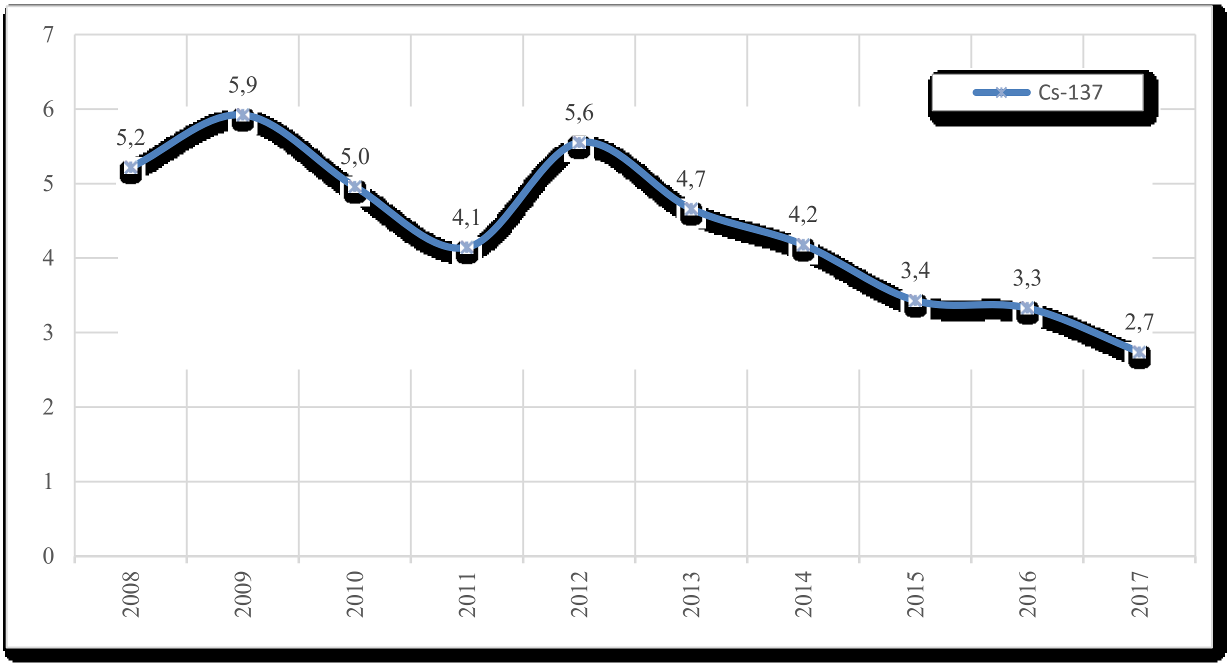


Figure. 3.1 Surface activity of soil in a layer 0÷5 cm in the zone of placement of SS Rivne NPP, kBq/m^2.

3.3.2 The Results of Control the Content of Radionuclides in Agricultural Products

The main foodstuffs of the local population were monitored in the zone of placement of the SS Rivne NPP - milk, vegetables, and grain crops. Samples were selected during maturation.

The samples were examined using γ-spectrometric analysis to determine the possible presence of radionuclides of technogenic origin, especially ^{131}I.

^{131}I was not registered in agricultural products in 2017. The presence of other man-made radionuclides, except ^{137}Cs of "Chornobyl" origin was not registered, too. The high content of this radionuclide in food is due to the higher value of transition coefficient of "soil-solution-plant" chain.

Control of Milk

The samples were taken in 12 settlements in private farms. The volume of 1 sample was 2.5 ÷ 3 litres.

All milk samples passed γ-spectrometric analysis without radiochemical preparation. According to "zero background", the volumetric activity of ^{137}Cs in milk prior to start-up of SS Rivne NPP unit was in a range of 6.3E-01 ÷6.6E +00 Bq/l.

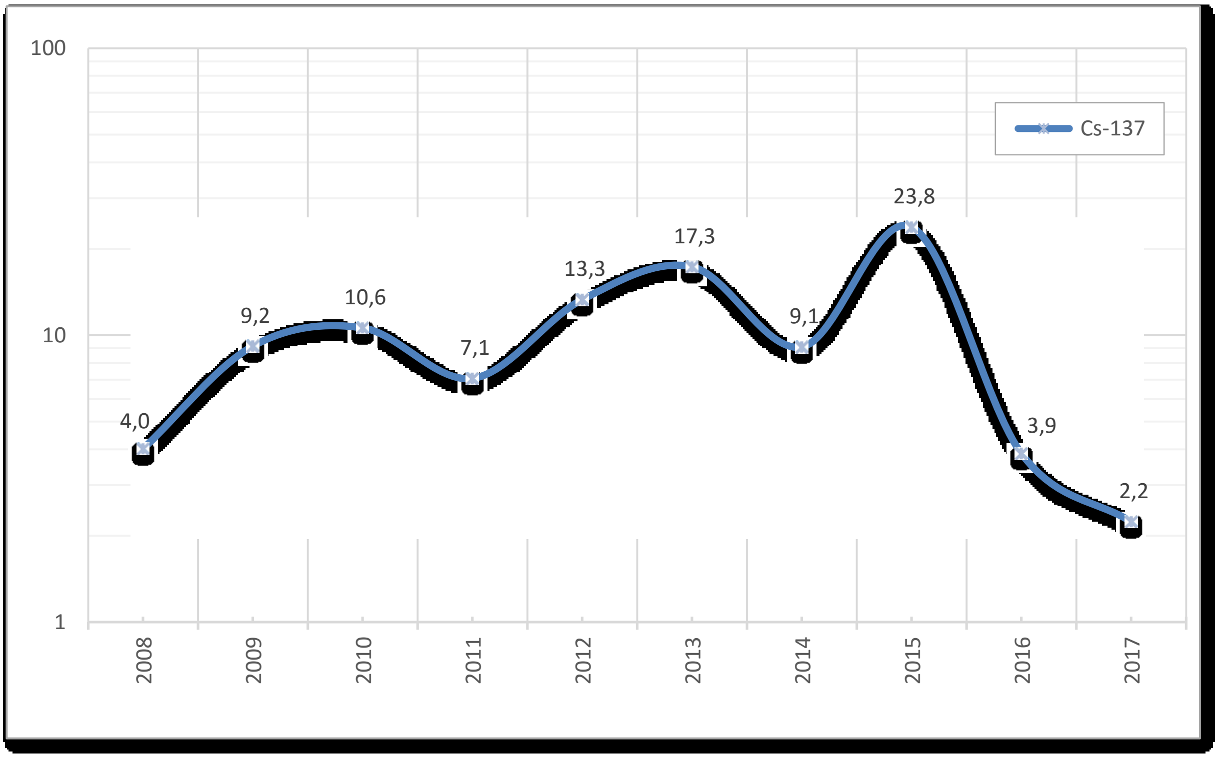


Figure 3.2. Average indicators of milk contamination in zone of placement of SS Rivne NPP, Bq/l.

Table 3.7. Volumetric activity of radionuclides in milk in 2017, Bq/l

Sampling point	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<8,7E-01	4,88E+01	<8,1E-02	<9,5E-02	<1,2E-01	<1,3E-01	3,74E-01
Bilska Volia	<6,4E-01	5,42E+01	<6,0E-02	<6,7E-02	<8,5E-02	<6,0E-02	3,85E+00
Velyka Vedmezhka	<6,7E-01	5,07E+01	<6,1E-02	<9,4E-02	<9,8E-02	<7,5E-02	1,21E-01
Zabolottia	<7,8E-01	5,24E+01	<8,0E-02	<1,3E-01	<9,8E-02	<1,0E-01	1,59E+00
Kostiukhnovka	<1,2E+00	5,10E+01	<1,4E-01	<1,5E-01	<1,5E-01	<1,3E-01	2,46E+00
Lubakhi	<4,7E-01	3,82E+01	<3,4E-02	<5,4E-02	<6,4E-02	<4,5E-02	2,94E+00
Manevychi	<8,4E-01	4,73E+01	<6,4E-02	<1,1E-01	<1,1E-01	<8,8E-02	4,95E+00
Polytsi	<1,2E+00	4,29E+01	<1,2E-01	<1,6E-01	<1,4E-01	<1,3E-01	2,96E+00
Stara Rafalivka	<5,8E-01	5,20E+01	<3,9E-02	<6,1E-02	<7,6E-02	<6,5E-02	2,29E+00
Sopachiv	<8,2E-01	4,27E+01	<6,0E-02	<9,3E-02	<1,2E-01	<9,4E-02	1,68E+00
Staryi Chartoryisk	<5,2E-01	5,25E+01	<4,8E-02	<7,7E-02	<8,2E-02	<6,0E-02	3,96E-01
Tsmyny	<5,5E-01	4,06E+01	<4,3E-02	<6,7E-02	<8,2E-02	<6,0E-02	3,30E+00

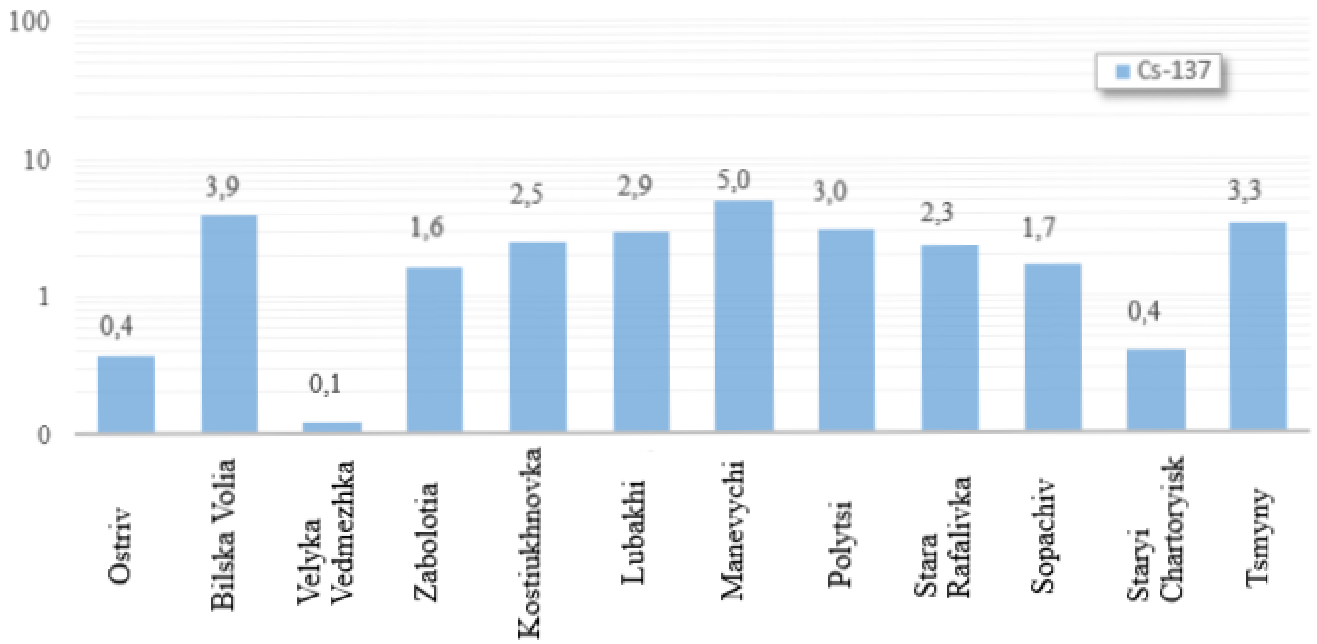


Figure 3.3. Volumetric activity of ^{137}Cs in milk of allocation zone of Rivne NPP in 2017, Bq/l.

The maximum content of ^{137}Cs was recorded in Manevychi checkpoint - 4.95 Bq/l. Permissible content of ^{137}Cs in milk is 100 Bq/l. Exceeding the upper bound of values of “zero background” by ^{137}Cs has not been fixed.

Control of Vegetables

The samples were taken in 12 settlements. The mass of 1 selected potato sample was 3 kg. According to “zero background”, the specific activity of ^{137}Cs in vegetables prior to the launch of Rivne NPP was in the range of 1.5E-02 ÷ 2.0E + 00 Bq/kg.

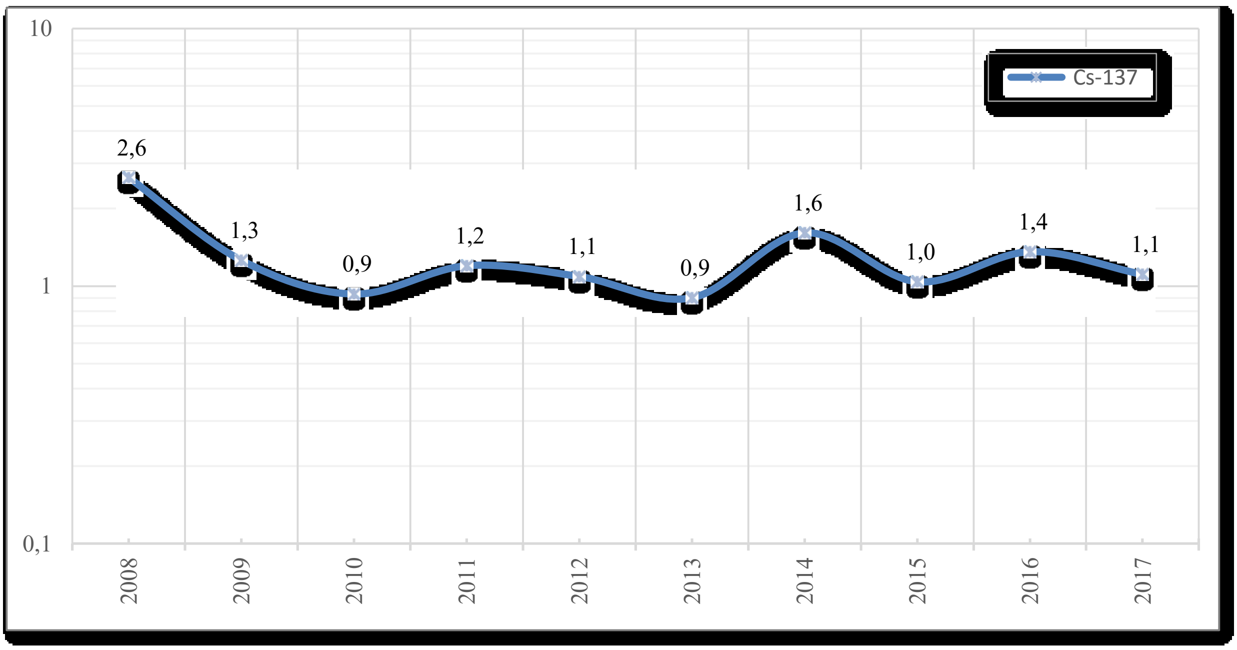


Figure 3.4. Average value of specific activity of radionuclides in potatoes in the zone of placement of SS Rivne NPP, Bq/kg

Table 3.8. Specific activity of radionuclides in potatoes in the zone of placement of SS Rivne NPP in 2017, Bq/kg

Sampling point	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<2,1E-01	9,42E+01	<4,9E-02	<4,9E-02	<2,5E-02	<3,5E-02	4,41E-01
Bilska Volia	<4,0E-01	1,41E+02	<4,0E-02	<5,2E-02	<5,7E-02	<4,5E-02	2,78E+00
Velyka Vedmezhka	<2,5E-01	1,36E+02	<6,1E-02	<6,2E-02	<2,6E-02	<4,4E-02	1,90E-01
Zabolottia	<2,7E-01	1,10E+02	<2,7E-02	<3,4E-02	<4,5E-02	<3,1E-02	1,12E+00
Kostiukhnovka	<3,9E-01	1,19E+02	<4,0E-02	<6,4E-02	<5,3E-02	<4,3E-02	7,85E-01
Lubakhi	<2,8E-01	1,11E+02	<2,6E-02	<3,4E-02	<5,2E-02	<2,7E-02	4,00E+00
Manevychi	<2,3E-01	8,26E+01	<2,4E-02	<3,2E-02	<4,6E-02	<2,7E-02	8,12E-01
Polytsi	<3,5E-01	1,23E+02	<3,6E-02	<5,5E-02	<5,6E-02	<3,7E-02	1,28E+00
Stara Rafalivka	<2,7E-01	1,17E+02	<2,5E-02	<3,3E-02	<4,5E-02	<2,6E-02	4,87E-01
Sopachiv	<2,1E-01	9,87E+01	<2,4E-02	<3,1E-02	<4,4E-02	<2,5E-02	6,37E-01
Staryi Chartoryisk	<2,2E-01	9,93E+01	<4,9E-02	<5,2E-02	<2,5E-02	<3,6E-02	4,89E-01
Tsmyny	<1,9E-01	1,26E+02	<4,0E-02	<4,2E-02	<2,0E-02	<2,9E-02	2,57E-01

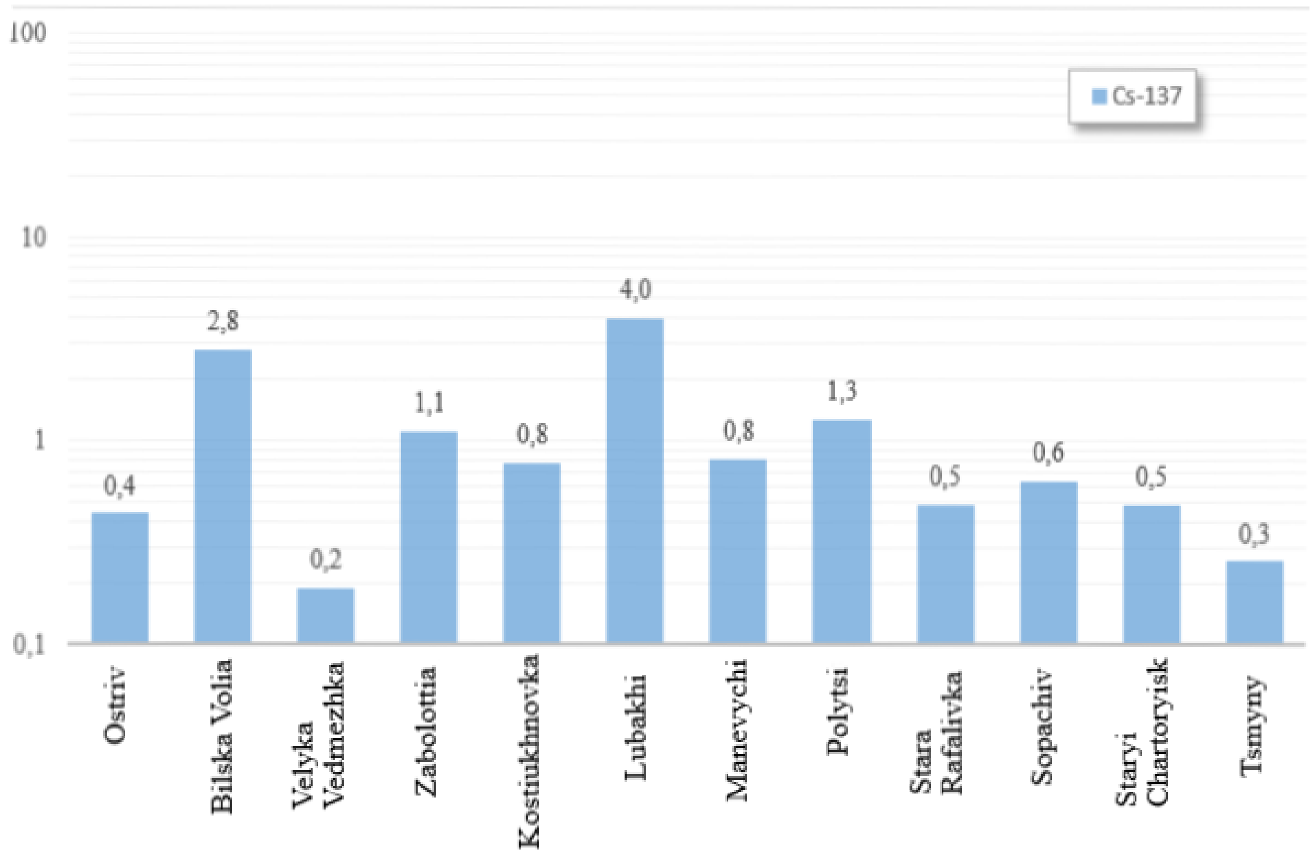


Figure 3.5. Specific activity of ^{137}Cs in potato samples of the placement zone of SS Rivne NPP in 2017, Bq/kg

The maximum content of ^{137}Cs in potato in 2017 was recorded in a control point “Liubahy” - 4.0 Bq/kg. Permissible content of ^{137}Cs in fresh potato is 60.0 Bq/kg. Exceeding the upper limit of values of “zero background” is fixed in 2 control points.

Control of Grain Crops

The samples were taken in 12 settlements in a zone of location of SS Rivne NPP. The mass of sample for each type of grain crops was 3 kg. All selected samples passed γ-spectrometric analysis without radiochemical preparation.

According to "zero background", the specific activity of ^{137}Cs in grain crops before the launch of SS Rivne NPP was in the range of 8.1E-01÷1.18E + 00 Bq/kg.

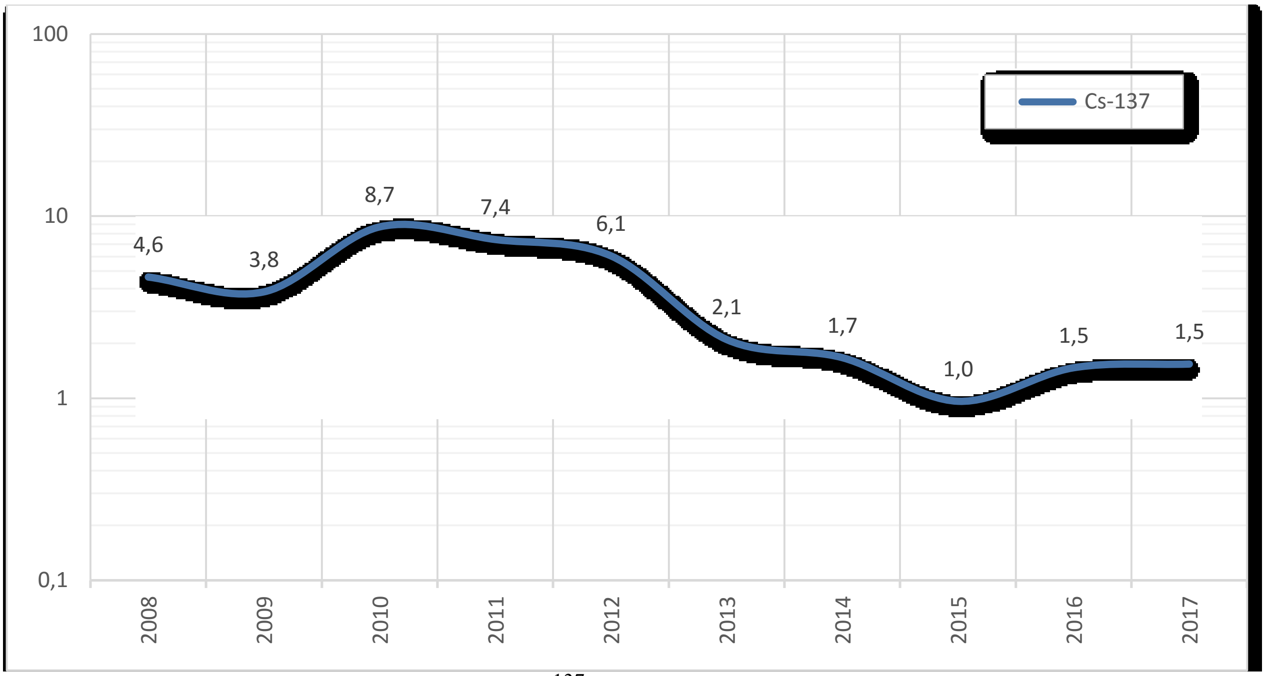


Figure 3.6. Average specific activity of ^{137}Cs in grain crops in a zone of placement of SS Rivne NPP, Bq/kg.

Table 3.9. Average specific activity of radionuclides in grain crops in 2017, Bq/kg

Sampling point	Subspecies	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	134Cs	^{137}Cs
Ostriv	Wheat	4,33E+00	1,11E+02	<8,5E-02	<1,2E-01	<1,4E-01	<1,0E-01	2,69E-01
Bilska Volia	Wheat	2,64E+00	1,18E+02	<5,1E-02	<8,6E-02	<7,9E-02	<6,9E-02	1,69E-01
Velyka Vedmezhka	Wheat	5,31E+00	1,24E+02	<6,2E-02	<1,1E-01	<1,0E-01	<8,8E-02	2,83E-01
Zabolottia	Wheat	2,61E+00	1,31E+02	<8,1E-02	<1,2E-01	<1,4E-01	<1,0E-01	1,31E+00
Kostiukhnovka	Oat	1,07E+01	8,91E+01	<1,9E-01	<2,3E-01	<1,8E-01	<2,1E-01	4,07E+00
Lubakhi	Rye	8,75E+00	1,43E+02	<7,4E-02	<1,1E-01	<1,2E-01	<9,4E-02	6,43E+00
Manevychi	Wheat	2,17E+00	1,41E+02	<6,2E-02	<9,0E-02	<9,4E-02	<7,2E-02	2,71E-01
Polytsi	Oat	8,35E+00	1,46E+02	<9,7E-02	<1,3E-01	<1,5E-01	<1,3E-01	7,37E-01
Stara Rafalivka	Oat	5,36E+00	1,30E+02	<1,2E-01	<1,6E-01	<1,8E-01	<1,5E-01	1,86E+00
Sopachiv	Wheat	1,67E+00	1,08E+02	<8,5E-02	<1,0E-01	<1,5E-01	<1,0E-01	1,50E+00
Staryi Chartoryisk	Oat	1,60E+01	1,05E+02	<8,3E-02	<1,2E-01	<1,6E-01	<1,2E-01	1,44E+00
Tsmyny	Wheat	1,3E+00	1,28E+02	<9,6E-02	<1,4E-01	<1,4E-01	<1,2E-01	1,97E-01

The specific activity of ^{134}Cs is less than the minimum detected activity for all control points. The ratio of the maximum value of the specific activity of ^{137}Cs (point of control "Lubakhi" - 6.43 Bq/kg) to the minimum was 38.0 - this indicates uneven pollution of the area of the location of the unit of SS Rivne NPP by the given radionuclide. It is evident from the data in Table 3.9 that the activity of ^{137}Cs does not depend on the distance to the SS Rivne NPP, which implies that the ^{137}Cs has a "Chornobyl" origin.

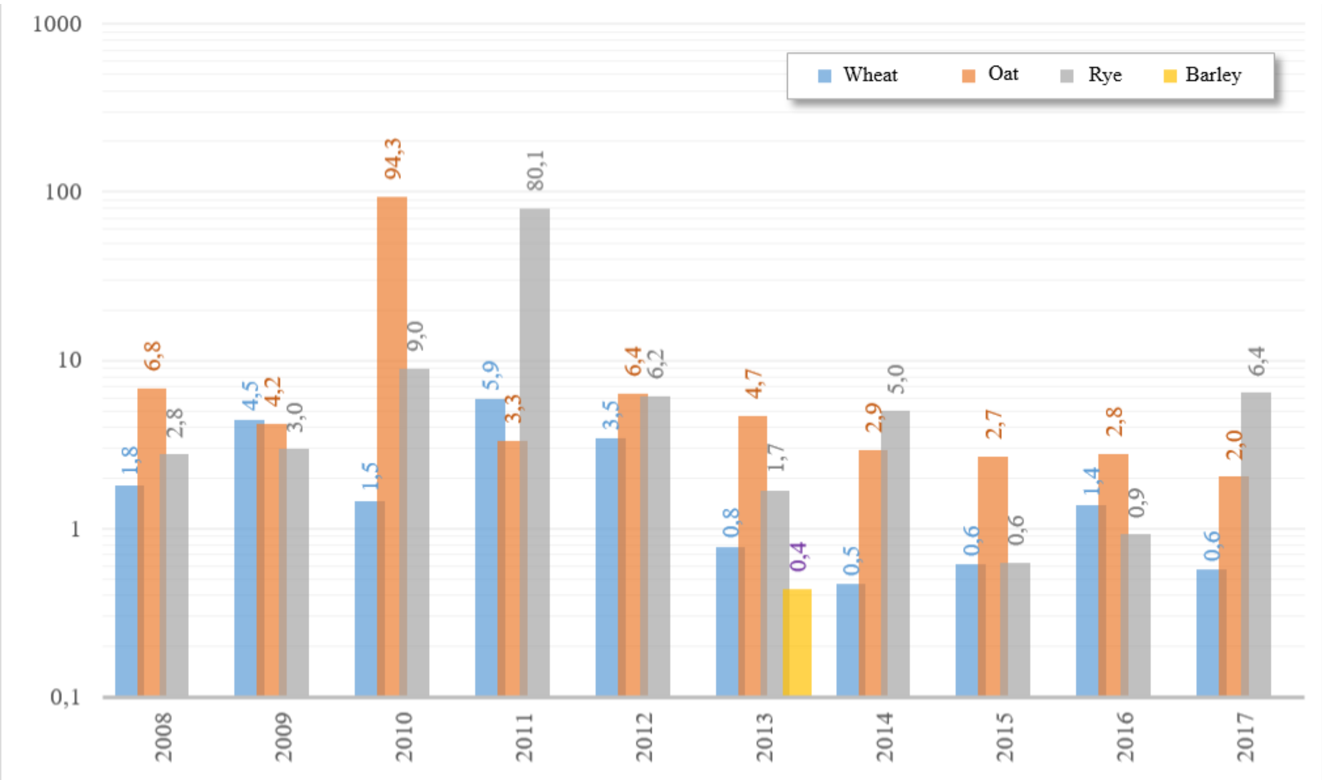


Figure 3.7. Average specific activity of ^{137}Cs in grain crops in the area of placement of the SS Rivne NPP, Bq/kg

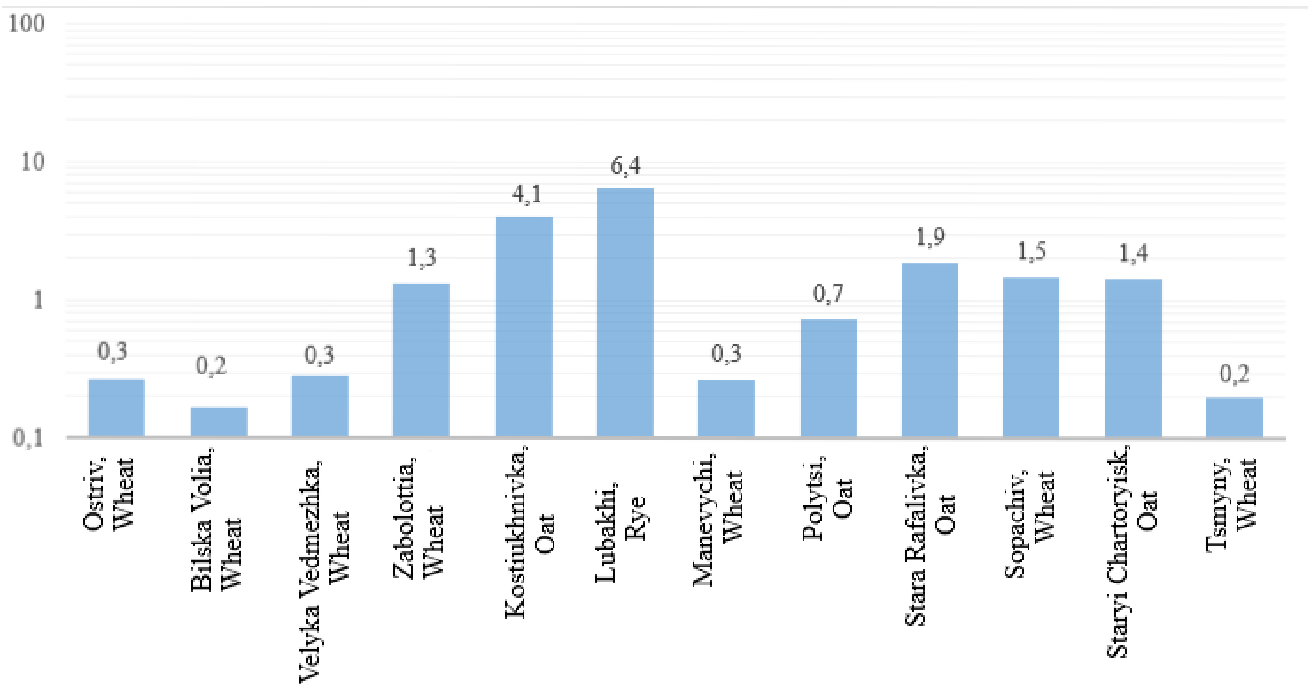


Figure 3.8. Average specific activity of ^{137}Cs in grain crops in the area of the distribution of the SS Rivne NPP in 2017, Bq/kg

For most objects of the environment, the activity of radionuclides is within the range of "zero background" measurements.

In the vicinity of location of Rivne NPP, the uneven contamination of the environment by radionuclide ^{137}Cs of "Chornobyl" origin is observed.

All soil samples which were taken from 0÷5 cm layer in 2017, the activity of ^{134}Cs was less than the level of minimum activity detected. The ratio of maximum value of the surface activity of ^{137}Cs to the minimum in the area of placement of Rivne NPP on virgin soils is 13.0, which indicates the heterogeneity of the contamination of surface layer of soil.

In 2017, the average value of specific activity of ^{137}Cs in milk was 44.6 times less, in potato - 54.1 times less than permissible values set in the document "Permissible levels of radionuclide content ^{137}Cs and ^{90}Sr in food and drinking water, 2006".

3.4 Impact on Geological Environment

The reliability of the operation of NPP buildings and structures depends on the stability of geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability — once in 100 years): magnitude 5, maximum estimated earthquake (probability — once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;
- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of geological environment and is the key factor for ensuring safe operation of SS Rivne NPP.

In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:

- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;
- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuously cooperates with leading scientific

organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013-2016.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

The analysis of control characteristics shows that the work of the Rivne NPP does not significantly change the quality of underground water. Radiation state of groundwater is satisfactory, content of ^{226}Ra, ^{137}Cs, ^{90}Sr is much lower than the values that are standardized in the Radiation Safety Standards of Ukraine.

3.5 Impact on Flora, Fauna and Objects of Nature Reserve Fund

The territory of the Rivne NPP OZ lies within the Volyn Polissya, which occupies the western part of the Ukrainian Polissya. Geographic location of this territory contributed to the formation of typical Polissya nature (predominance of moraine-fluvioglagic sedimentary deposits, domination of sod-podzolic soils, high bogginess and forest coverage). Specific features of this territory are geological structure (domination of chalk and marls of the upper Cretaceous in the base rock, and occurrence of basaltic rocks in the southern part).

Natural vegetation was mainly preserved; the share of plowed land at the most part of the territory is insufficient and varies from 10% in the northern and eastern parts to 20-25% in the western part. Only in the central part it rises to 43.5%. Forests are the dominant vegetation; the average forest coverage is 49.6%. There are a lot swamps on the territory being studied, and these swamps differ both by origin and area.

The animal world of the Rivne NPP OZ is represented by animal complexes typical for Polissya. More than 60 mammals species and about 200 birds species live there. Rodents are the dominant mammalians; however, predators (common fox, wolf, the raccoon dog, least weasel (Mustela nivalis, stoat (Mustela erminea)) are also found. A wolf, a raccoon dog, a ermine, and so on. Birds are predominantly of the tree-shrub species. Song-birds (black grouses, hazel grouses, and wood grouses) are also found in the Volyn Polissya region. The following reptile spices should be mentioned: the adder, the grass snake, the smooth snake, the anguine lizard, the viviparous lizard, fresh-water turtle.

Years of researches have shown that radionuclide emissions do not increase the activity of man-made isotopes (^{137}Cs, ^{90}Sr etc.). Accumulated radionuclides in plants during normal operation of the power plant will not exceed the permissible norms; and the current contamination by ^{137}Cs of “the Chornobyl” origin has been studied in detail within the monitoring zone. As to accumulation of radionuclides in plants, the highest contamination is currently found in marsh plants with highest concentration in mosses and mushrooms and lower concentration levels — in cranberries and blueberries.

Care must be taken as to consumption of forest and swamp products, and particularly, mushrooms. Taking into account wider ecological amplitude of blueberries, its radionuclide contamination can vary greatly depending on local conditions. Blueberries, which are currently collected and procured quite intensively, must be carefully monitored for content of radionuclides.

On the whole, based on the analysis of changes in the background concentration of radionuclides with increase of distance from the power units of SS Rivne NPP, it can be concluded that the radiation regime of the plant during its normal operation does not affect the vegetation and does not cause any changes in the radiation level of individual plant species.

Technical design solution on cooling of process water in cooling towers and spray pools (instead of a cooling pond) allowed minimizing adverse impact of the plant on the ecosystem and preserving the valuable floodplain of the Styr River with its meadow, shrub, and forest animal complexes.

4 IMPACT ON SOCIAL ENVIRONMENT

4.1 Brief Description of the Current Social Environment in the Observation Zone

The Rivne NPP is located in a mixed forest zone in western Volyn Polissia — in the northwestern part of the Rivne Region, 120 km away from the regional centre, in the Volodymyretskyi District, on the Styr River. This Ukrainian NPP is nearest to the neighbouring states.

SS Rivne NPP site choice was due to low fertility of sandy land and great distance from densely populated areas. The Rivne NPP and its satellite town Varash (former Kuznetsovsk) are located in the most stable seismic zone of Ukraine. The recurrence of magnitude 6 earthquakes according to the MSK-64 seismic scale is once in 5000 years.

The 30 km observation zone of SS Rivne NPP is within the boundaries of two regions: Rivne and Volyn. The size of population in 90 settlements over the territory of about 3,000 km^2 is about 130 thous. people.

SS Rivne NPP is located in the moderate continental climate zone. West winds are predominant. Air quality is generally good due to limited industrial activities. The Styr River is the main source of surface water. Forests cover 50 % of SS Rivne NPP territory and are of a considerable economic and environmental value. Agricultural land use accounts for 27 %. 48 territories within the OZ of SS Rivne NPP are classified as nature reserve fund.

The OZ of SS Rivne NPP, which covers 2826 km^2, includes a total of 109 settlements with 143 thous. residents, with the population density of 58.82 people/km^2 in the Region of Rivne and 37.19 people/km^2 in the Region of Volyn.

Satellite town of SS Rivne NPP, Varash, is 3 km away from the power plant and is the largest town in the observation zone. The town's population is about 42,000 people. The density of population within this territory made 55 people/km^2 back in 1973, while currently it makes 3,684 people/km^2. Other relatively large nearby settlements include the urban type settlements of Manevychi (Volyn Region), Volodymyrets and Rafalivka (Rivne Region).

Demography as of 2017 is characterized by 46.7 % of urban population and 53.3 % of rural population. Development of electricity production capacities promoted urbanization process. The highest increase in population was observed in the NPP satellite town due to labour migration. Urban population growth in the region was accompanied with decrease in rural population (due to migration).

The estimated size of actual urban population as of 1 January 2017 made 42.2 thous. people. In 2016, the population decreased by 311 people, which made 7.4 people per 1,000 people of the actual population.

The size of population increased due to natural (264 people) and migration (47 people) growth.

Natural population growth level in 2016 made 6.3 people per 1,000 people of the actual population.

The birth rate made 11.9 live-born infants per 1,000 people of the actual population, and the death rate made 5.6 dead per 1,000 people of the actual population.

Figure 4.1. Location of settlements included in the 30-kilometer zone of SS Rivne NPP

The urban type settlement of Volodymyrets with the population of about 9.0 thous. people (8.699 thous. people) and population density of 1,447 people/km ^{2} is an investment-attractive region notable for its advantageous geographical location, well-developed transport and communications infrastructure, bank system, considerable industrial and construction potential, spare qualified workforce and executive staff, and reserves of primary natural resources. This is the place where two unique deposits of high-quality basalt suitable for mineral wool and stone-cast ware manufacture are located. There also are vast deposits of peat, white silica sand, clay, amber, zeolitic tuffs, and copper.

The size of population in the urban type settlement of Rafalivka (since 1959) as of 2017 made 3.278 thous. people, and population density made 264 people/km^2. Rafalivka has a railway station of the same name on the Kovel — Sarny line. The facilities that currently operate in Rafalivka include a sawmill, an asphalt plant and a furniture plant.

According to the data of the last all-Ukrainian population census (2011), the size of population in the urban type settlement of Manevychi made 11,190 people; it increased by 17.3 % compared to the data of 1989 census (8,937 people). Manevychi is the biggest urban type settlement in Volyn. As of 2017, the size of population here made 11,119 thous. people, while the population density reached 197.89 people/km^2.

The town of Varash, which owes its uprising and development to the construction of the NPP, is the only town within the 30 km observation zone, with the population size several-fold greater than that in the Volodymyrets and Manevychi district centres.

Varash appeared in 1973 as an NPP constructors' settlement with population of 14.79 thous. people (at that time). In 1984, Varash (former Kuznetsovsk) received a city status. Its population reached 23.8 thous. people as of 1 January 1985;

36.2 thous. people as of 1 January 1995;

41.2 thous. people as of 1 January 2000;

42.2 thous. people as of 1 January 2017.

Based on the data obtained within the framework of Kuznetsovsk Master Plan correction project (now Varash) ("Dipromisto", 1996), a swell in population in 1973-1985 is mainly due to a positive migration balance, while in 1986-1991, due to the completion of the 3rd power unit and moratorium on construction of the 4th unit, positive migration balance reduced several-fold (to 365 people/year from 1987), and from 1992 until present it makes about 500 people/year.

The rate of natural population growth was also decreasing until 1991 (from 760 to 455 people/year), and starting from 1992, the natural growth rate has made about 400 people/year.

However, the population in Volodymyrets (district centre) grew from 8.26 thous. people in 1995 to 9 thous. people in 2000 (by 740 people in 5 years), and made 9.0 thous. people as of 2017. The population dynamics in Manevychi district centre is as follows: from 9.08 thous. people to 10 thous. people (increased by 992 people in 5 years); the population size makes 10.12 thous. people as of 2017.

Urban population dynamics in 1995-2017 is shown in Table 4.1.

Таблиця 4.1. Urban population dynamics in the SPZ in 1995-2017

Name of settlement	Population size (thous. people)		
	1995 р.	2000 р.	2017 р.
Town of Varash	36,2	41,2	42,2
Sett. of Volodymyrets	8,26	9,0	8,69
Sett. of Manevychi	9,08	10,0	10,12

The OZ of SS Rivne NPP is characterized by low rates of industrial development and moderate rates of agricultural development. Low-tech industrial production is predominant in the region. Available enterprises mainly operate in food, wood processing and road-building industries, as well as in construction materials production. Basic agricultural crops include wheat, rye and oat. The total area of plantings is 18,500 hectares and tends to reduce due to economical reasons.

The specifics of social and economical living conditions of population within the OZ of SS Rivne NPP is defined by annual amount of subventions invested in the regional infrastructure.

Therefore, the most important factor of impact on the demographic situation within the 30 km zone is the Town of Varash that arose due to the construction and operation of SS Rivne NPP.

Construction of the nuclear power plant involved a significant number of young people of working age, who obtained highly qualified employment during construction and operation of the NPP.

4.2 Impact of SS Rivne NPP Operations on Population Health in the Observation Zone

The ultimate goal and main task of all environmental protection measures are preserving and promoting people’s health, which is the main criterion of the state of environment. In this regard, assessment of the environment may only be provided based on its actual and foretasted impact on population health.

Construction and operation of nuclear power facilities, including nuclear power plants, result in a change of radiation, environmental and health situation in the respective location areas, which may have an adverse impact on the health of population residing on these territories.

In 1976-1979, studies of radiation conditions of natural environment locations before NPP commissioning were conducted in the area of SS Rivne NPP construction, and so-called “zero background” was determined. The study results are used in assessing the radiation impact of SS Rivne NPP power units throughout their entire operation period.

The situation is currently becoming more complicated due to the fact that the major part of the Rivne NPP adjacent territory appeared to be contaminated as a result of the Chornobyl Accident in 1986. Against the background of anthropogenic environmental contamination (resulting both from operations of Rivne NPP and various industrial and agricultural facilities), emergency release of Chornobyl radionuclides caused an extra population exposure.

Figure 4.2 shows radiation contamination of a part of the territory of Ukraine with ^{137}Cs as of 10 May 1986. The Town of Varash in this map stands by its former name, Kuznetsovsk.

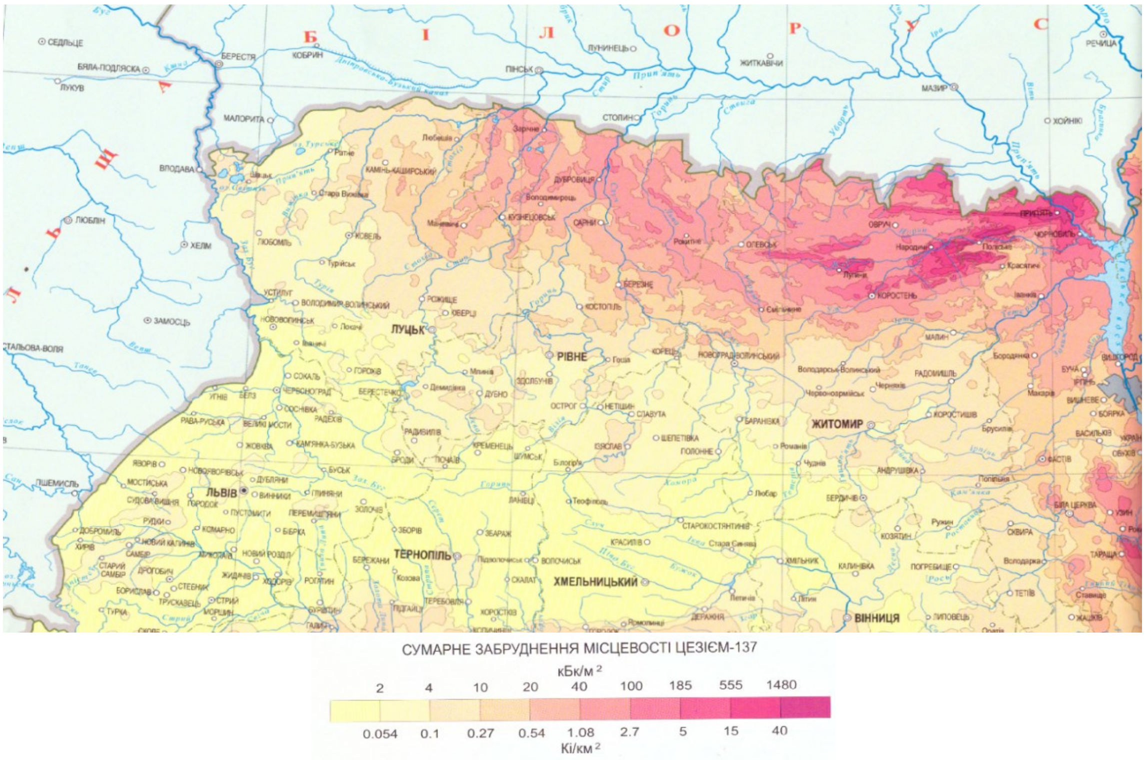


Figure 4.2. ^{137}Cs contamination of a part of Ukraine's territory.

Figure 4.3. shows radiation contamination of a part of Ukraine's territory with ^{90}Sr.

Strontium isotopes contamination is of a mixed nature: on ChNPP adjacent territories it is mainly due to a fuel component of emissions, while in regions that are 150-300 km away from the ChNPP in a south trace direction, the condensation component becomes predominant, so ^{90}Sr contamination has extended well beyond the exclusion zone.

The highest levels of ^{90}Sr contamination are observed along the west (fuel) trace and within the south trace, where fallouts had both fuel and condensation components.

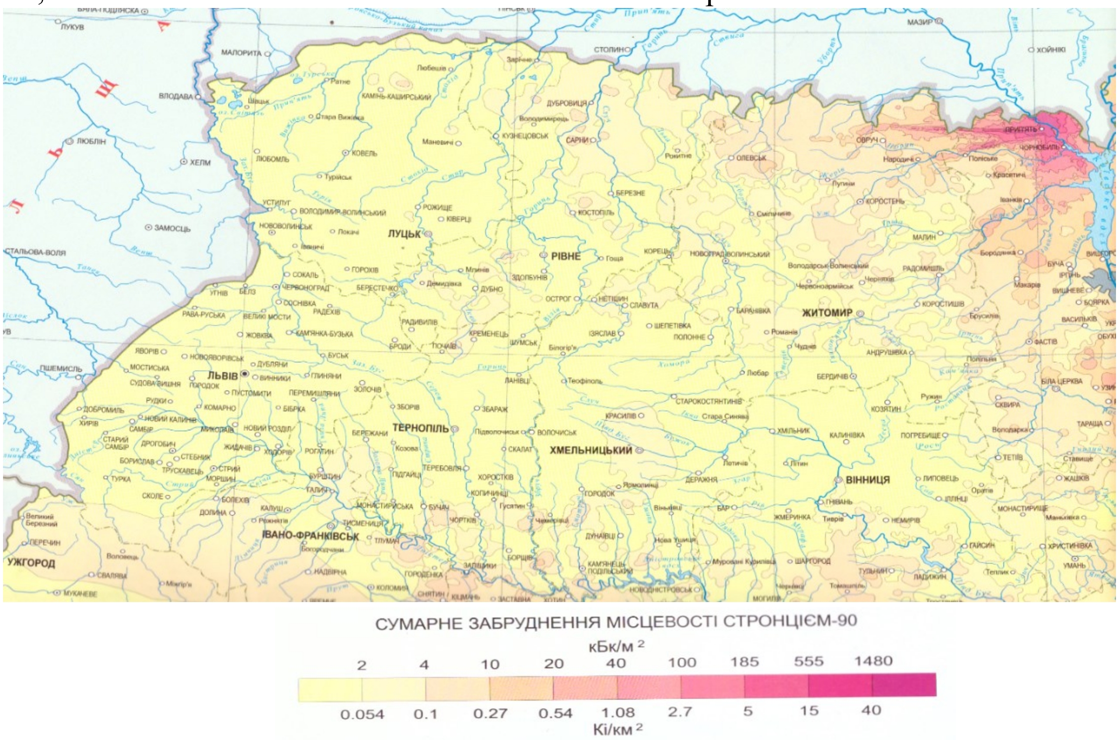


Figure 4.3. ^{90}Sr contamination of a part of Ukraine's territory.

This circumstance increases the risk of adverse anthropogenic impact on population health, since many chemical substances can change their action against the radiation background.

Numerous researches by Ukrainian and foreign authors suggest increased disease incidence in population residing within the territory that suffered contamination of various degrees after the Chornobyl Accident.

Population residing near SS Rivne NPP benefits from the environment being used by a very small number of industrial facilities, therefore it is marginally affected by industrial pollution. SS Rivne NPP is the major industrial facility in the region

During normal operation of SS Rivne NPP, the radiation conditions and population doses in the region are defined by the existing natural background radiation. SS Rivne NPP radiation impact on the population and the environment does not exceed 0.05 % of the dose level produced by natural radiation sources, and does not change the natural radiation level in the area around the NPP.

Hazardous radiation levels exist only for personnel performing radiation hazardous works, however these risks are brought to a minimum if radiation safety rules are followed. No hazardous radiation risks are present for other works and beyond working hours during normal operation of SS Rivne NPP.

Observed contribution of SS Rivne NPP in air, water and soil pollution do not exceed the permissible levels and is insignificant compared with other pollution sources. The results of long-term radiation monitoring indicate the absence of a substantial radiation impact of the NPP on the environment and, consequently, on the population health in the OZ.

The major contribution in human body radiation exposure within the OZ during normal operation of the NPP is due to natural radionuclides and their decay products. The impact of artificial radionuclides from long-range fallout, Chornobyl radionuclides and, much less, radionuclides from SS Rivne NPP releases on the radiation amount is significantly lower. The hourly dose formed from natural radionuclides exceeds the dose from annual SS Rivne NPP releases.

As a result, it can be said that Rivne NPP has no adverse effect on the population health within the SS Rivne NPP OZ.

5 IMPACT ON ANTHROPOGENIC ENVIRONMENT

5.1 Description of the Current State Within the Observation Zone

Industry within the 30 km zone around SS Rivne NPP is represented by food industry enterprises (bakery plants, dairy plants), construction material enterprises, quarries and a peat plant, motor transport enterprises, and a road construction management office. A section of the Kyiv-Kovel railway line passes 150 m south of the industrial site of the NPP. The nearest railway station Rafalivka is 5 km east of the NPP. Kyiv-Kovel state motor road passes about 20 km south of the industrial site of the NPP. There are also several gas stations, Rafalivskyi Karier PubJSC (a quarry) for the extraction of sand, gravel, clay and kaolin, Polytskyi basalt quarry, etc. within the OZ around SS Rivne NPP. In total, there are 28 industrial facilities within the OZ around SS Rivne NPP: 13 in the Volyn Region and 15 in the Rivne Region.

Public institutions are concentrated in the Town of Varash. Housing fund within the 30 km zone (except for Varash) is represented by one-story buildings with a significant degree of wear. Residential construction is not provided with district water supply, sewage and heat supply networks, even in district centres (Manevychi and Volodymyrets). Public institutions located within the zone (except for Varash) also have no utility support.

Stationary sources of atmospheric air emissions at SS Rivne NPP are concentrated on 7 production sites. Air pollutant emissions from stationary sources at each site are regulated based on separate permits.

To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for air emissions 14 sources of air emissions are equipped with gas treatment units (GTU). Certificates were provided for each GTU. Gas treatment equipment is operated in accordance with the Regulations on Technical Operation of Gas Treatment Units. Persons responsible for the technical operation of GTUs were appointed by order of the Director General of SS Rivne NPP. In accordance with the design documents and working conditions, operating manuals for each GTU were developed and approved. Daily time records are kept for each GTU.

- Annual reports are submitted to the Main Statistics Department and the Department of Ecology and Natural Resources of the Rivne Regional State Administration according to the form 2-TP (air). Reports are developed using a calculation method based on the data on the use of raw materials, fuel, materials, and equipment operating time. During the year, stationary sources of SS Rivne NPP release 33 to 37 t of pollutants into the air, including:

- non-methane volatile organic compounds - 18-25 t;
- nitrogen compounds - 5-9 t;
- substances in the form of suspended solid particles (microparticles and fibres) -1.4-2.7 t;

sulphur compounds - 1.4-2.7 t, etc.

Air pollutant emissions from the NPP are 2-3 thousand times less than that from a coal-fired TPP with a similar installed capacity.

Sampling and monitoring of the radionuclides content in the surface air are carried out in accordance with the radiation control regulations in force at Rivne NPP once every 10 days at 16 control stations. The volumetric activity of anthropogenic radionuclides in atmospheric air over 37 years of observations did not exceed the standard values as per NRBU-97. The volumetric activity for ^{90}Sr and ^{137}Cs is within the “zero background”.

Operation of SS Rivne NPP has no adverse impact on the existing agricultural, industrial and civil buildings.

Public institutions located within the zone (except for Varash) have no utility support.

The total area of residential buildings and the main civilian facilities in Varash and in the Volodymyrets and Manevychi district centres are presented in Table 5.1.

Table 5.1. Main civilian facilities in settlements within the 30 km zone around the SS Rivne NPP

Name of settlement	Total housing area, m^2	Hospi tals	Community centres, clubs	Schools	Kindergartens
Town of Varash	598719	1*	3	6	12
Sett. of Volodymyrets	126669	1**	6	6	3
Sett. of Manevychi	129540	2	2	2	-

* - the specialized primary healthcare unit No. 3 has a transfusion department, Kuznetsovsk Town District Laboratory Research Department of SE Rivne Regional Laboratory Centre of the State Sanitary and Epidemiological Service of Ukraine, Kuznetsovsk Interdistrict Disability Evaluation Board.

A network of pharmacies, dental offices, ultrasound and massage rooms is being developed in the town. A health care centre operated at Rivne NPP and insurance medicine is being actively developed.

In Varash, an English language school, language club, public library, libraries for children and youth, dance theatre school, modern choreography school, photo and video school, 12 kindergartens, 7 schools (including one gymnasium), as well as “Signal” driving school in Rafalivka and massage courses were established and operate. Sports facilities include “Energetic” swimming pool, CYSS of the Department of Education and CYSS at Rivne NPP, as well as vocational training centres VTC No. 1 and VTC No. 10.

** - Volodymyrets CDH runs a transfusion department, Volodymyretskyi District Department of Kuznetsovsk Town District Department of Laboratory Research of SE Rivne Regional Laboratory Centre of the State Sanitary and Epidemiological Service of Ukraine.

A network of pharmacies, veterinary pharmacies and medical centres is being actively developed in Volodymyrets and the region in general. The town has an optical store, a paediatrician’s office, dental offices, “Rodolad” private family medical centre, health insurance companies, etc. District department of Professional Disinfection Communal Enterprise operates in Volodymyrets.

Within the 30 km zone around SS Rivne NPP in the Volodymyretskyi District, medical facilities operate in Rafalivka, the villages of Kidra, Ozero, Velyki Tseptsevychi, and there are MOS in the villages of Sobishchytsi, Krasnosillia, Lypne, and Kanonychi.

In Manevychi, only 2 medical facilities operate: Manevychi Central District Hospital and Manevychi District Primary Healthcare Centre. The settlement has the Manevychi Children’s and Youth Sports School, a general education school levels I through III and a gymnasium. There also is a District Community Centre and a Department of Culture at Manevychi District State Administration.

5.2 Impact on Anthropogenic Objects

During normal operation, the impact of SS Rivne NPP on the anthropogenic environment is limited by the following factors:

- activities and infrastructure that may develop in adjacent territories of the NPP are restricted for security reasons: such restrictions include, in particular, potentially hazardous activities, recreational activities, flying objects, transportation of hazardous substances;
- the presence of the NPP promotes local economy, small and medium-sized businesses, providing direct or indirect services related to operations of the NPP;
- SS Rivne NPP satellite town profits from certain infrastructure investments by the NPP.

Harmful air releases and water discharges, thermal releases and discharges, as well as water consumption by the NPP do not significantly affect the anthropogenic environment.

In the case of design basis accidents at SS Rivne NPP, including the MDBA, their negative impact on the man-made objects will not exceed the permissible limits and will not require any special measures.

In the case of an analysed beyond design basis accident, temporary restrictions on the use of food produced within a restricted area along the accidental radioactive trail may be necessary.

So, during normal operation, SS Rivne NPP does not produce an adverse impact on the anthropogenic environment.

5.3 Impact of Man-made Objects on SS Rivne NPP Operations

According to the Code of Civil Protection of Ukraine, anthropogenic security characterizes the state of protection of population and territories against anthropogenic emergencies.

The reliability of the operation of NPP buildings and structures depends on the stability of geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability — once in 100 years): magnitude 5, maximum estimated earthquake (probability — once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

The construction site of SS Rivne NPP was selected in 1965 by the government commission as the most favourable site in the Rivne Region of the Ukrainian SSR based on the entire set of all factors, in particular geotechnical. The site was selected in compliance with all regulatory requirements then in force, and agreed upon with the ministries and departments concerned. Over 1800 wells were drilled during the design process. No caverns were found during the survey of the territory.

However, in April 1982, a crater with a diameter of 3 m and a depth of 2.5 m was formed in the excavation for workshop in the special building of unit No. 3, which was under construction. The results of additional geotechnical surveys demonstrated that karst-suffosion processes in the geological section of SS Rivne NPP site in chalk rocks (depth of occurrence of 25 ÷ 40 m) are possible. In connection with the individual manifestations of this process that occurred at SS Rivne NPP site, the commission formed by the Council of Ministers of the USSR in 1983 and the Ministry of Energy of the USSR determined the appropriate measures to ensure reliable and safe operation of operating power units No. 1 and No. 2, unit No. 3 (which was under construction), and unit No. 4 (which was on the design stage).

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;
- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Essential structures of power unit No. 4 were built on piles, which are based on basalts and, consequently, completely cut through the layer that is exposed to karst processes, which ensures the reliability of their operation. Soil cementation was carried out under the rest of buildings and structures of power unit No. 4.

On 20 April 2002, a meeting of an independent expert group chaired by V. M. Shestopalov, Member of the National Academy of Sciences of Ukraine, was held at SS Rivne NPP to discuss the geotechnical state of the industrial site and base soils of structures at Rivne NPP. The following was established by the expert group:

- the structures were operated in a stable mode, levels of soil subsidence and core samples from the buildings over the entire period of operation were well below the design values;
- the efficiency of the anti-karst measures under buildings of power units No. 1-3 (in particular, cement grouting of the chalk layer) is confirmed with time;
- continuous attention at SS Rivne NPP was paid to the geological and anthropogenic state of the environment and to the reliability of operation of the buildings;
- the possibility of building power unit No. 4 on piles based on basalts, which will cut through the chalk layer, raises no doubts.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of geological environment and is the key factor for ensuring safe operation of SS Rivne NPP.

- In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:
- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;
- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuously cooperates with leading scientific organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Annual reports are drawn up based on the works performed.

Within the frame of extension of operational lifetime of power units No. 1 and No. 2, SE Kyiv Institute of Engineering Surveys and Research “ENERGOPROEKT” performed a set of geotechnical surveys and geophysical soil studies in 2008. According to the results of the studies, Scientific and Technical Report on Geotechnical Survey (a comprehensive analysis of the soil conditions at the bases of buildings and structures) 14-349/07-08, 10-439.1 was issued with a positive conclusion on further safe operation of buildings and structures.

Within the frame of extension of operational lifetime of power unit No. 3, SE Kyiv Institute of Engineering Surveys and Research “ENERGOPROEKT” developed Scientific and Technical Report on Complex Geotechnical and Geophysical Survey 14-126-08, 10-726-1 in 2014. The results of the studies suggested that the engineering and geological situation within the structures of power units No. 1-3 are in line with the operational lifetime extension, namely:

- karst monitoring did not record any active karst processes;
- the observation data on subsidence of buildings did not exceed the permissible values;
- according to hydrogeological monitoring data, the hydrogeological situation is characterized as stable and controlled by all indicators;
- soil condition ensures reliable operation of structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013-2016.

According to the results of the surveys, specialists of Prydniprovska State Academy of Civil Engineering and Architecture issued positive opinion on further extension of operation of power unit buildings and structures. Decisions on further operation of power unit buildings and structures were agreed with the SNRIU.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

6 TRANSBOUNDARY ENVIRONMENTAL IMPACT ASSESSMENT

In accordance with the requirements of the International Convention on Environmental Impact Assessment in a Transboundary Context, as ratified by the Law of Ukraine No. 534-XIV dated 19 March 1999, the radiation environmental impact of Rivne NPP in a transboundary context, i. e. its impact on the territories of the neighbouring states, has been assessed. The impact of RNPP has been assessed both during normal operation and during accidents.

The degree of environmental impact was assessed taking into account the amounts of radioactive releases, which were monitored daily or once a month.

The amounts of radioactive releases are monitored by IRG, LLN and iodine radionuclide groups in the following ventilation systems:

- VS of power units No. 1, 2;
- VS-1 at PR of power units No. 3, 4;
- VS-2 at PR of power units No. 3, 4 (during operation of 3TL-21, 4TL-21 systems);
- VS at SPB of power units No. 3, 4.

IRG release activity was measured on a continuous basis using PING-206S (units Nos. 1, 2, 3) and RKS-07P (unit No. 4) radiation detectors.

LLN and radioiodine samples were taken on a continuous basis using AFA-RMP-20 and AFAS-I-20 filters. Filters were sampled and checked using FHT-770S radio detectors on a daily basis for the purposes of in-process monitoring of LLN release (following 1 day exposure and not taking into account the activity at the time of filter installation). In-process monitoring of radioiodine was performed by γ-spectrometry at the Radiation Safety Laboratory.

For the purposes of radionuclide content monitoring, AFA-RMP-20 filters were kept for a month and then tested at the External Radiation Monitoring Laboratory by γ-spectrometry using GEM solid-state detectors and DSPEC PLUS multichannel pulse analysers by ORTEC (USA). Release activity calculation was in compliance with the requirements of MM-I.0.03.025-14 “Model procedure for gamma-spectrometry of gamma-emitting radionuclides activity in loads sampled from NPP process media”.

The acceptable gas-aerosol release (GAR) levels are calculated in accordance with NRBU-97 requirements taking into account the limit dose rate, and are not affected by NPP capacity. The acceptable and reference GAR and liquid discharge levels at RNPP were approved by the MoH of Ukraine.

Table 6.1. Calculated values of air radionuclide releases from SS RNPP facilities during normal operation

Radionuclide group	Radionuclide name	Release, Bq/year
IRG	^{88}Kr	2.35×10^{12}
	^{133}Xe	1.69×10^{13}
	^{135}Xe	4.23×10^{12}
Iodine	^{131}I	9.43×10^{7}
	^{133}I	5.04E$\times10^{7}$
	^{135}I	1.31×10^{7}
LLN	^{137}Cs	6.28×10^{6}
	^{134}Cs	9.66×10^{5}
	^{60}Co	7.27×10^{6}
	^{58}Co	1.09×10^{6}

Radionuclide group	Radionuclide name	Release, Bq/year
	^{54}Mn	1.22×10^{6}
	^{51}Cr	4.56×10^{6}
	^{90}Sr	2.60×10^{5}
	^{59}Fe	3.28×10^{5}
	^{95}Zr	5.80×10^{5}
	^{95}Nb	2.23×10^{6}
	^{110m}Ag	4.71×10^{6}
Tritium	^{3}H	1.01×10^{12}
Radiocarbon	^{14}C	1.99×10^{11}

The absolute distances and weather sectors indicated by arrows in Figure 6.1.

Figure 6.1. The distance to neighboring countries from the Rivne NPP

<u>The distance to neighboring countries from the Rivne NPP</u>

Belarus - 60 km
Poland - 130 km
Lithuania - 310 km
Slovakia - 340 km
Moldova - 360 km
Romania - 370 km
Hungary - 410 km
Czech Republic - 510 km
Austria - 700 km
Germany - 710 km

6.1 Doses at Borders With the Neighboring States During Normal Operation

The calculation of total expected individual doses from SS Rivne NPP in representatives of the population at borders with the neighbouring states, is given in Table 6.2 and in Figure 6.2. The distances in Figure 6.2. Dependences of the total dose on distances for two population categories — infants under 1 YOA and adults — have been shown. Expected annual doses were calculated after 50 years of releases. As seen from the table, the critical group in this case is represented by infants who are exposed to higher doses. Calculations for the critical group represented by children under 10 resulted in mean values between adult and infant doses. This data is omitted.

Table 6.2. Expected dose, nSv/year

Country	Infants	Adults
Belarus	1.5	1.3
Poland	0.82	0.7
Lithuania	0.3	0.26
Slovakia	0.35	0.3
Moldova	0.26	0.22
Romania	0.2	0.17
Hungary	0.29	0.25
Czech Republic	0.2	0.18
Austria	0.15	0.13
Germany	0.14	0.12

However, the expected doses are rather low. The maximum value is expected to occur at the border with Belarus, which is the nearest country to RNPP. These doses are within 1 nSv/year, which is well below the limit dose rate for NPP releases, which is equal to 40,000 nSv/year (see NRBU-97) and population radiation rates during normal NPP operation in Russia, which is equal to 200,000 nSv/year

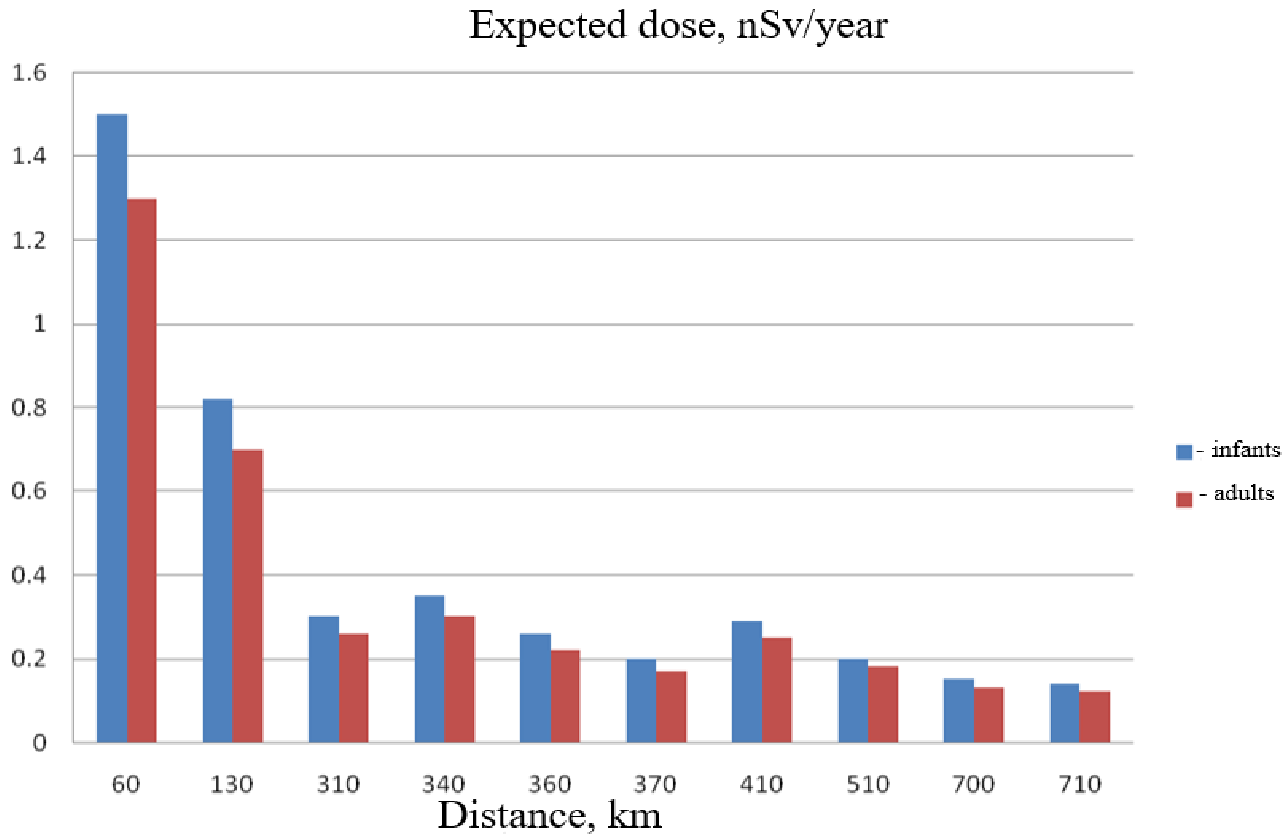


Figure 6.2. Total expected individual doses from the NPP in population (the distances refer to countries in Figure 6.1)

So, the impact on the neighboring countries will be well below the established dose rates and limits for individual effective annual doses of 1 mSv (1,000,000 nSv) for the population.

Nonuniform reduction of doses based on the distance is due to the weather conditions, which are only measurable for 16 discrete sectors. Vectors from RNPP to the nearest borders of different countries (see Figure. 6.1) are located in different sectors, so, even though the doses reduce as the distance grows, the wind pattern may reverse this dependence. In Figure 6.2, this is true for Lithuania (310 km) and Slovakia (340 km), as well as for Romania (370 km) and Hungary (410 km).

Let's analyse partial shares in full doses for different radionuclides and radiation routes in infants at the border with Poland, as an example. The relative ratios of the above data are nearly the same for other countries, however their values are proportional to the full dose (Figure 6.3).

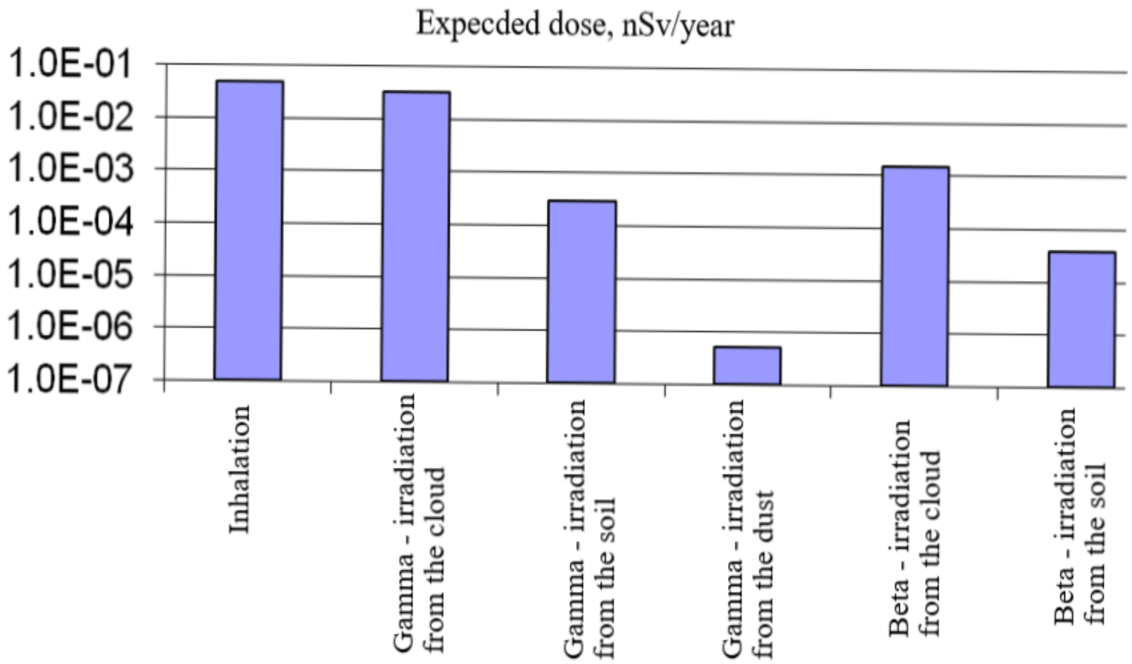


Figure 6.3. Relative share in expected individual doses for infants at the border with Poland

Figure 6.3 shows shares (for inhalation and external radiation) in the full expected dose over a year after 50 years of releases in infants within 130 km from RNPP (at the border with Poland). The maximum share of 0.05 nSv/year is due to inhalation intake. The value is practically the same for gamma-ray photon radiation from the release cloud. The share of gamma radiation from soil is lower by two orders of magnitude. With the full dose at this distance of 0.82 nSv/year, radiation from the above sources accounts for about 5.6 %, while the rest of the dose is obtained from food products.

The maximum share of 0.56 nSv/year is due to milk consumption. The share of cereals is lower; it makes 0.47 nSv/year.

The share of fruits and berries, which contain radionuclides that affect breast milk, is 2 times lower (0.27 nSv/year). Root crops and green vegetables account for a significant share, also absorbed through breast milk. Dairy products (cream, butter, cheese, etc.), similar to meat products, account for a negligible share. In general, food products provide a major share (94.4 %) in the total expected dose.

The major share in the total expected dose over a year after 50 years of releases of all radionuclides during normal operation is due to the following radionuclides: ^{14}C, ^{3}H, ^{131}I and ^{88}Kr, see data in Figure 6.4. This figure shows calculated shares of different radionuclides in expected individual doses in infants at the border with Poland.

It should be noted that the listed shares in the total dose reduce as the distance grows roughly the same as the total dose in Figure 6.2.

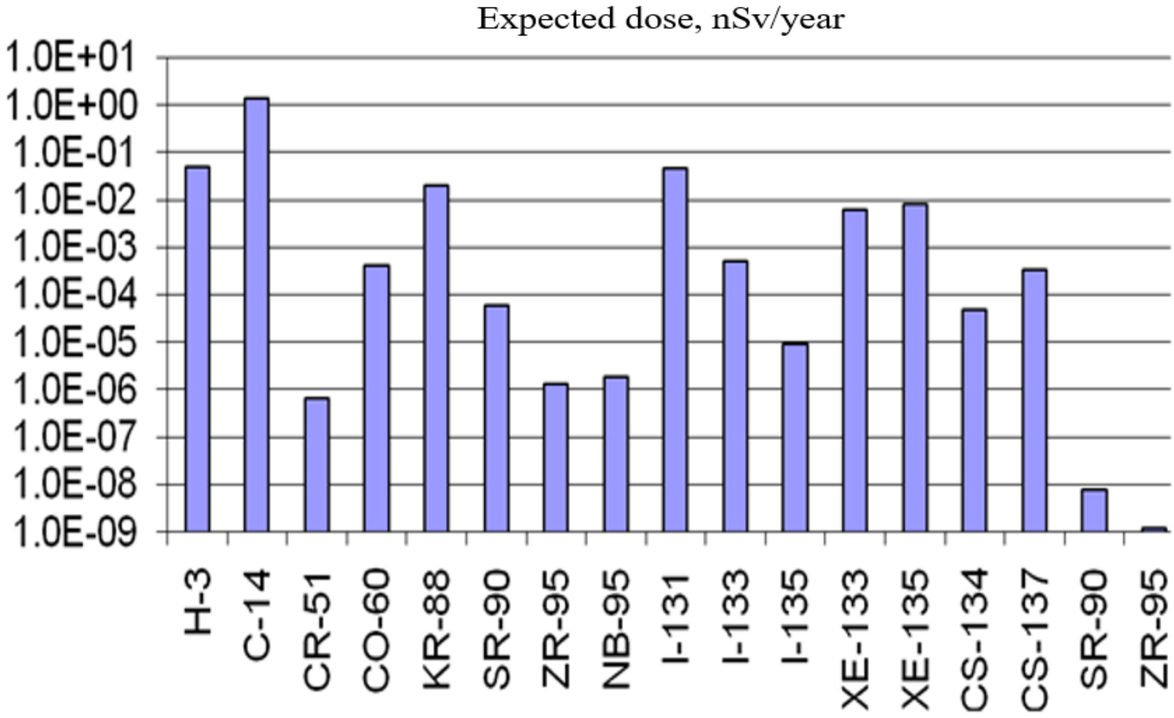


Figure 6.4 Relative shares of different radionuclides in expected individual doses in infants at the border with Poland

6.2 Transboarding Impact in Emergency Situation

The radiation impact of Rivne NPP was analysed based on the following maximum design basis accident (MDBA): an accident caused by double-ended rupture of the cooling system pipeline (loss-of-coolant nuclear reactor accident) at normal energy level.

Radionuclide intake during the beyond design basis accident (BDBA) was determined based on the limit value of environmental release of ^{137}Cs at the level of 30 TBq in accordance with the safety requirements of European operators for designs of nuclear power plants with light water reactors (LWR). ^{137}Cs isotope was chosen due to its prevalent value for long-term environmental pollution as well as its health impact.

Other isotopes in the form of aerosol (i. e. all radioactive decay products, except for inert gases and gaseous iodine isotopes) are released into the environment in proportion to this value, even if these isotopes are released into the atmospheric air.

The release activity of inert gases and gaseous iodine isotopes was calculated at 0.5 % of the total daily activity within the containment. The conservative value of the total release activity over the entire period of the release was established at the level of 7-fold release activity during day one.

The conservative release height is considered to be at the surface air level, which corresponds to the forecast release routes in case of major accidents due to containment leakage.

The total list of radionuclides that may be released in the environment, except for illustrative isotopes, includes other radioisotopes from the same group, which are present in the general member in proportion equal to that of the sum of decay products in the reactor core with respect to the illustrative isotope.

The dose of the proposed source member should be calculated taking into account the release of separate radioisotopes based on the time interval of linear duration of 0 to 24 hours following the accident - a conservative approach compared to the considered release duration of 7 days.

Table 6.3 shows radionuclide release parameters during the MDBA. The accident duration is taken to be 60 minutes. Other accidents that result in lower radionuclide releases are omitted.

Table 6.3 — Radionuclide release activities during the MDBA at RNPP, Bq

Radionuclide	Half-life	Release during MDBA
^{88}Kr	2.84 hours	2,00E+13
^{90}Sr	29.1 years	3,10E+11
^{103}Ru	39.6 days	4,50E+12
^{106}Ru	1.01 years	6,60E+11
^{131}I	8.04 days	4,98E+12
^{132}I	2.3 hours	2,70E+12
^{133}I	20.8 hours	4,00E+12
^{135}I	6.61 hours	2,30E+12
^{134}Cs	2.06 years	7,80E+11
^{137}Cs	30.0 years	5,00E+11
^{140}La	1.68 days	8,40E+12
^{141}Ce	35.2 days	1,40E+13
^{144}Ce	284 days	8,60E+12

Primary radionuclides and their respective releases in case of the BDBA are listed in Table 6.4.

Table 6.4 — Radionuclide release activities during the BDBA at RNPP, Bq

Radionuclide	Release amount, TBq	Radionuclide	Release amount, TBq
^{133}Xe	3,50E+05	^{136}Cs	1,50E+01
^{85}Kr	2,10E+03	^{131m}Te	2,00E+01
^{85m}Kr	5,30E+04	^{129m}Te	8,00E+00
^{87}Kr	1,10E+05	^{132}Te	2,00E+02
^{88}Kr	1,40E+05	^{127}Sb	1,60E+01
^{131m}Xe	2,10E+03	^{129}Sb	4,60E+01
^{133m}Xe	1,10E+04	^{90}Sr	5,00E+00
^{135}Xe	1,10E+05	^{89}Sr	6,00E+01
^{135m}Xe	7,70E+04	^{91}Sr	7,50E+01
^{138}Xe	3,20E+05	^{103}Ru	3,00E+00
^{131}I	1,00E+03	^{99}Mo	4,00E+00
^{132}I	1,50E+03	^{140}La	5,00E+00
^{133}I	2,10E+03	^{91}Y	4,00E+00
^{134}I	2,30E+03	^{141}Ce	4,00E+00
^{135}I	2,00E+03	^{144}Ce	3,00E+00
^{137}Cs	3,00E+01	^{239}Np	4,80E+01
^{134}Cs	6,00E+01	^{140}Ba	1,00E+02

Calculations of expected effective doses for 50 years at different distances from RNPP during the MDBA and BDBA are shown in Figure 6.5. The continuous curve in Figure 3.6 demonstrates the dependence of the effective dose for 50 years on the distance in case of a BDBA, while dashed curve indicates the same in case of a MDBA.

Based on the data in Figure 6.5, expected efficient doses reduce rapidly as the distance grows, and expected efficient doses during the BDBA are higher than the same during the MDBA by approx. two orders of magnitude.

The Radiation Safety Standards of Ukraine set the doses that require countermeasures to protect the population for radiation accidents.

The dose of 1 Gy for 2 days has not been exceeded since the total effective dose for 50 years is much below this value.

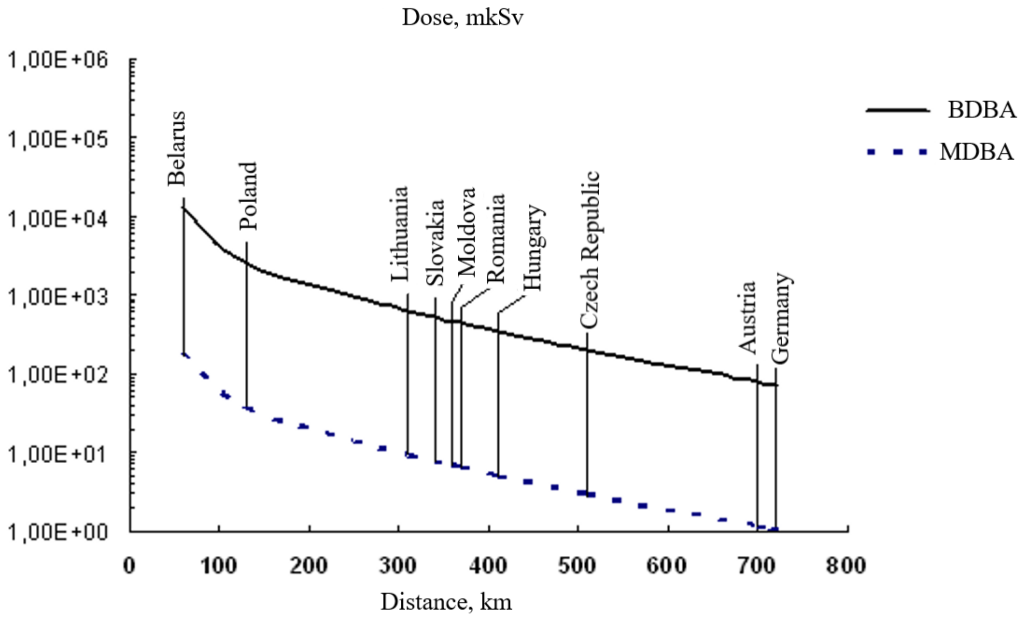


Figure 6.5. Dependence of the expected effective dose on distance during the MDBA and BDBA at RNPP

The dose of 5 mSv for the entire body for the first 2 weeks has not been exceeded since the calculation for the Republic of Belarus, which is the nearest country to RNPP, for the same period results in a value of 0.19 mSv for 2 weeks.

7 COMPREHENSIVE MEASURES TO ENSURE ENVIRONMENT CONDITION AND SAFETY COMPLIANCE

7.1 Protective Measures

SS Rivne NPP was designed in accordance with the requirements of the regulatory documents and the emergency response system is in operation, which is an interconnected set of technical means and resources, organizational, technical, radiation and hygienic measures implemented by SE NNEGC "Energoatom" to prevent or reduce radiation exposure to personnel, the population and the environment in the event of a nuclear or radiation accident at the NPP, as well as to provide civil defence.

According to the document, the emergency preparedness and response system (ERS) of SS Rivne NPP is defined as a component of the Preparedness and Response System of SE NNEGC "Energoatom" for the event of accidents and emergencies on NPPs of Ukraine, which is an interconnected set of technical means and resources, organizational, technical, radiation and hygienic measures implemented by the operating organization to prevent or reduce radiation exposure to personnel, population and the environment in the event of a nuclear or radiation accident at the NPP.

ERS has two interrelated levels:

- Level of SE NNEGC "Energoatom" Directorate (Company's Management level ERS);
- NPP level (NPP ERS).

The main goals of SS Rivne NPP ERS are:

- maintenance of the required level of SS Rivne NPP emergency preparedness;
- response to accidents and emergency situations at SS Rivne NPP including implementation of measures to protect personnel, population and the environment.

The main SS Rivne NPP ERS measures to maintain the required level of emergency preparedness are:

- development and timely review of the emergency plan;
- outfitting and maintaining the technical support centre and internal and external crisis centres in good working condition;
- arrangement of interaction with the SE NNEGC "Energoatom" crisis centre, centre for organization of interaction and assistance to NPPs, Information Centre of the State Regulatory Authority for Nuclear and Radiation Safety, and regional and local authorities of the territorial and functional subsystems of the unified civil defence system;
- maintaining in good working condition and improving the system for collecting, processing, documenting, storing, displaying and transmitting data from SS Rivne NPP crisis centres, alarming and communication systems;
- timely creation and maintaining the preparedness state of the emergency system: control and measuring devices and equipment, personal protective equipment, decontamination and sanitation means, tools, devices and other emergency means;
- training of emergency personnel, emergency training, including plantwide emergency training, development of schedules and training programs;
- maintaining and updating regulative, organizational and process documentation for emergency preparedness and response;
- ensuring accident response readiness in case of commissioning of new radiation-hazardous objects at SS Rivne NPP.

The main accident and emergency response measures at SS Rivne NPP ERS are:

- identification and classification of accidents and other hazardous events at SS Rivne NPP;
- alarming for SS Rivne NPP management and personnel, the population of the neighbouring town, responsible persons of the operating organization, the state regulatory body for nuclear and

radiation safety, central and local executive authorities, local self-government bodies, other bodies, institutions and organizations participating in emergency response, informing them about the occurrence of an accident and initiated countermeasures;

- introduction of the emergency plan, cancellation of actions according to this plan;
- support of the main control room personnel, operational staff of SS Rivne NPP related to beyond design basis accident management;
- estimation and forecasting of accident scenarios, consequences, estimation of radioactive substances releases and discharges, monitoring and prediction of radiation condition changes, personnel exposure doses;
- implementation of works on the accident consequences elimination, including urgent emergency construction, repair and other works;
- logistic support of emergency measures;
- implementation of measures for the protection of SS Rivne NPP, radioactive contamination zones;
- interaction with the state regulatory body for nuclear and radiation safety;
- interaction with management bodies and forces of the "Nuclear power and fuel and energy complex" functional subsystem of the Ministry of Energy and Coal Industry of Ukraine, other territorial and functional subsystems of the unified civil defense system involved in emergency response;
- documenting the accident conditions and emergency response measures. The main ERS measures for personnel protection are:
- personnel radiation protection measures;
- delivery of health care.

The main ERS activities for the protection of population and the environment are:

- in-depth monitoring of radiation parameters for the environmental objects and population exposure doses within the OZ;
- prediction of population radiation exposure doses within the OZ;
- informing central and local executive authorities, as well as local self-government, about the results of monitoring and exposure dose prediction;
- providing recommendations to central and local executive authorities as well as local self-government bodies on countermeasures to protect the population.

Emergency response actions performed by the NPP with the exception of measures for the protection of the population and the environment are limited to the NPP site and the sanitary protection zone. The population and the environment protection measures performed at the NPP are limited to the observation zone.

7.2 Compensation Measures

7.2.1 Compensation for Environmental Damage

During the last years, the legal management of SS Rivne NPP has not received any materials that should be interpreted as claims requesting for compensation for environmental damage, or these claims were not acknowledged in the procedure established by law. Cases of penalty payment by the accounting department of SS Rivne NPP for violating the legislation on environmental protection. These amounts were deducted in full from the wages of employees in accordance with Article 132 of the Labour Code of Ukraine.

7.2.2 Social and Economic Management of Risk for Population Within the Observation Zone Around the NPP

SS Rivne NPP is not only an environmentally friendly site for the production of thermal and electric energy, it also has an annual social guarantee in the form of a state subvention, which adds to budgets of settlements within the nuclear facility observation zone.

In accordance with the current legislation of Ukraine, the population permanently residing within the 30-kilometre observation zone around NPP has the right to receive social and economic compensation for risks caused by operation of NPP, which particularly includes: development and maintenance of a special-purpose social infrastructure in good condition, preferential tariffs for the consumed electric energy set in accordance with the Law of Ukraine “On Electricity”

According to the Resolution of the Cabinet of Ministers of Ukraine, the distribution of state subventions between local budgets of settlement within the observation zones of nuclear power plants is as follows:

- 30 % - for regional budgets;
- 55 % - for district and regional subordination city budgets;
- 15 % - for budgets of satellite-towns of nuclear facilities.

These funds are used exclusively for the purposes and in the manner established by the Cabinet of Ministers of Ukraine.

Subventions are directed, first of all, for:

- construction, reconstruction, capital and current repair of facilities of special social infrastructure and protective structures of civil defence;
- purchase of respiratory protective equipment and stable iodine pills;
- population training on the use of protective equipment and civil defence facilities.

Control over the purposeful use of funds by local authorities and local self-government bodies is carried out in accordance with the current legislation.

Taking into account the subvention amounts for socio-economic compensation for risks to the population within the observation zone, Rivne NPP is the main budget-forming enterprise in the region contributing to its sustainable economic development.

In 2017, the government directed more than 32 million hryvnias (UAH) of state subsidies to finance social and economic compensation measures for the population living in the OZ of SS Rivne NPP.

Distribution of subventions to local budgets in 2017 was as follows:

- Rivne region (regional share) - UAH 7 million 18.3 thousand;
- Volyn region (regional share) - UAH 2 million 757.9 thousand;
- Manevitsky district (Volyn region) - UAH 7 million 227.6 thousand;
- Volodymyrets district (Rivne region) - UAH 9 million 895.9 thousand;
- Sarny district (Rivne region) - UAH 646 thousand;
- Kostopilsky district (Rivne region) - UAH 153.6 thousand;

Town of Varash (Rivne region) - UAH 4 million 888.1 thousand.

7.3 Protection Measures

7.3.1 Radioactive Fallout Protection Measures

Warning or mitigation of radioactive emissions is ensured by the following technical solutions:

- cleaning of air containing radioactive substances by means of filters;
- using closed loops to prevent leaks of liquid substances containing radioactive components;
- arrangement of a special system for collecting and storing LRW and SRW;
- establishment of SPZ and OZ;

ongoing monitoring of emissions into the air, as well as levels of radioactive contamination of soils, flora and water in the SPZ and OZ.

7.3.2 Non-radiation Impact Protection Measures

Appropriate organizational measures taken to ensure stable operation of SS Rivne NPP power units are as follows:

- hydrological station has been put into operation on the Styr River in Varash (downstream of the water intake and discharge of Rivne NPP);
- power units regime schedule based on condition of the Styr River has been developed; the Styr River.
- purification of one hundred percent of added water for feeding water circulation systems at the make-up water treatment facilities;
- minimum sanitary water consumption from the Styr River during the low-water months of the year;
- the following instrumental measurements are carried out by a certified laboratory: industrial emissions into the atmosphere from stationary sources; circulation and surface waters; soils, underground waters and atmospheric air in the areas of waste disposal sites. The results are recorded in the primary accounting documents;
- hazardous waste is removed, as well as secondary raw materials are sold;
- civil liability insurance to cover environmental accidents at SS Rivne NPP and insurance for hazardous goods transportation;
- subdivisions carry out primary accounting of emissions, water use, wastes, develop and submit environmental protection reports to the management of SS Rivne NPP, SE NNEGC “Energoatom”, tax inspectorate, as well as state statistics, management and supervision bodies;
- maintenance, repair and reconstruction of production assets related to environmental protection is carried out;
- in-house supervision, including instrumental and laboratory supervision, is ensured as well as inspections of the environmental protection legislation compliance at SS Rivne NPP by state supervisory bodies;
- environmental tax and rent payments for the use of natural resources (water) are calculated and paid.

Scheduled environment protection measures are carried out in due time; work progress monitoring system is established and operating. The industrial activity of SS Rivne NPP does result in any adverse changes in the environment.

7.4 Radiation Monitoring of the Environment

In 1978, two years prior to commissioning of the power unit of Rivne NPP, the external radiation monitoring laboratory was established at the plant with the main function of identification of radiation impact from plant operation on the population and environment. In 2001, the laboratory of automated radiation monitoring system (ARMS) was established.

Radiation monitoring is implemented in accordance with “Technical Specification on Radiation Monitoring” 132-1-Р-ЦРБ, agreed with the Main State sanitary doctor of the facility and State Nuclear Regulatory Inspectorate of Ukraine. According to the Technical Specification, about 2500 environmental samples in the territory of Rivne NPP location are taken and measured.

The monitoring process comprises monitoring of radioactive releases into the atmosphere, monitoring of atmospheric air, precipitations, flora, pine-needle, soil, agricultural products, dose rates, liquid effluents, water, bottom deposits, fish and weeds of the Styr River. In general, the radiation monitoring covers 43 out of 110 settlements of OZ of Rivne NPP.

The normative document NRBU-97 specifies the dose limits for the personnel that works with the sources of ionizing radiation (Category A for exposed persons) and population (Category C).

A dose limit is the main radiation and health-related standard, which aims at limitation of radiation influence on the personnel and population from all industrial ionizing radiation sources (IRS) in the situations of practical activity. The dose limit for industrial IRS is 1 mZv/year for the population, whish is several times less than radiation dose from the natural sources. The quota of 8% was set for NPP from this limit to fulfill operation of all power units, independent from their number.

Regulation and monitoring of the Category B exposure is conducted upon calculations of the annual radiation effective dose for the critical groups. The critical group is a population group, which can obtain the highest levels of radiation from the source based on their age and gender, social and professional conditions, place of living and other indicators.

Limitation of the Category B exposure is accomplished through regulation and control of the activity of environmental objects (water, air), gas and aerosol releases and liquid effluents during plant operation. For gaseous and aerosol releases and liquid effluents, the allowed radiation levels are established. At these levels, the total annual effective dose of a critical group representative, with regard to all radionuclides present in the releases and effluents, does not exceed the quota for the dose limit. The established levels are reviewed and agreed on a regular basis with the Ministry of Health Protection of Ukraine.

In order to reduce the personnel and population exposure limit below the dose limits, based on the actual achieved radiation adequacy level, the plant introduced the radiation monitoring levels. The monitoring levels are defined based on the analysis of actual releases and effluents for the last five years.

For the prompt response to the changed release and effluent activity, the operator NNEGC "Energoatom" introduced the additional indicators – administrative technological release levels. The release levels are defined for each power unit during at-power operation and during maintenance activities.

During operation, the plant conducts continuous monitoring of non-exceedance of administrative technological, reference and allowed levels of releases and effluents from Rivne NPP, as well as analysis of the manmade radionuclides activity in comparison with the values of "zero" background.

From 2000, the laboratory of external radiation monitoring was certified to conduct activities in the field of radiation monitoring of the environment. The next certification was performed in 2015. The certification covered verification of legitimacy and adequacy of equipment and methodological support; amount and qualification of the personnel, equipping of the working places, their compliance with the sanitary norms. The laboratory is equipped with the state-of-the-art measuring equipment by the advanced world manufactures. The work of the laboratory is subject to the regular inspections with participation of the representatives of the State Inspectorate for Technical Regulation and Consumer Policy (Derzhspozhivstandard) of Ukraine, State Oblast Administration for Ecology.

In addition to monitoring of the environmental radiation impact from Rivne NPP, the continuous monitoring is performed from April 2007 using automated radiation monitoring system (ARMS).

ARMS includes:

- 16 control and monitoring stations on the territory of Rivne NPP site:

✓ 6 stations of gas and aerosol release monitoring, conduct measurements of the dose rate in the ventilation stacks; concentration of radioactive inert gases, iodine, aerosols; conduct sampling to determine tritium concentration in the releases;

✓ 2 stations on the territory of the plant site, conduct measurement of the dose rate, iodine and aerosol concentration in the atmospheric air;

✓ 7 stations located on the roofs of main buildings of the site, conduct measurement of the dose rate.

- 13 stations of the territory of SPZ and OZ, conduct measurements of:
  - ✓ dose rate;
  - ✓ iodine and aerosol concentration in the atmospheric air during an emergency situation;
  - ✓ sampling of aerosols and atmospheric air, precipitations for lab monitoring;
  - ✓ ^{137}Cs, ^{60}Co activity in the stormwater sewage system, volume of discharged water, sampling of water to determine tritium concentration.

The ARMS system also includes two mobile monitoring stations, which conduct a complex of measurements similar to the scope of stationary monitoring stations. The stations are equipped with the additional equipment for identification of locations, carrying out of γ-spectrometry measurements, identification of meteorological parameters, sampling of the environment.

The mobile stations are equipped with the devices for information transfer via the satellite communication channels and mobile operator networks.

With the help of four meteorological complexes, more than 50 meteorological parameters are defined in the near-surface layer of the atmosphere, and meterological parameters are identified at the elevation up to 3000 m.

Radiation and meteorological information is used in the program complexes for calculation of the population doses from the actual releases and effluents (RNPP Doses) and doses for all settlements of Observation Zone in case of emergency situations. The program complexes are developed by “Institute of Radiation Protection” of the Academy of Technological Sciences of Ukraine.

The calculation methods are agreed with the Ministry of Health Protection of Ukraine. From 2017, the European system for forecasting of the radiation accident consequences RODOS is in place.

Information on the radiation and meteorological situation, in the real-time mode, is available for the personnel of Rivne NPP. It is also provided together with the technological parameters of Rivne NPP into the Crisis Centre of NNEGC “Energoatom”, Crisis Centre of State Nuclear Regulatory Inspectorate of Ukraine, Rivne State Administration, Oblast Administration of the State Emergencies Service.

The systematic measurements of radioactive material concentration in the atmospheric air, soil, flora and food in the Sanitary protection zone and Observation Zone, confirm absence of significant impact of Rivne NPP on the population and environment.

During the entire period of NPP operation, the content of radionuclides in the air of Rivne NPP’s Observation Zone was at the level of annual average concentration, peculiar for the pre-commissioning period.

The indications of γ-radiation level in the surrounding settlements did not change after commissioning of Rivne NPP. And, it is not possible to point out the radiation impact of Rivne NPP, in comparison to the natural background, even with the help of state-of-the-art measuring equipment.

Information on correlation of release activity and allowed values, established by the Ministry of Health Protection of Ukraine is presented in the diagram below (Figure 7.1)

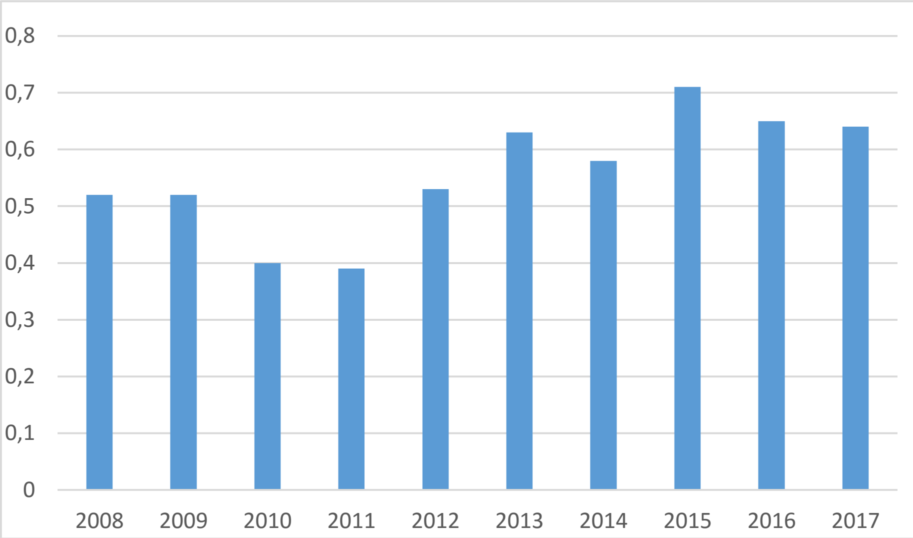


Figure 7.1. Index of gaseous and aerosol releases of Rivne NPP as related to the allowed release.

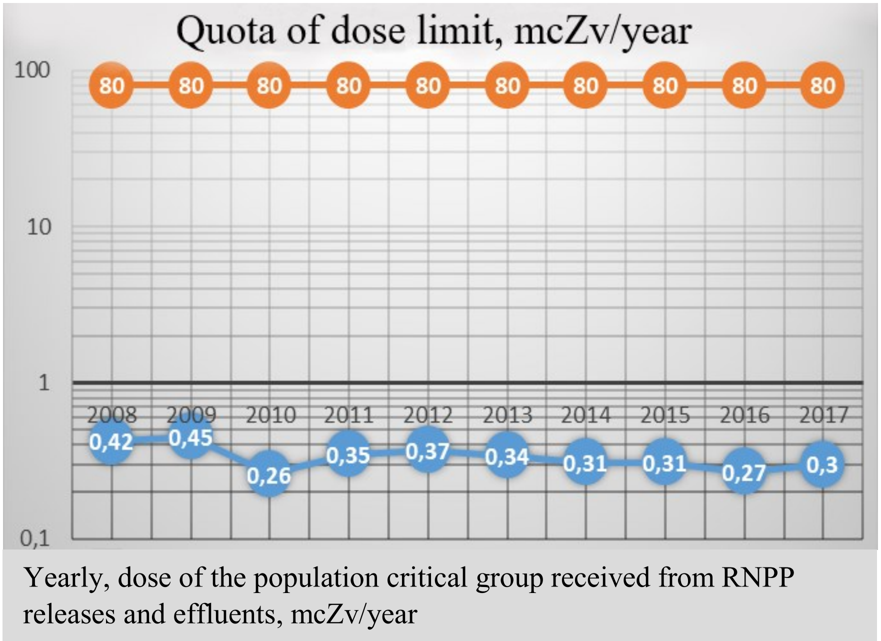


Figure 7.2. Comparative characteristics of the quota of dose limit and dose of the population critical group from the releases and effluents of Rivne NPP, mcZv/year

The main indicator, which characterizes the plant impact on the population of the Observation Zone is a maximum possible dose on the border of SPZ (dose for the population critical group). The normative document NRBU-97 specifies the quota at the level of 80 mcZv/year – a limit of the yearly population radiation dose from the NPP release and effluents.

From January 2006, the plant applies a program on dose monitoring complex for the population critical groups, which is intended for calculation of the radiation dose, formed by actual gaseous and aerosol releases and liquid effluents on the CA border during a calendar year.

The calculation methodology is agreed with the Ministry of Health Protection of Ukraine. The calculation results, presented in the diagram (Figure 7.2), show that the actual radiation impact of RNPP on the population for the last ten years did not exceed 0.5% from the quota of the dose limit, specified in NRBU-97, and is hundred of times less than the radiation from the natural sources.

7.5 Informing the Public About the Assessment of the Environmental Impact of the SS Rivne NPP Site

Quick provision of the information to the public on the events at SS Rivne NPP and formation of positive attitude to nuclear energy is carried out by the Department of the Information and Public Relations. In accordance with Article 10 and 11 of the law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” this task is carried out by the press-center, public relations department, editors and radio and television broadcasting, and by the local newspaper “Energia”, included into the management structure.

Information Center of SS Rivne NPP is located at:

5 Nezalezhnocti Square, Varash, 34400, Rivne oblast,

e-mail:informsentr@mail.ua, official site of SS Rivne NPP: www.rnpp.rv.ua.

Tel.: 2-14-43, 2-11-96, Facebook page: rnpp.polissia.

Pursuant to the law of Ukraine the citizens have the right to receive complete and true information about the nuclear facilities activity.

Information Center operates in four main areas:

- excursion activities;
- exhibition activities;
- work with the public of SS Rivne NPP Observation Zone;
- educational activity.

The main goal of power plant policy in the area of public relations is maintaining stable and positive public opinion at SS Rivne NPP location, i.e. the conditions contributing to successful production activity of the enterprise.

Work with the public from the Observation Zone of SS “Rivne NPP” and co-operation with public organizations.

Twice a week the press in Rivne, Volyn and Lviv oblast is monitored which provides the opportunity to track the need in information, prepared by the Department of Information and Public Relations, and the quality its of perception. The result of the monitoring is the collection of publications about SS Rivne NPP activity.

Regional mass media published 1199 articles about SS Rivne NPP in 2014, 160 articles – in 2015, 1905 articles – in 2016, 1688 articles – in 2017, that shows the interest in the events at SS Rivne NPP. The main topic of the articles is the reliability of power units operation, radiation safety, measures on modernization and reconstruction aimed at power unit safety improvement, social partnership, interrelation with local government, development of infrastructure of the adjacent to SS Rivne NPP areas.

In order to demonstrate the high level of safety and reliability of national nuclear power plants, the press-tours of regional media were held at Rivne NPP in 2014 and 2015. The representatives of regional and local TV companies, information agencies, print and electronic media, public organizations of Volyn and Rivne oblast participated in those press-tours. In 2014 together with the Association “Ukrainian Nuclear Forum” within the European week of stable energy the press-tour on the topic “Nuclear Energy and its Impact on Climate Moderation” was held for the representatives of the central media, and in 2015 the 4th SE “NNEGC “Energoatom” Summer School and excursion to the production site were held for the participants of the Spring Nuclear School.

In 2014 the workshops for teachers of Fundamentals of Health and Safety from district and regional schools were held on the basis of the Information Center; as well as a meeting with teachers and students of Lesya Ukrainka Eastern European National University and Ternopil Ivan Puluj National Technical University. In the occasion of the 10th anniversary of SS Rivne NPP unit 4 commissioning the photo contest and photo exhibition were held.

The following excursions are organized for the public and guests of the town:

The Information Center took the prominent position among the cultural and entertainment establishments of the town and region. Visits to the Information center are included in the list of places to visit during the excursions to the Western Ukraine.

Given that the main succession pool of our enterprise is the young people from the town and adjacent areas, Rivne NPP pays much attention to vocational-oriented education.

Information materials are disseminated among SS Rivne NPP personnel, town, district, regional organizations and institutions, educational establishments.

In 2017 the contests for students from the Observation Zone settlements were conducted: essays and brain-rings on the topic “Nuclear Energy and the World”, drawings on the topic “The peaceful atom unites Ukraine”. Also in 2017 a competition was held for the best creative work - a sketch of the color design of the auxiliary building facade of SS “Rovno NPP” on the topic “NPP: building the future together!”.

The department employees meet with the public of the Observation Zone, students of higher educational establishments.

The enterprise personnel gets information through the plant media – radio broadcasts and newspaper, and through the electronic means – an electronic screen, a plasma panel at check point 1, as well as information boards at check points 1, 2, Production and Laboratory building.

The newspaper “Energia” is published weekly in a printing form with an average circulation of 2000 copies and in an electronic form on SS Rivne NPP website. The information content of the newspaper is constantly improved. Hourly radio broadcasts go on air twice a week (Tuesday and Friday). The editors of television and radio broadcasting, in addition to their own programs, create programs “Pulse of RNPP”, which are broadcast on the regional television in Rivne and Lutsk.

The television programs of the editorial staff were regularly transmitted to the Press Service of SE “NNEGC “Energoatom” to be placed on national channels. Continuous attention is paid to SS Rivne NPP safe operation, preparation and conducting outages, financial and economic state of the plant, coverage of international reviews, particularly IAEA and WANO missions.

Particular attention is focused on forming the personnel’s commitment to the safety culture principles. Issues of industrial safety, labor discipline, health protection and rest of NPP workers, their social protection were raised. Specific attention has been paid to the usage of funds provided to compensate the risk of the public living within the plant Observation Zone.

The information on the electronic board is updated daily.

The presentations dedicated to public and professional holidays, information about meetings, visits of colleagues, messages from the trade union committee, results of photographic materials on the history of the Rivne NPP, and mass cultural events are demonstrated on the plasma panel.

The Information and Public Relation Department personnel participate in the events conducted at SS Rivne NPP or under the assistance of SS Rivne NPP to cover them in the mass media.

In order to present the plant the department employees participated in the exhibition "Energy Forum of Fuel and Energy Complex of Ukraine: Present and Future».

The Information and Public Relation department specialists as a part of information support brigade participated in the plant emergency response drill. During a year the personnel provided the preparation and printing of booklets for Emergency Preparedness and Response Department, photo album devoted to the 10^{th} anniversary of power unit 4 commissioning, updating of Walk of Fame and Wall of Fame, the personnel of the RTR editors office produced videos devoted to the anniversaries of departments and subdivisions. The Information and Public Relations department comprehensively assisted SS Rivne NPP in organization and conducting "Come in vyshyvanka" event devoted to the Constitution Day of Ukraine and covered it in the media.

During 2017 the personnel updated Walk of Fame and Wall of Fame, the personnel of the RTR editors office produced videos devoted to the anniversaries of departments and subdivisions. The Information and Public Relations department together with social facilities administration organized and conducted patriotic flashmob "Chain of Unity" before the Day of Unity of Ukraine and for the Constitution Day of Ukraine – ethnic defile of vyshyvanka.

Within the limits of the available financing, subscriptions of periodicals for 2015-2018 were carried out for departments and subdivisions of the plant.

CONCLUSIONS ON SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Rivne NPP produces heat and electricity. Electricity production is accomplished at four power units with VVER-440 reactor and VVER-1000 reactor, with total installed capacity of 2835 MWt. The capacity factor is 74.2%.

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008) and World Association of Nuclear Operators (WANO) (1988, 1989, 1993, 1995, 1997, 2001, 2003, 2005, 2012, 2014, 2015, 2016, 2018 years).

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:

- protection safety systems;
- localizing safety systems;
- auxiliary safety systems;
- control safety systems.

Each power unit is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

The process of economic operations, including all environmental impact factors and technical solutions, is intended to eliminate or reduce harmful releases, discharges, leaks and radiation in the environment.

VVER-440 and VVER-1000 reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel.

Minimization of radioactive releases and discharges and their impact on the environment and the public is provided by the following main engineering solutions:

- decontamination of air which is removed and which contains radioactive isotopes using aerosol and iodine filters;
- decontamination of process vent on filters-absorbers, where gas is held up in order to reduce relative activity (radioactive decay of the major part of inert noble gases isotopes (xenon (Xe), Krypton (Kr);
- air releases from the premises of reactor compartment controlled access area and auxiliary building through vent stacks of 150 m high, that provides necessary dispersion of radioactive substances in atmosphere;
- establishment of barriers to prevent propagation of radioactive substances by way of the reactor compartment containment, lining of the premises with LWR sources by corrosion resistant steel;
- implementation of closed process and component cooling systems to prevent discharges of liquid substances containing radioactivity;
- implementation of special system for SRW collecting, as well as SRW and LRW storage;
- prevention of non-controlled releases and discharges;
- arrangement of NPP SPZ;
- organization of continuous technological dosimetry monitoring of discharges and releases, air, soil, vegetation, water contamination monitoring in the SPZ and OZ.

Production of the electricity at the nuclear power plants comes along with generation of radioactive waste in the course of the main technological process, as well as during routine and maintenance operations. The stable development of the nuclear energy field in the country requires safe management of the radioactive waste at all phases of waste formation and existence. The RW management system is an important component in the entire safety systems while using nuclear energy.

The main principles of the RW management at the NPP is minimization of waste formation and interaction between all phases – from formation to disposal.

The sources of non-radioactive impact are both main production facilities (main building, auxiliary buildings) and auxiliary facilities and structures.

The sources of chemical impact on atmosphere under normal operation and emergency situations are gas releases during process equipment operation through the ventilation systems and smoke stacks.

It shall be noted that operation of the above mentioned installations is periodic and has almost no impact on the environment.

Waste management at SS Rivne NPP is carried out in compliance with the requirements of laws and sanitary and hygienic standards of Ukraine. Solid domestic wastes are transferred to the public utility landfill of town of Varash. In compliance with the “Provision on the Interrelations of SS “Warehouse” with SS NPP, SS “AtomKomplekt”, SS “AtomProjectEngineering” and the Directorate for Organization of Internal Inspection of SE “NNEGC “Energoatom” ПЛ-Д.0.45.551-13, the wastes of spent luminescent lamps, monitors, batteries, spent and worn buses were transferred to the specialized enterprises for further disposal through RV VP SG.

Physical impact of SS Rivne NPP site on the environment is characterized by:

- thermal impact on the air environment associated with operation of NPP process equipment cooling systems (spray cooling ponds and cooling towers);
- increased humidity due to the evaporation of water into the atmosphere from spray cooling ponds and cooling towers;
- thermal impact on the water environment associated with the discharge of blowdown water from the main cooling system;
- impact on the water environment (the Styr river) associated with the irretrievable water consumption;
- impact of the electric field of 330/750 kVt transmission lines;
- noise during equipment operation and traffic.

The complex of planning, technical, technological (process), organizational measures and decisions regarding the limitation of negative impact is aimed at providing regulatory indicators for environmental protection.

The existing regulatory documents do not have requirements to the allowed limits of heat releases. Monitoring of heat releases is performed by measuring the consumed water, which is collected from the River Styr for service needs and consumed water that returns to the river.

Taking into account that impact of the plant cooling systems is quite insignificant on the climate parameters, and that impact of the cooling towers and spray ponds is practically implicit on the microclimate and environment outside the sanitary protection zone within the radius of 2.5 km, no special activities are foreseen with regard to limitation of these influences during NPP operation.

Sanitary protection zone is an area around NPP where the level of the public exposure can exceed the dose limit quota for category C. Within the Sanitary protection zone it is prohibited to live, the restrictions on production activity not related to NPP are established, and radiation monitoring is carried out.

The size of SS Rivne NPP SPZ is 2.5 km, and OZ area is 30 km.

The size of SPZ and OZ are officially introduced in accordance with SS Rivne NPP document, namely the “Decision on the size and boundaries of Sanitary protection zone and Observation Zone of Rivne NPP” No. 132-1-Р-11-ЦРБ.

To control non-spreading of the radioactive materials into the ground waters, the radiation monitoring of underground waters is conducted on the territory of Rivne NPP site. To control the underground water supply sources, the content of radionuclides is measured in the artesian wellholes.

There are 35 check-wellholes, and water is sampled from the bottom layer at a depth of 10÷14 meters from the surface. The frequency of water sampling from the check and artesian wellholes is once per quarter. Each sample is measured in terms of Σβ-activity using α/β radiometer MPC-9604 and specific activity of tritium is measured using liquid scintillational radiometer Tri-Carb 3170 TR/SL. The samples of check-wellholes are averaged and are subject to γ-spectrometeric analysis. The activity of man-made isotopes in the groundwaters is thousand times less than the level of allowed concentration in the portable water.

The network of artesian well-holes consists of nine wells, organized on the territory of the water withdrawal point "Ostriv". The samples of water are taken from the special collector, and go through γ-spectrometry and measurement of tritium activity. The water of artesian wellholes has no isotopes of manmade nature.

The ecological and chemical laboratory of environmental protection service (EPS) performs analysis of the surface and sewerage (discharge) waters three times a week using 25 indicators. The analysis of monitored indicators prove that the values of the maximum allowed effluents (in tons) were not exceeded, the sewerage water is within the purity limits, and contains the same natural impurities like the source river water, and operation of Rivne NPP does not input the significant changes into the quality of surface waters.

SS Rivne NPP has little influenced on the change of water-physical properties of adjacent soils due to changes in the level of groundwater during its construction. It is possible to talk about the joint influence of SS Rivne NPP and land-use only in case of overshooting of SS Rivne NPP emissions to agricultural soils, when, as a result of agrochemical treatment, pollutants penetrate down the soil profile to the depth of plow sole and evenly mix. In fact, there is an acceleration of the migration process of those small amounts of pollutants which can settle on soil due to the emissions from a nuclear power plant.

During the reporting period, the maximum contribution to the specific activity of the soil is due to the presence of ^{137}Cs isotope that over all reporting years exceeds the "zero background", but this contamination is explained by the consequences of Chernobyl accident.

The main foodstuffs of the local population were monitored in the zone of placement of the SS Rivne NPP - milk, vegetables, and grain crops. Samples were selected during maturation.

The samples were examined using γ-spectrometric analysis to determine the possible presence of radionuclides of technogenic origin, especially ^{131}I.

^{131}I was not registered in agricultural products in 2017. The presence of other man-made radionuclides, except ^{137}Cs of "Chornobyl" origin was not registered, too. The high content of this radionuclide in food is due to the higher value of transition coefficient of "soil-solution-plant" chain.

The maximum content of ^{137}Cs was recorded in Manevychi checkpoint - 4.95 Bq/l. Permissible content of ^{137}Cs in milk is 100 Bq/l. Exceeding the upper bound of values of "zero background" by ^{137}Cs has not been fixed.

For most objects of the environment, the activity of radionuclides is within the range of "zero background" measurements.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

The analysis of control characteristics shows that the work of the Rivne NPP NP does not significantly change the quality of underground water. Radiation state of groundwater is satisfactory, content of ^{226}Ra, ^{137}Cs, ^{90}Sr is much lower than the values that are standardized in the Radiation Safety Standards of Ukraine.

The assessments have shown that the major share of gas-aerosol release within the dose during operation of power units of SS Rivne NPP will be by inert gases through irradiation from the cloud. The maximum annual average concentrations of these radionuclides in the air were obtained in the east direction at a distance of about 1.5 km from the plant. They made: 1.351×10^{-11} Ci/m^3

(0.5 Bq/m^3) for ^{133}Xe; 2.703×10^{-13} Ci/m^3 (0.01 Bq/m^3) for ^{85}Kr; 5.406×10^{-14} Ci/m^3 (0.002 Bq/m^3) for ^{41}Ar.

Non-exceedance of the effective dose of 100 mrem/year (1 mSv/year) per population (Category B) is possible when maximum air concentrations of these radionuclides are as follows: 26.489×10^{-8} Ci/m^3 (9.8 kBq/m^3) for ^{133}Xe; 54.06×10^{-8} Ci/m^3 (20 kBq/m^3) for ^{85}Kr; 0.973×10^{-8} Ci/m^3 (0.36 kBq/m^3) for ^{41}Ar, which is 10^3-10^6 times higher than the maximum design concentrations of radioactive noble gases during normal operation of the power units.

On the whole, based on the analysis of changes in the background concentration of radionuclides with increase of distance from the power units of SS Rivne NPP, it can be concluded that the radiation regime of the plant during its normal operation does not affect the vegetation and does not cause any changes in the radiation level of individual plant species.

Technical design solution on cooling of process water in cooling towers and spray pools (instead of a cooling pond) allowed minimizing adverse impact of the plant on the ecosystem and preserving the valuable floodplain of the Styr River with its meadow, shrub, and forest animal complexes.

During normal operation of SS Rivne NPP, the radiation conditions and population doses in the region are defined by the existing natural background radiation. SS Rivne NPP radiation impact on the population and the environment does not exceed 0.05 % of the dose level produced by natural radiation sources, and does not change the natural radiation level in the area around the NPP.

Hazardous radiation levels exist only for personnel performing radiation hazardous works, however these risks are brought to a minimum if radiation safety rules are followed. No hazardous radiation risks are present for other works and beyond working hours during normal operation of SS Rivne NPP.

As a result, it can be said that Rivne NPP has no adverse effect on the population health within the SS Rivne NPP OZ.

The radiation impact of Rivne NPP was analysed based on the following MDBA: an accident caused by double-ended rupture of the cooling system pipeline (loss-of-coolant nuclear reactor accident) at normal energy level.

Radionuclide intake during the BDBA was determined based on the limit value of environmental release of ^{137}Cs at the level of 30 TBq in accordance with the safety requirements of European operators for designs of nuclear power plants with light water reactors (LWR). ^{137}Cs isotope was chosen due to its prevalent value for long-term environmental pollution as well as its health impact.

Other isotopes in the form of aerosol (i. e. all radioactive decay products, except for inert gases and gaseous iodine isotopes) are released into the environment in proportion to this value, even if these isotopes are released into the atmospheric air.

The main indicator, which characterizes the plant impact on the population of the Observation Zone is a maximum possible dose on the border of SPZ (dose for the population critical group). The normative document NRBU-97 specifies the quota at the level of 80 mcZv/year – a limit of the yearly population radiation dose from the NPP release and effluents.

In case of radiation accidentals, the existing radiation protection and control systems take into account only the radioactive influence of the Rivne NPP, which is also limited to the NPP monitoring area. The expected exposure doses of the population living in the observation zone and the neighboring states do not exceed the established dose rates and the individual effective annual dose of 1 mSv, indicating that there is no significant negative transboundary impact.