APPROVED BY

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«05» December 2018

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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2018

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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.

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". Production wastes	
3		Assessment of SS Rivne NPP impact on the environment	
	2.	Climate and microclimate. Air environment. Chemical air pollution. Attachments	
	3	Air environment. Influence of the radiation factor on the atmospheric air	
	4	Geological environment	
	5	Water environment	
	6	Soils. Flora and fauna, reserve areas.	
4		Assessment of impact 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 assessment	
7		Transboundary impact of production activities on the environment	

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-ТВ-СОНС, 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-ВР, 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- ВР, 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.

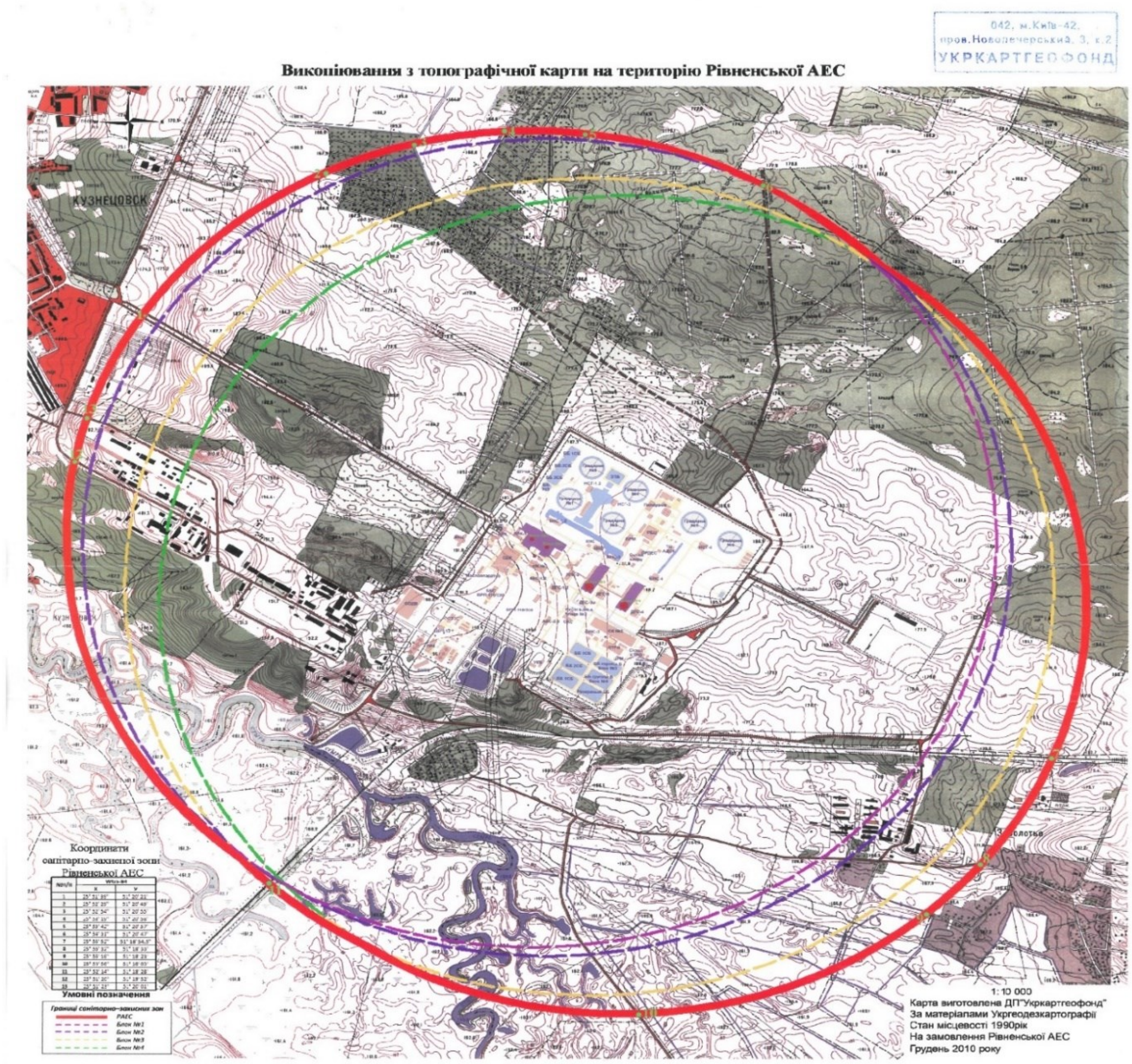


Figure 1.1. The boundary of SS"Rivne NPP" SPZand the boundaries of SPZof power units 1, 2, 3, and 4.

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) $\frac{\text{mCi}}{\text{month} \cdot 1000\ \text{MW(el.)}}$	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.

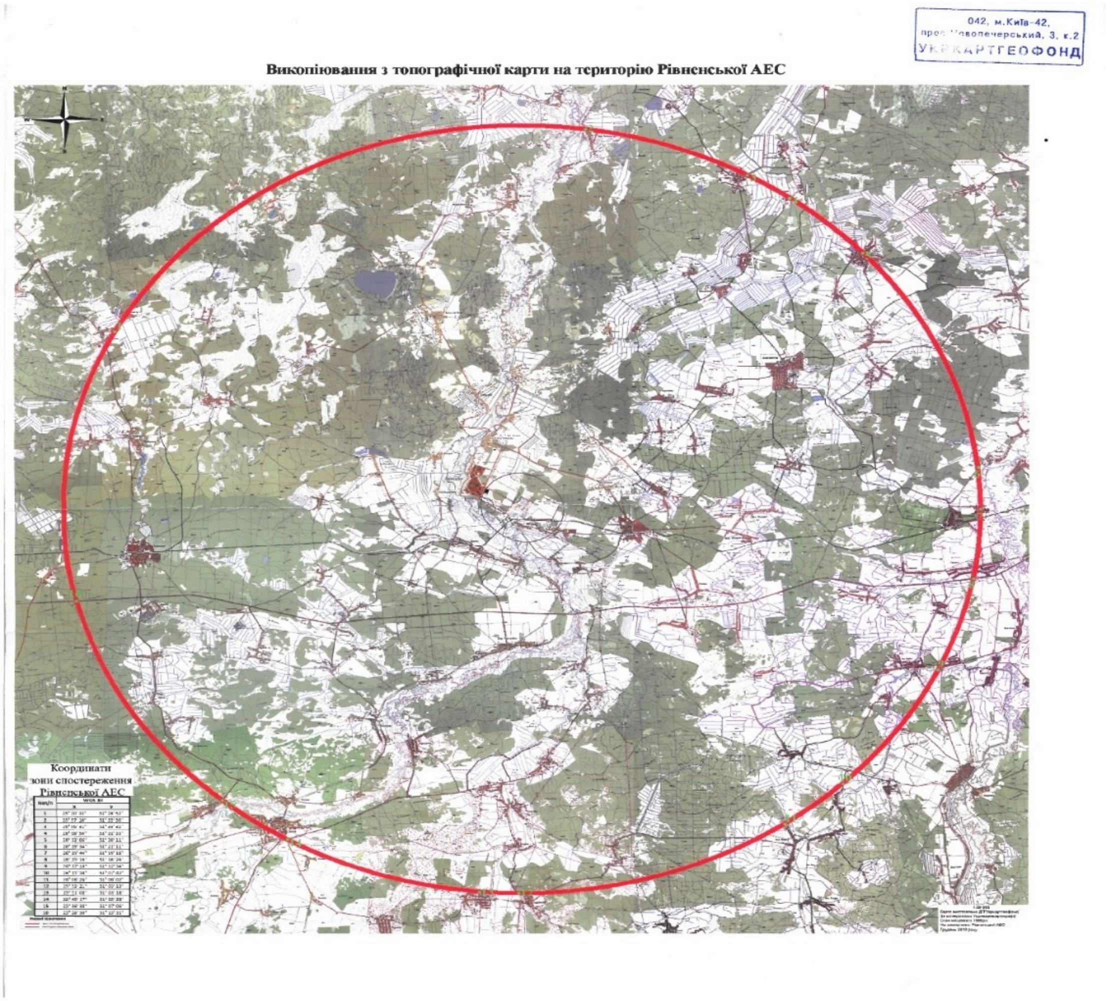


Figure 1.2. The observation zone of SS Rivne NPP

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].

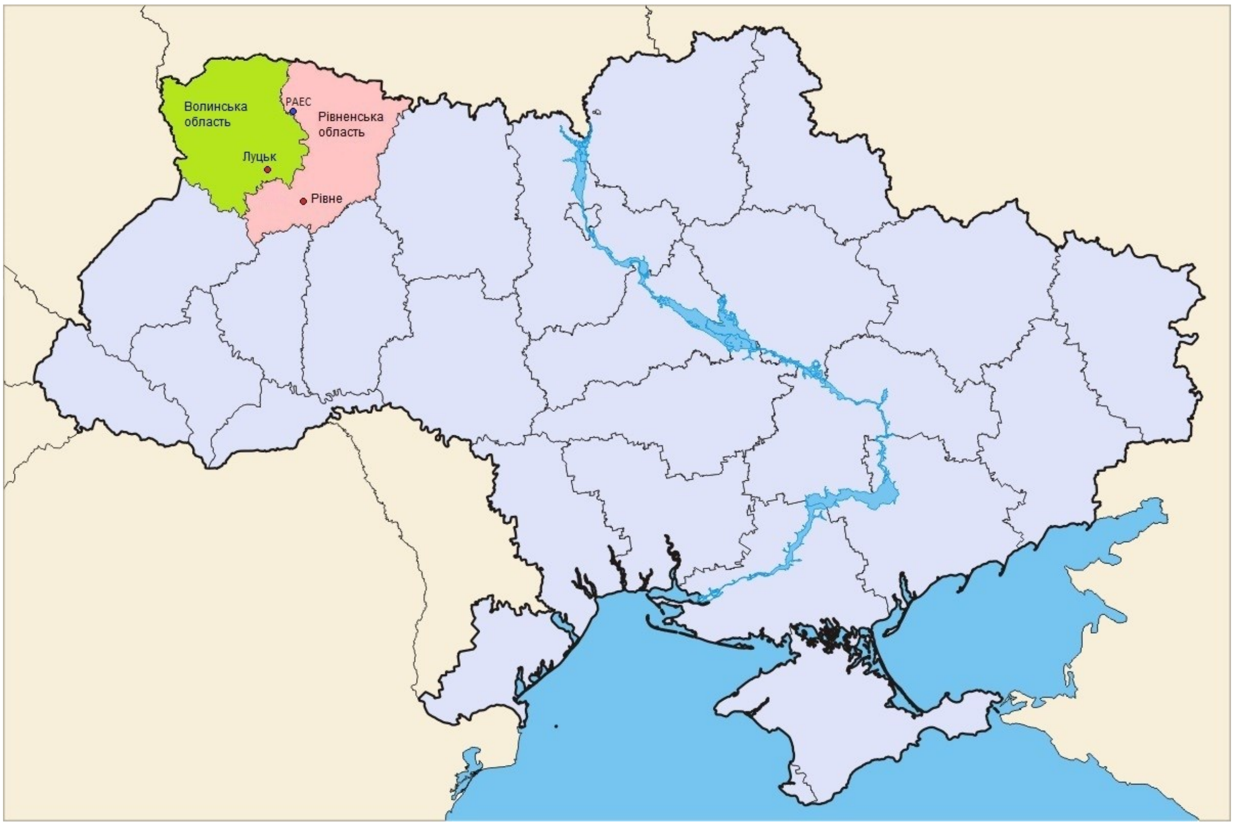


Figure 2.1. Location of Rivne nuclear power plant.

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, insituttions – 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].

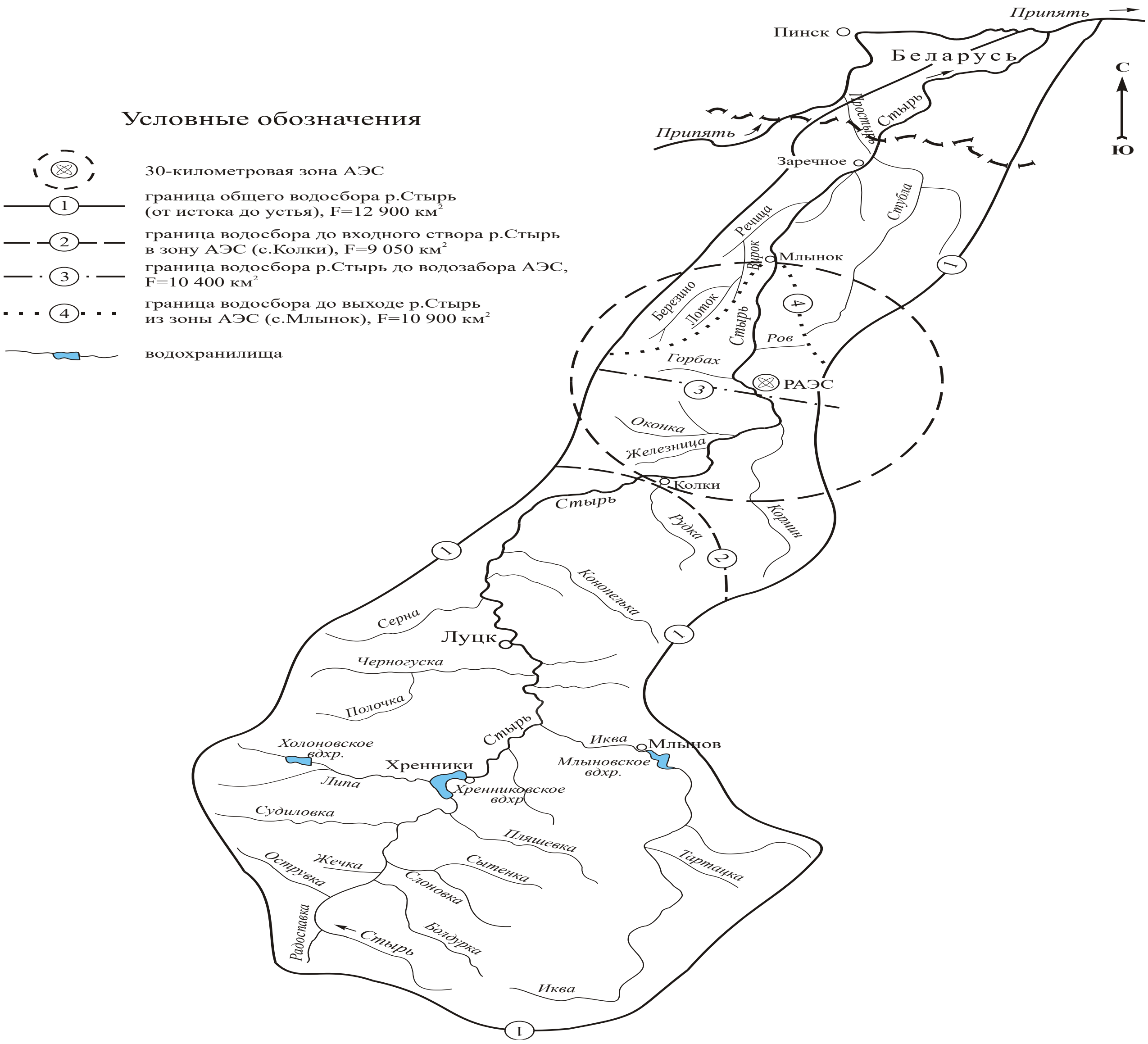


Figure 3.1. Schematic plan of the flood basin of the river Styr

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.

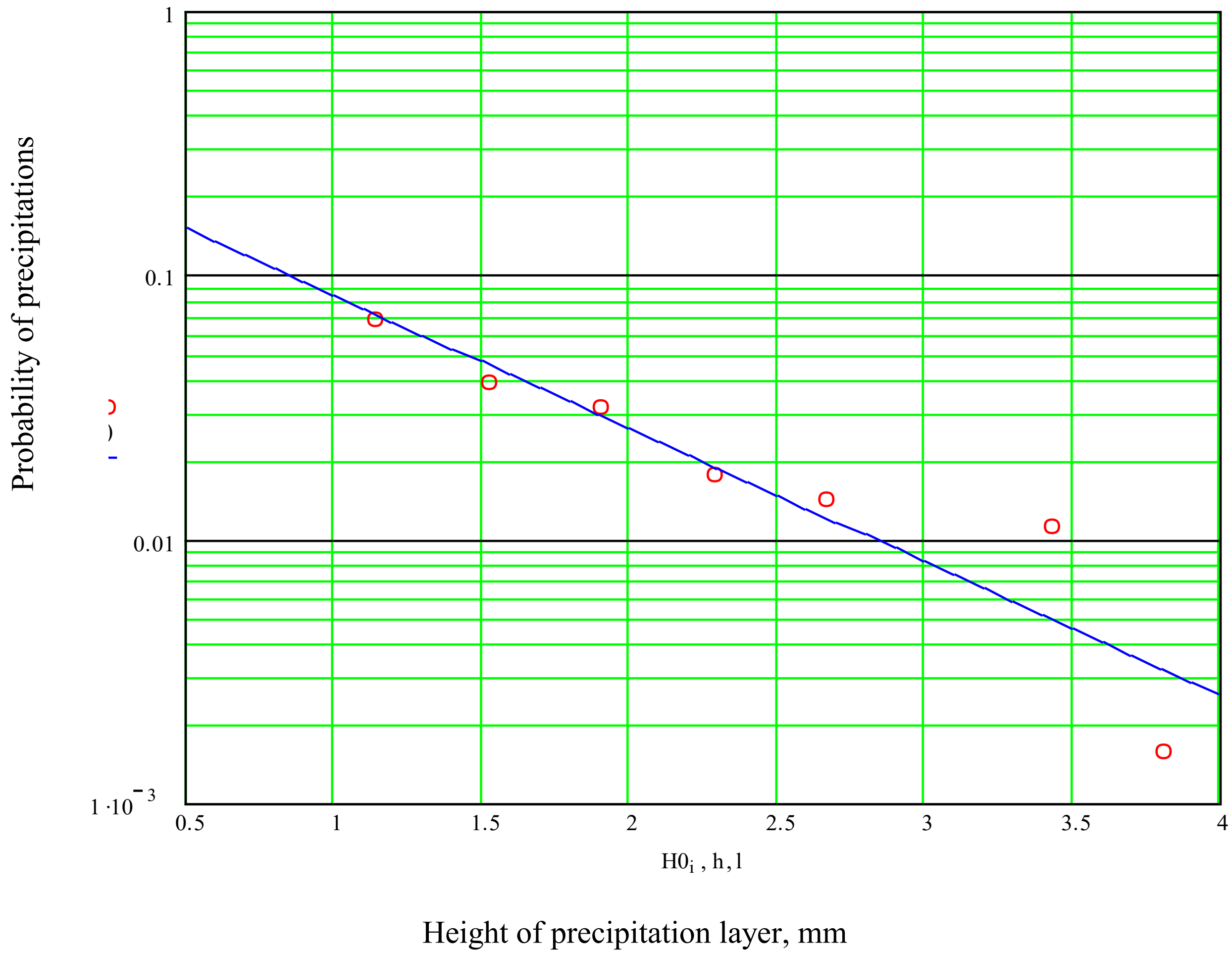


Figure 3.2. Precipitation intensity during 20 minutes rain

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:

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

$$b = -462.401$$

$$a = 2.855$$

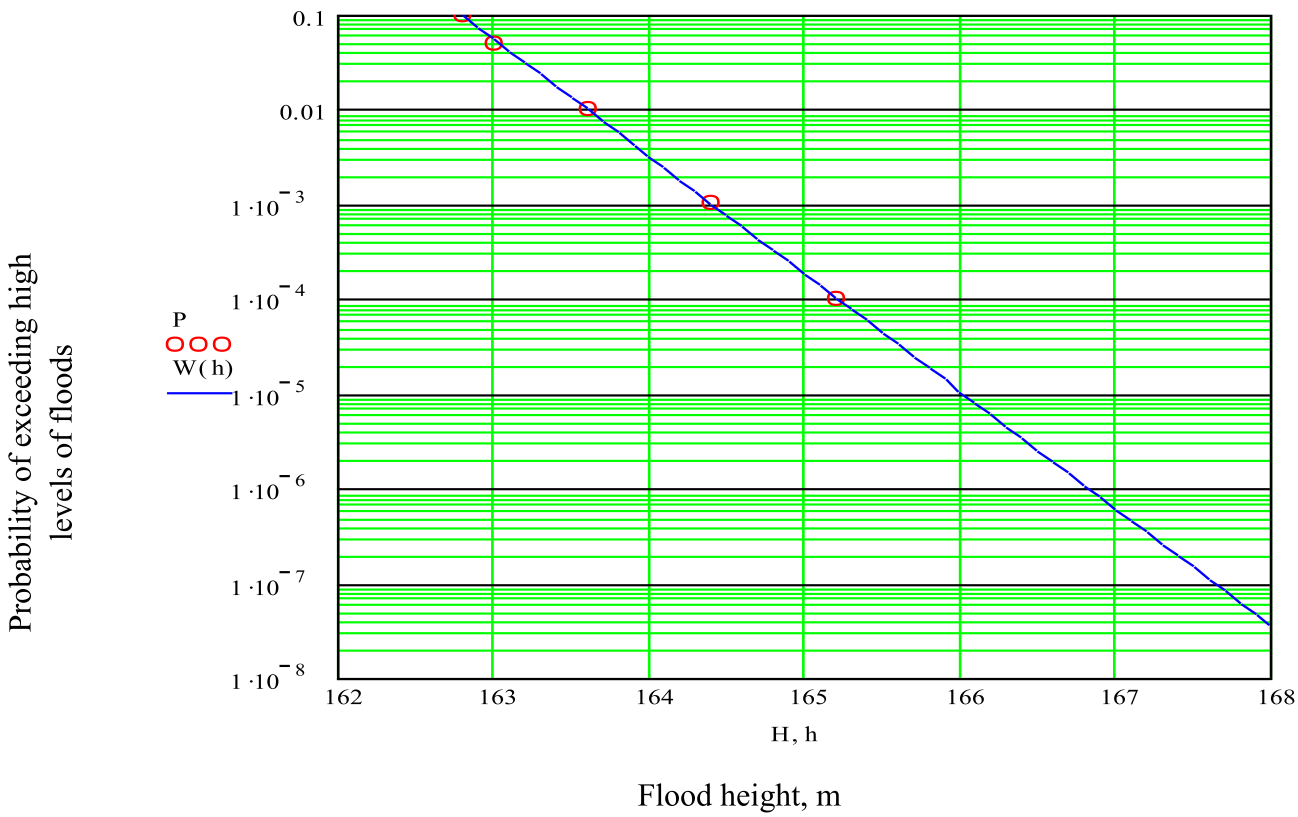


Figure 3.5. Probability of exceeding high levels of floods on the river Styr

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.

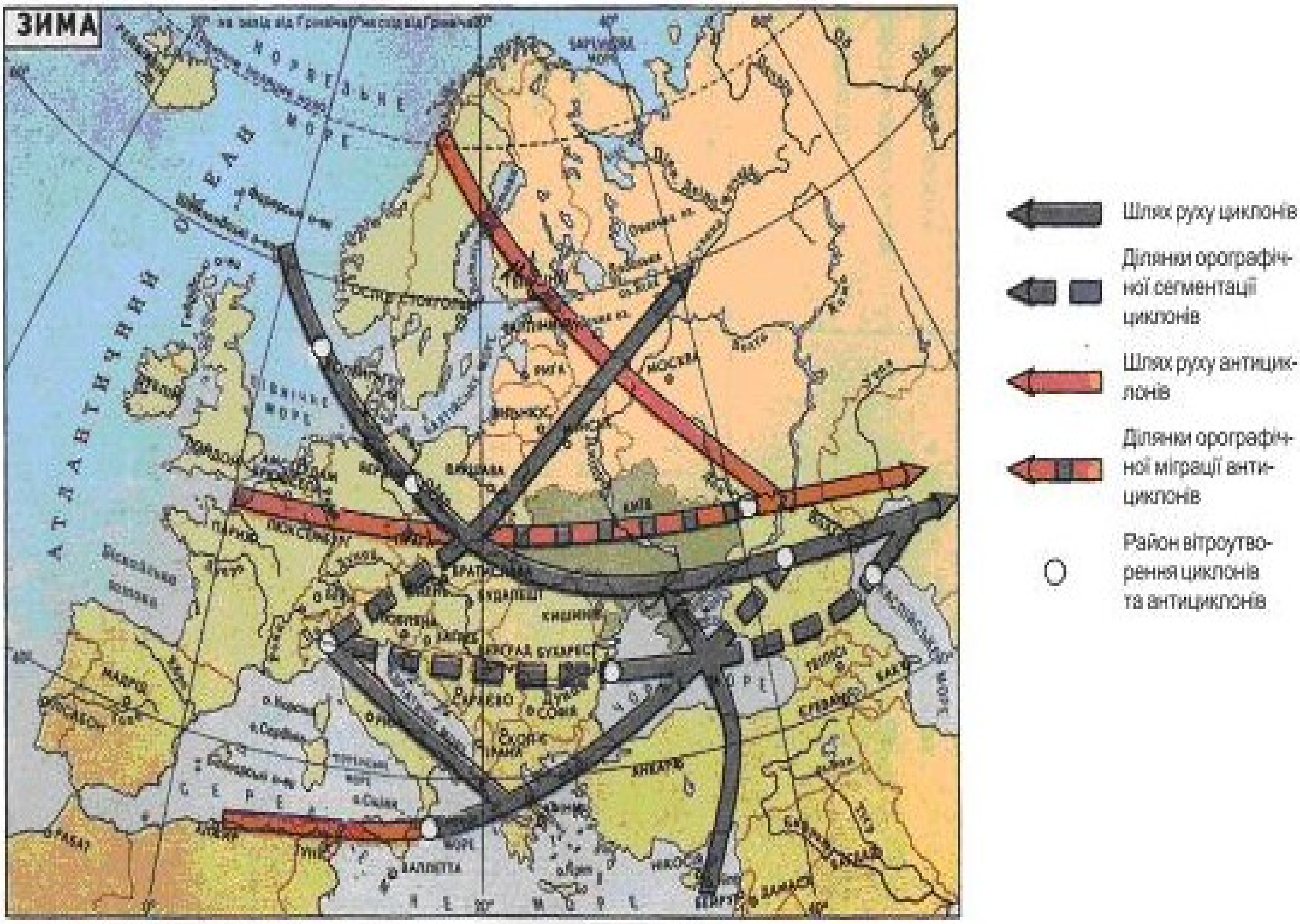


Figure 3.6. Main routes of cyclones and anticyclones in winter

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.

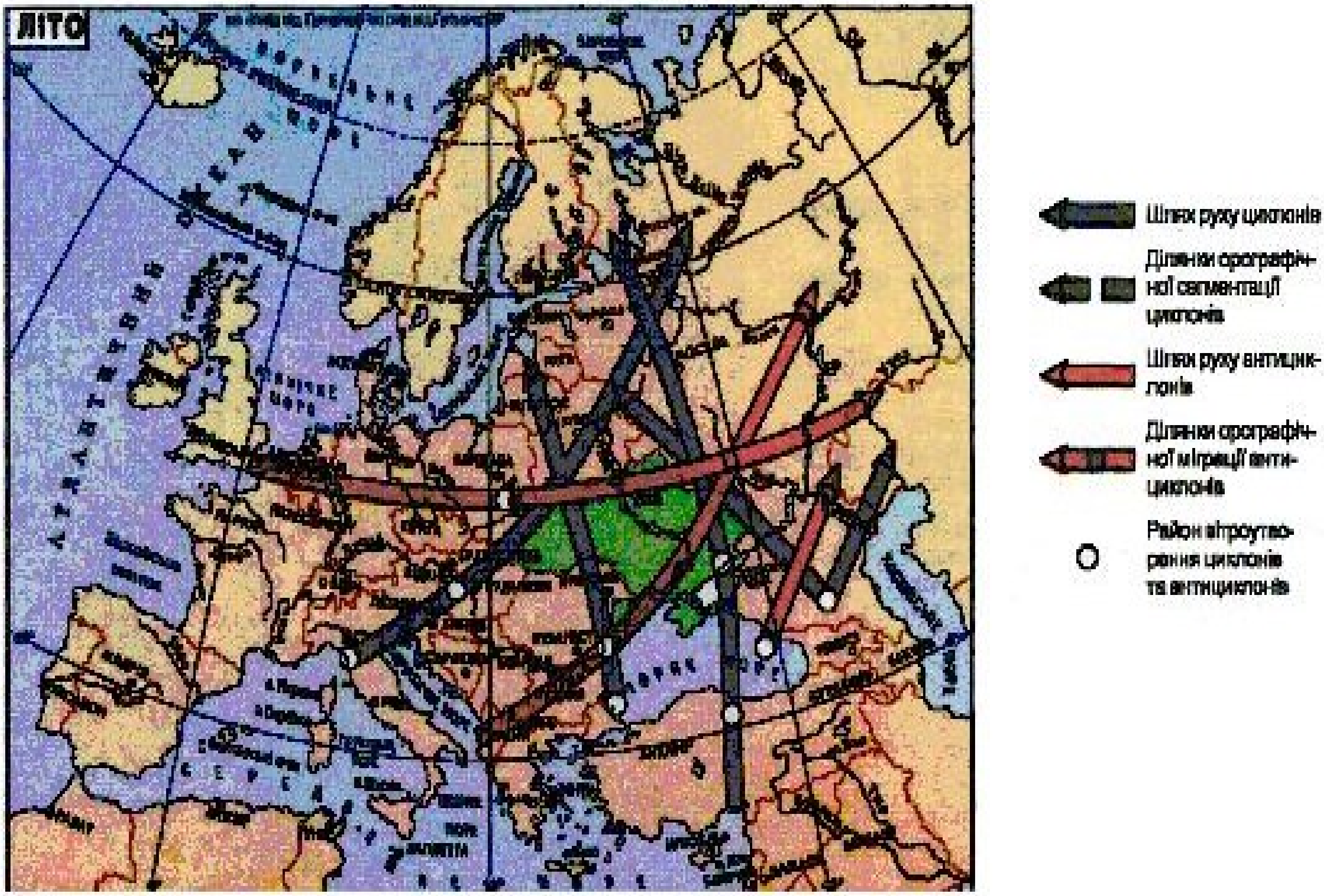


Figure 3.7. Main routes of cyclones and anticyclones in summer

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 (СНіП 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: $35 \times 1.2 = 42$ 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.

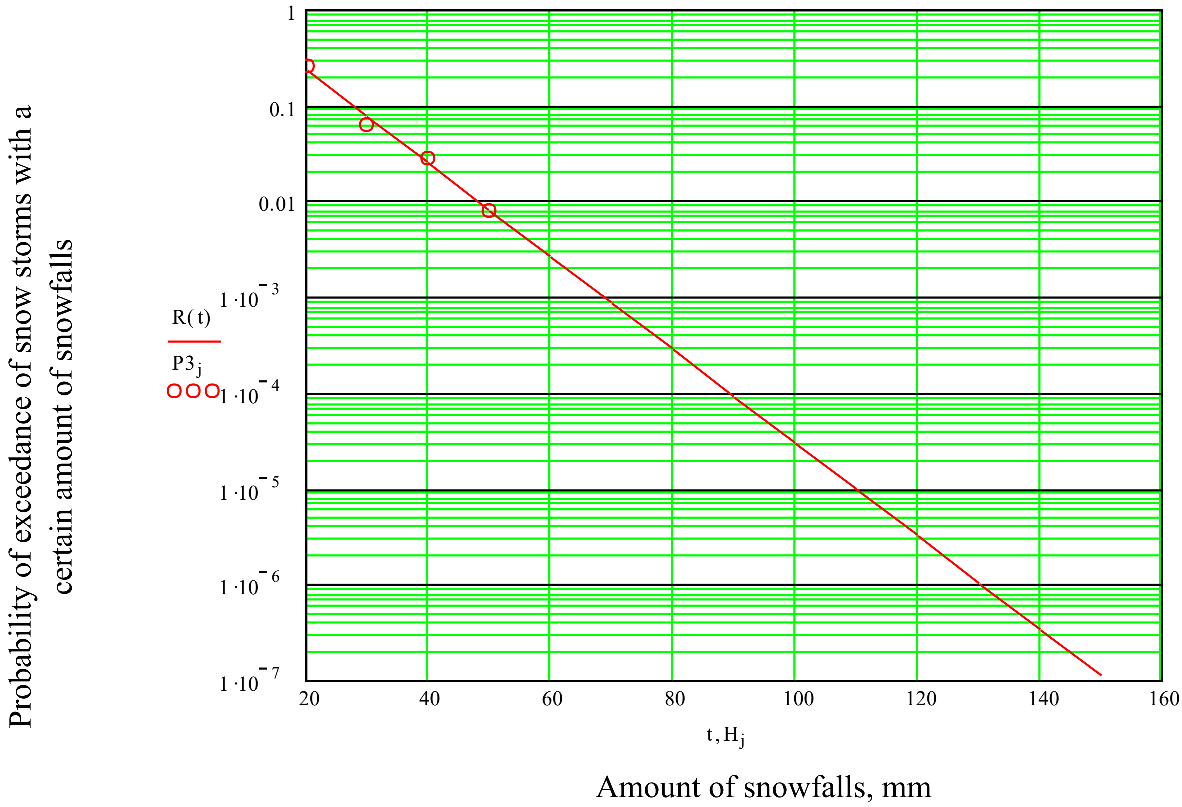


Fig. 3.8. Probability of exceedance of snow storms with a certain amount of snowfalls in the area of Rivne NPP location

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 $1.1 \div 1.7\times10^{-9}$ 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 (АТ03-13.51281 .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 (АТ03-13.51351.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 (АТ03-13.51311 .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

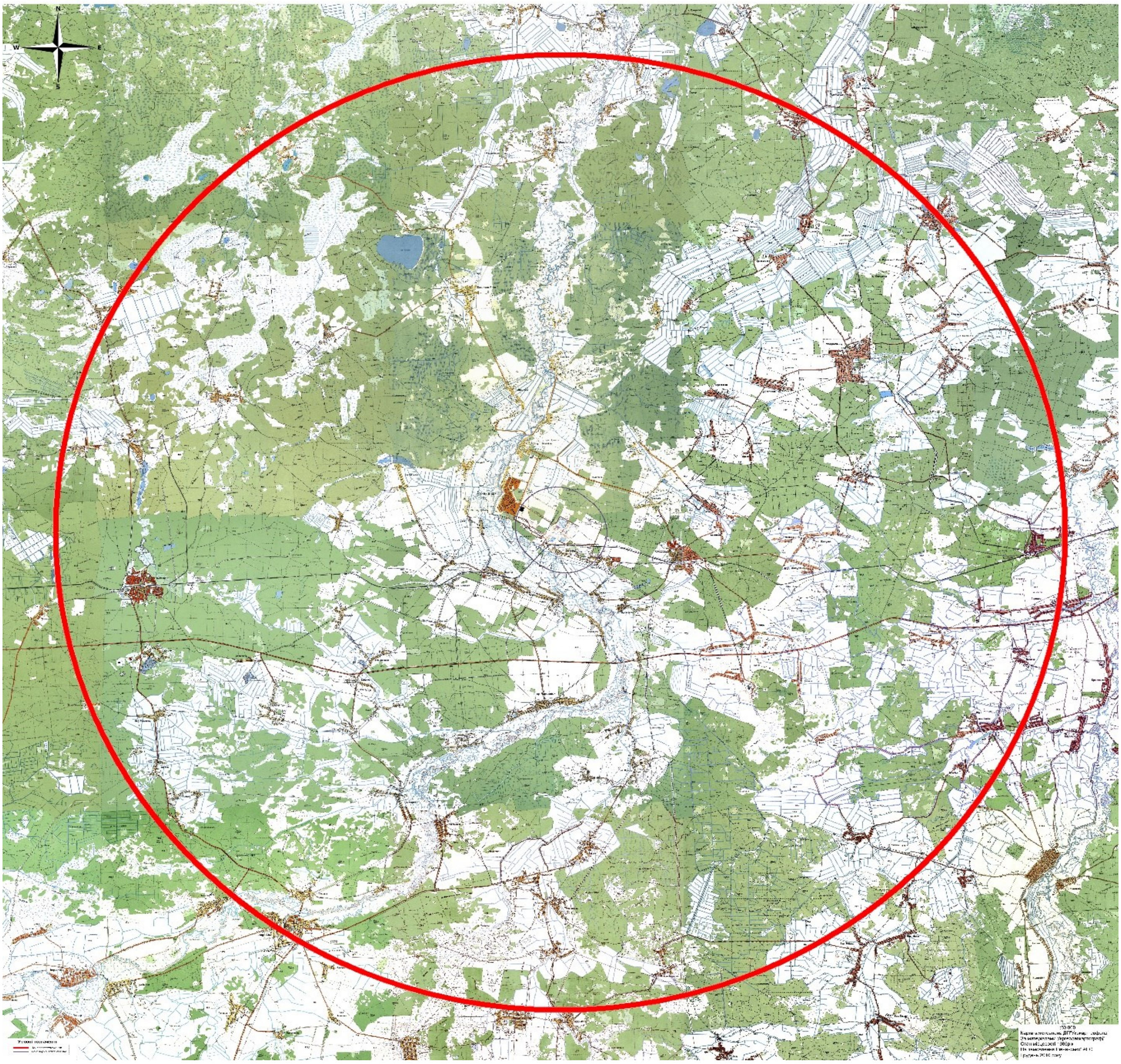
3.1 Procedure for service acceptance-transmission, due dates and reports for each completed phase are defined in the work schedule as per the contract.

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.

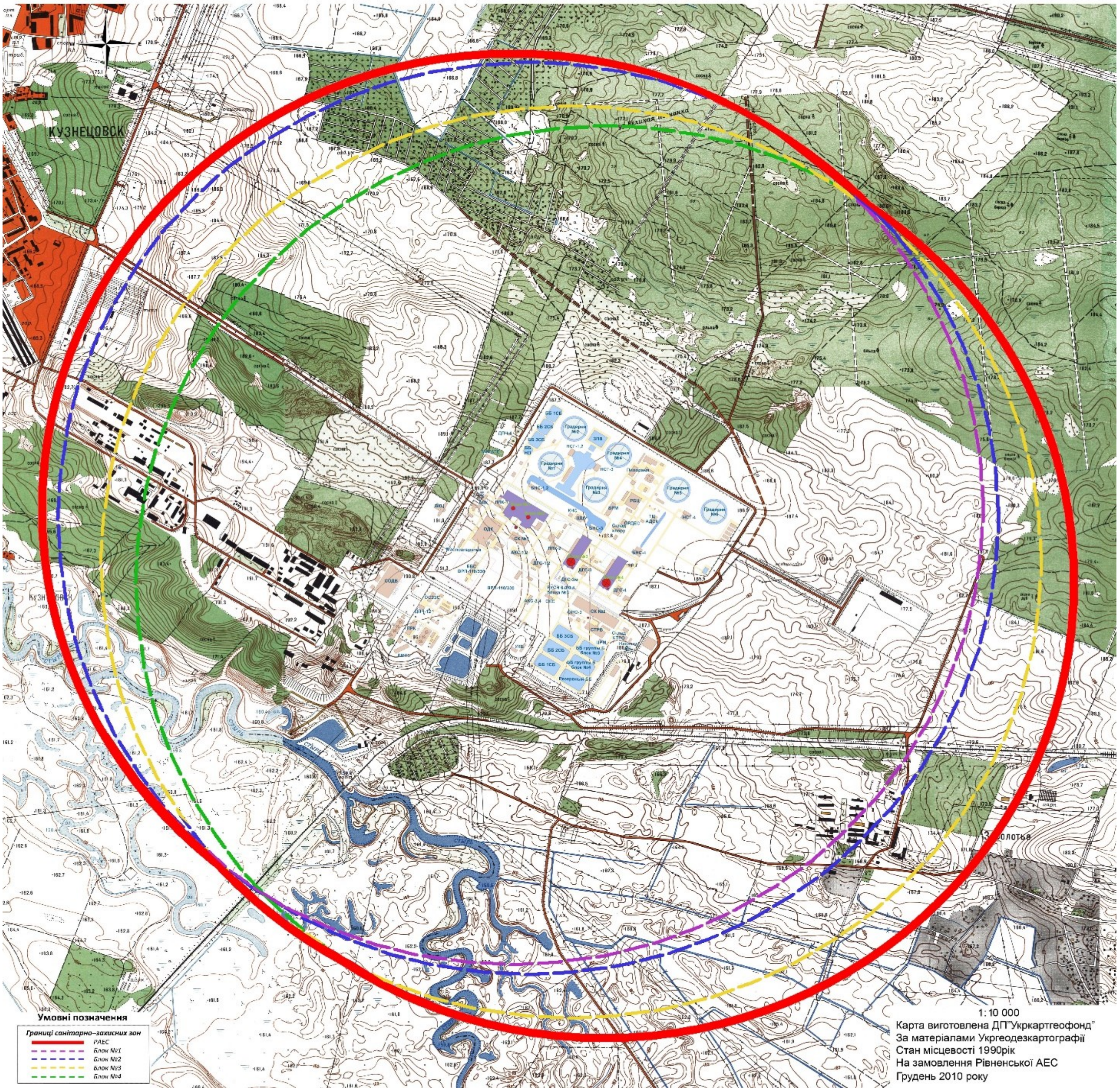
Attachment B

Map
Observation zone of Rivne NPP



Attachment C

Map
Sanitary protection zone of Rivne NPP



Attachment D

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]:

$\alpha(k) = 1{,}5$ at $k \le 1$;

$\alpha(k) = 1$ 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.

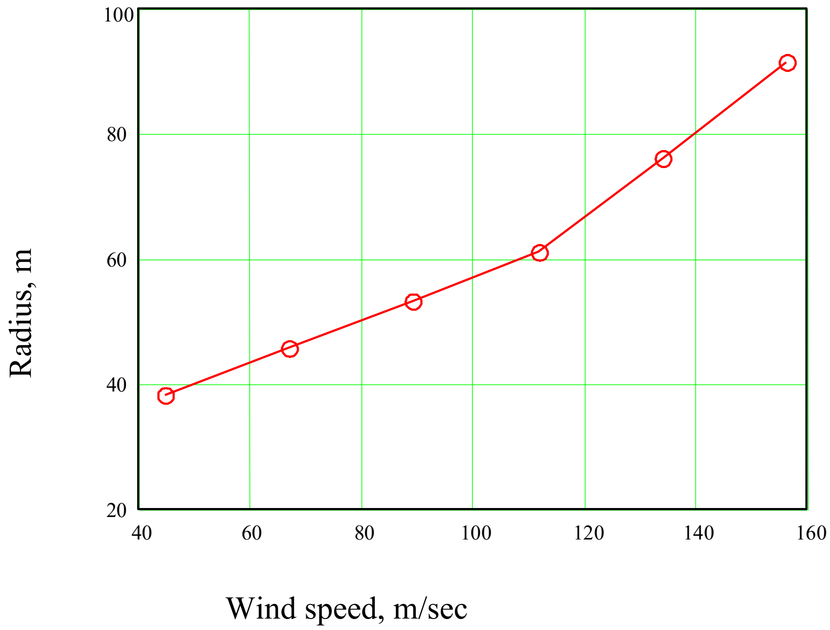


Fig. 1 – Dependence of the radius corresponding to the maximum speed of the air flow rotation ona the maximum wind speed

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 ІД 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,…n_0)

$$F_i(k) = i \cdot \alpha_k \cdot L_k \cdot W_k / S + 1/S \cdot \sum_{j=0}^{k-1} n_j \cdot \alpha(k) \cdot L_j \cdot W_j$$ 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.

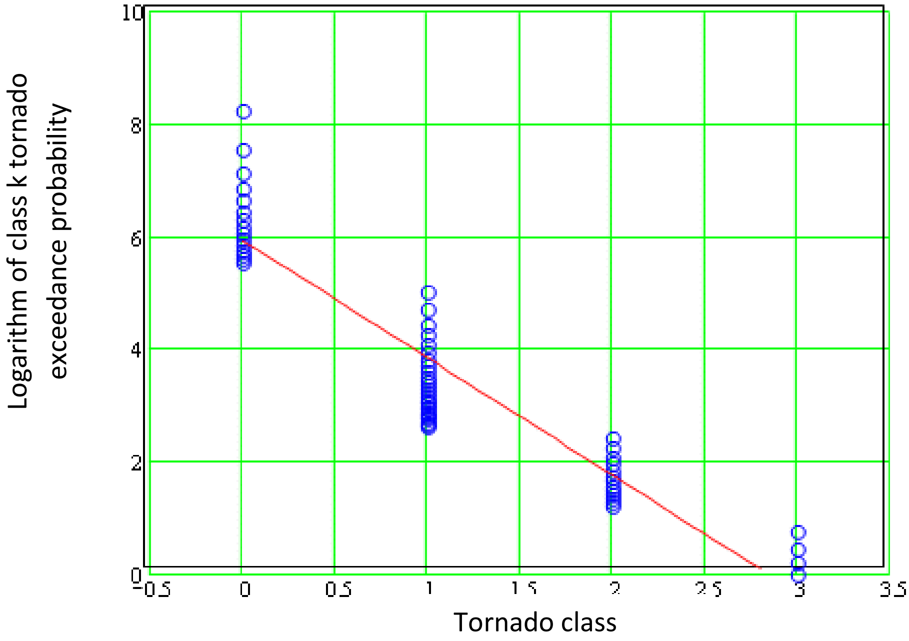


Fig. 2 Logarithm of Class k tornado exceedance probability

Figure 3 shows the dependence of Class k - $P_0(k)$ tornado exceedance probability, formed using the formula:

$$P_0(k) = 1{,}11 \cdot 10^{-6} \cdot (1 - \exp(-(a \cdot k + b)))$$

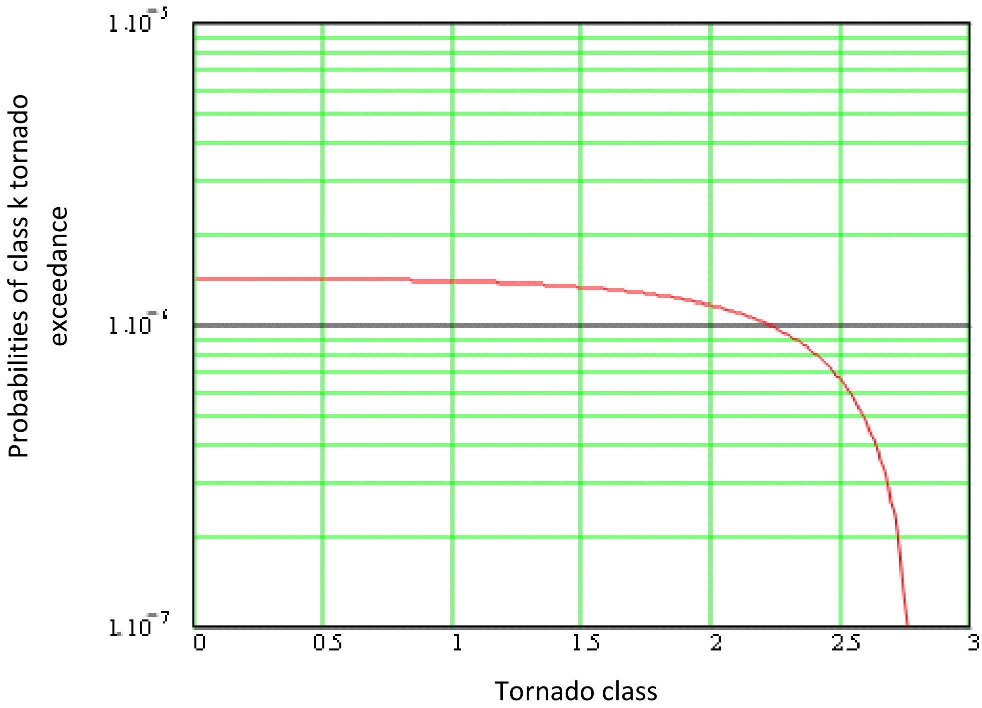


Fig. 3. Dependence of Class k tornado exceedance probability

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)								Calm ness
	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)								Calm ness
	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

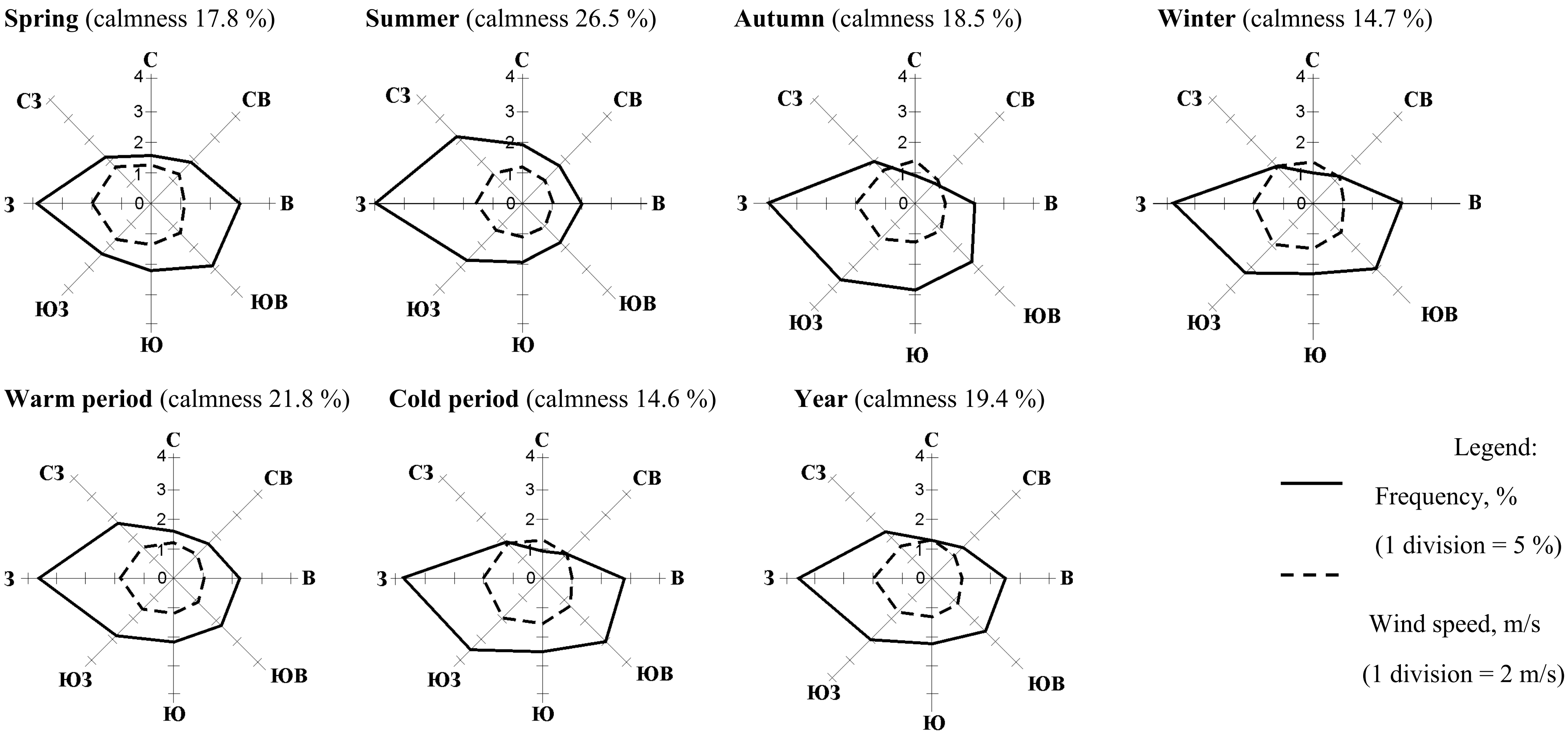


Figure 1 – Wind rose at the meteorological station Lyubeshov (by seasons, periods, and for a year)

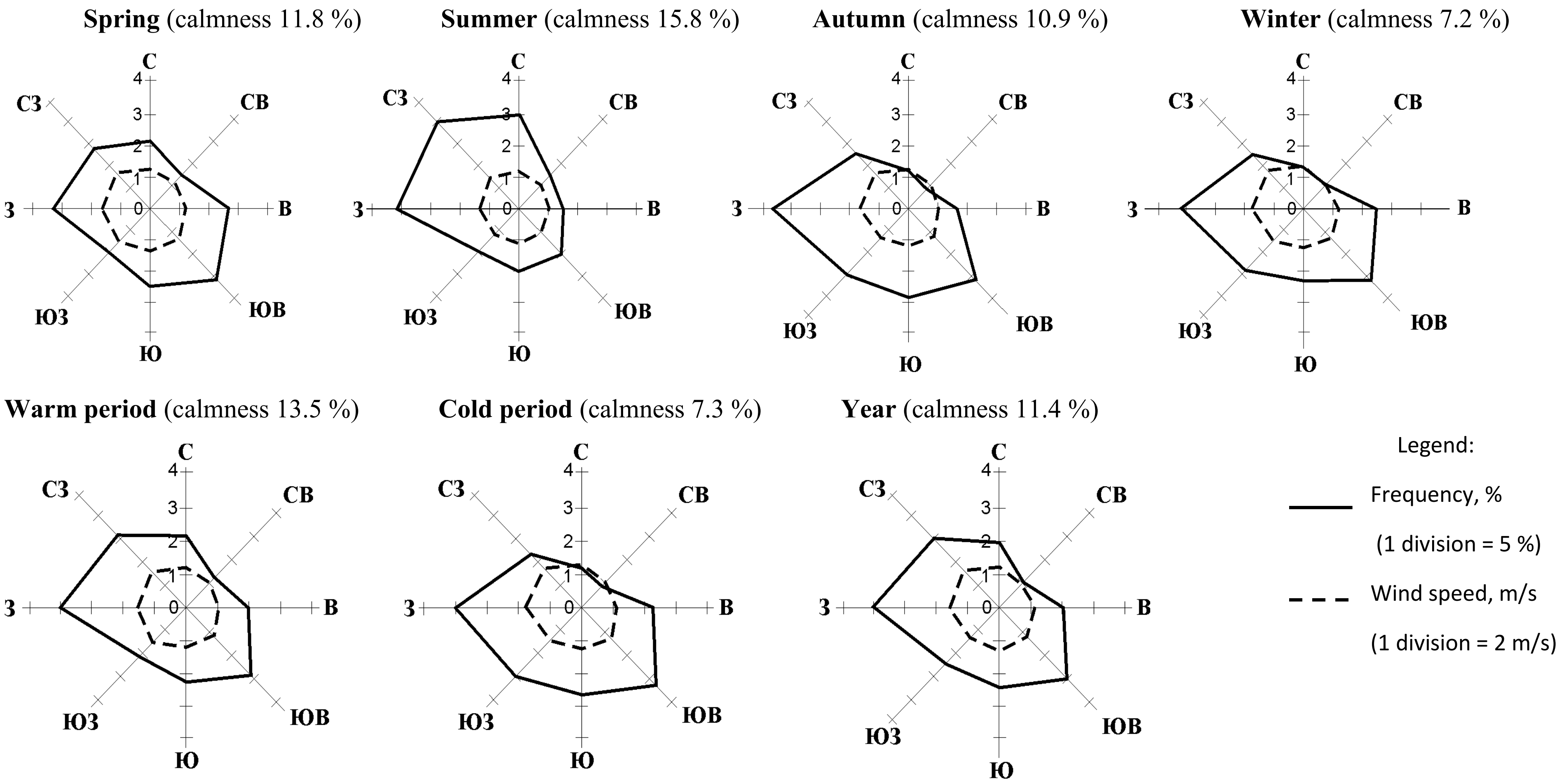


Figure 2 – Wind rose at the meteorological station Manevichi (by seasons, periods, and for a year)

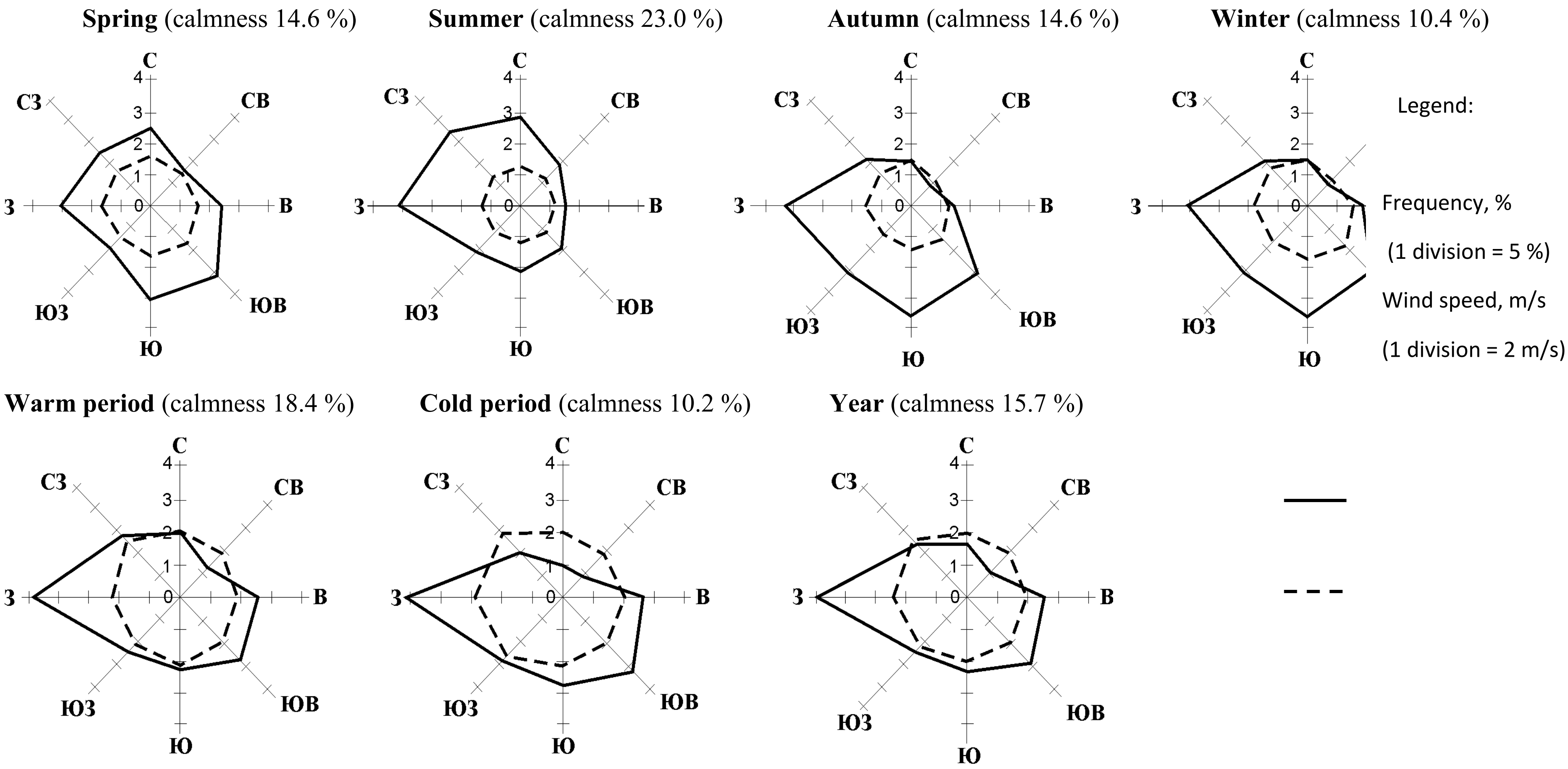


Figure 3 – Wind rose at the meteorological station Sarny (by seasons, periods, and for a year)

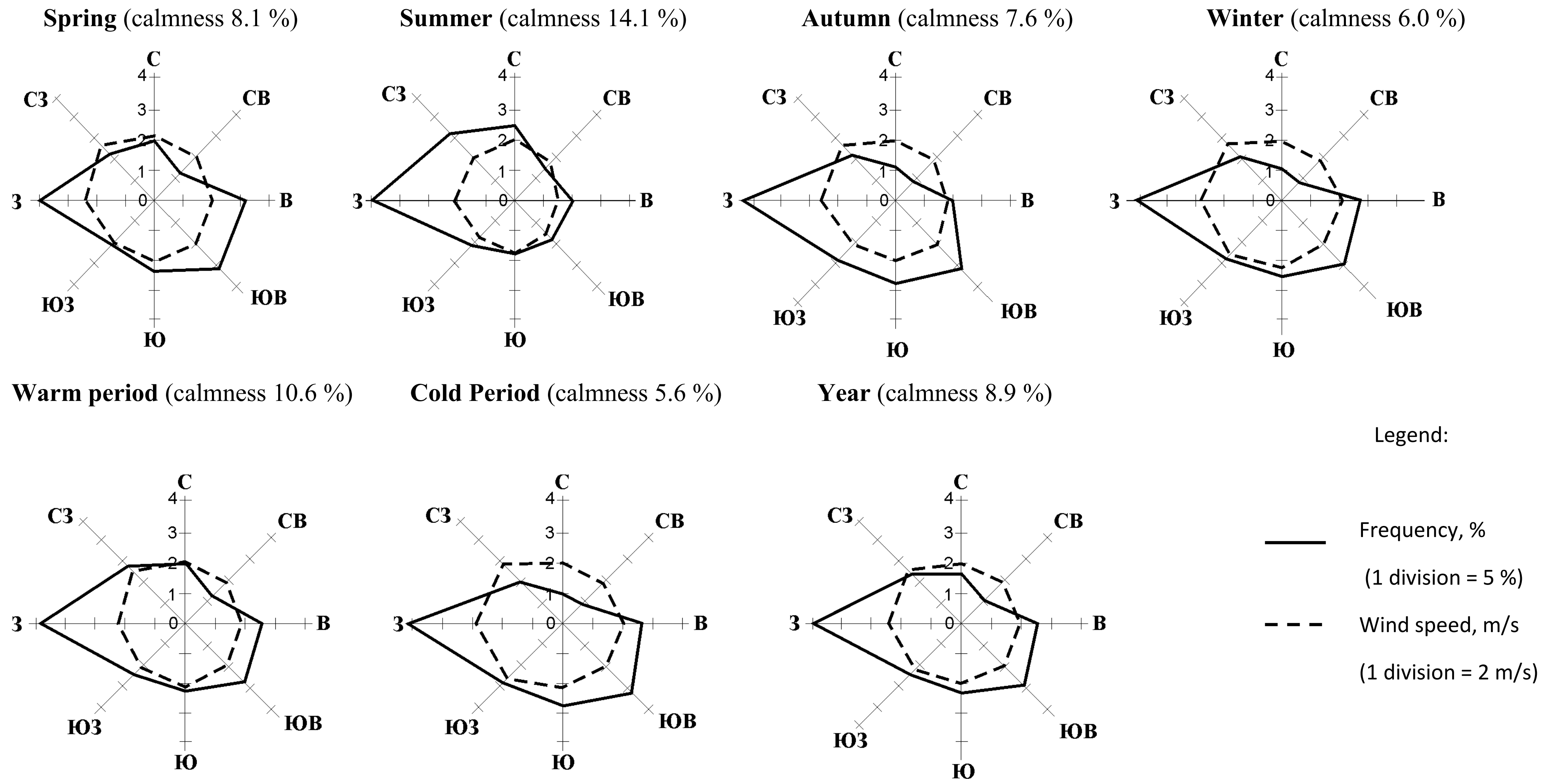


Figure 4 – Wind rose at the meteorological station Rivne (by seasons, periods, and for a year)

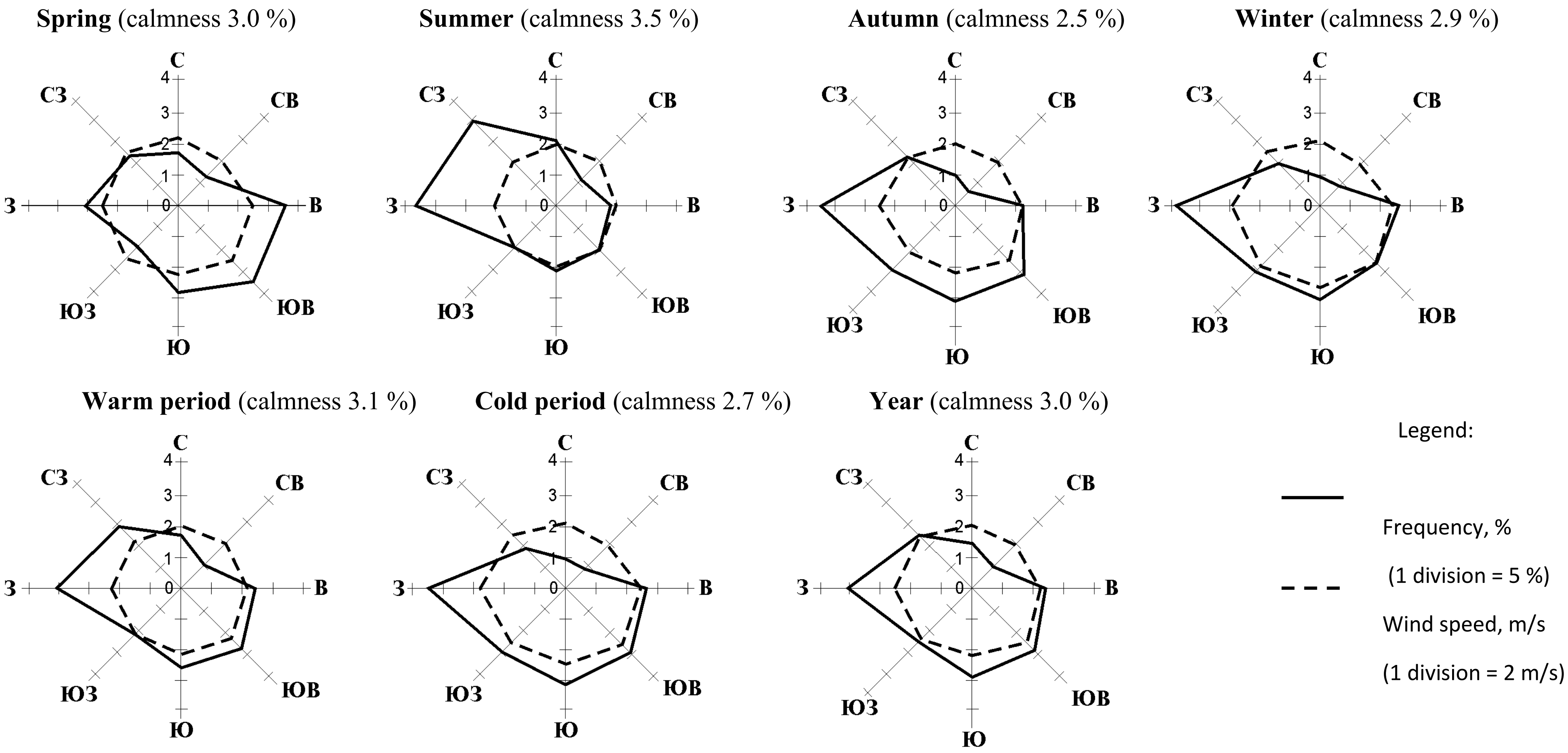


Figure 5 – Wind rose at the meteorological station Lutsk (by seasons, periods, and for a year)

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 ºC.

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

"___" 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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2018

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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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TABLE OF CONTENTS

REPORT COMPOSITION
SS Rivne NPP site environmental impact assessment

Book No.	Section No.	Name	Note
1		EIA justification. Physical and geographical characteristics of the SS Rivne NPP location area.	
2		General description of SS Rivne NPP	
3		SS Rivne NPP site environmental impact assessment	
	1	Climate and microclimate. Atmospheric air. Atmospheric air chemical pollution. Appendices	
	2	Atmospheric air. Radiation factor impact on atmospheric air	
	3	Geological environment	
	4	Water environment	
	5	Soils. Plant and animal world, protected areas.	
4		Assessment of impact on the surrounding social and anthropogenic environment	
5		Comprehensive measures to ensure environment condition and safety compliance	
6		Non-technical summary of SS Rivne NPP site environmental assessment	
7		Transboundary impact of the production activity on the environment	

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].

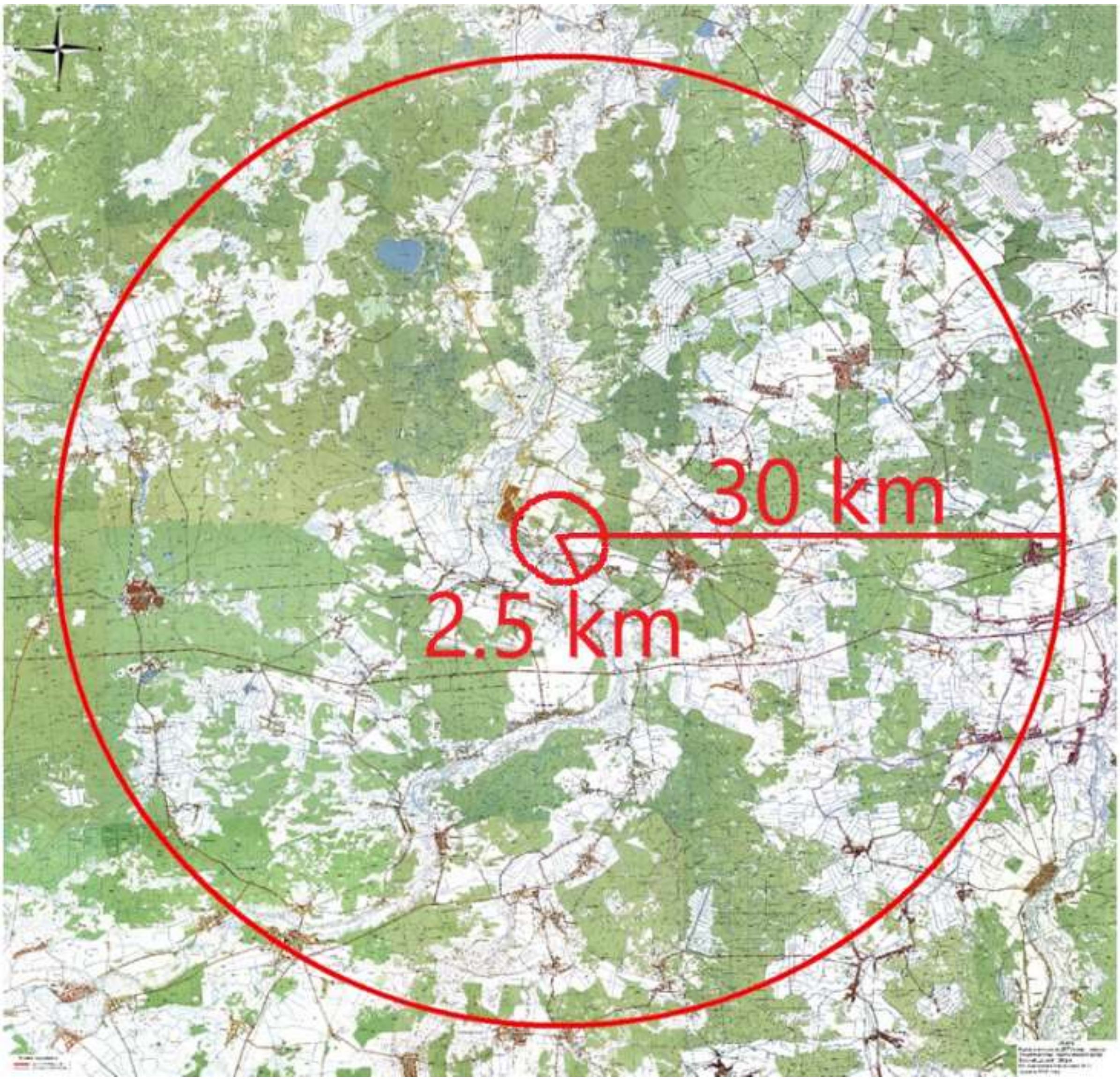

Fig.1.2. The territory of SS “Rivne NPP”

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 (B 213) reactor – units 1, 2 and VVER-1000 (B 320) – units 3, 4;
- K-220-44 turbine type – units 1, 2 (2 turbines per power unit) and K-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 EП 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 EП-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 $15 m^3$. 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 cСт (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 82.6°C, freezing temperature - 41.6°C. 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.

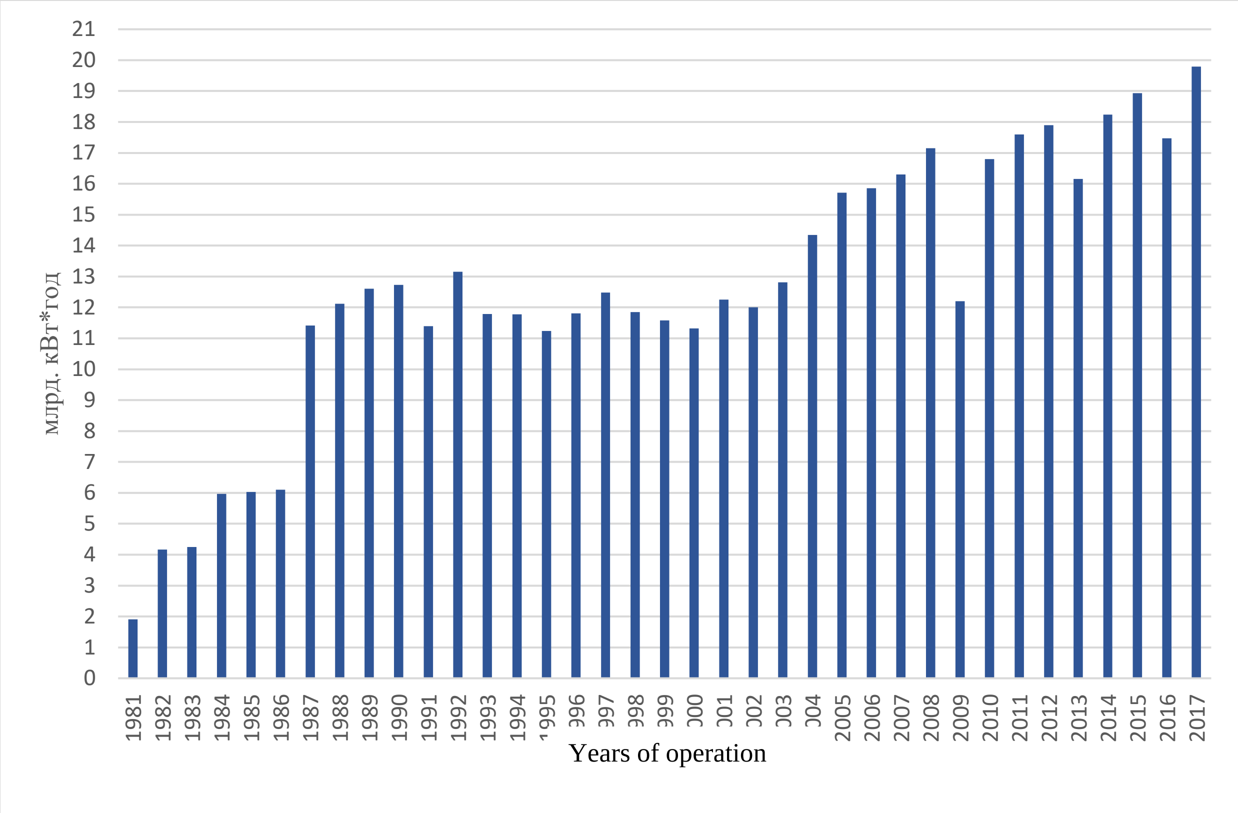


Fig.1.3. Annual electricity produced by Rivne NPP.

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.

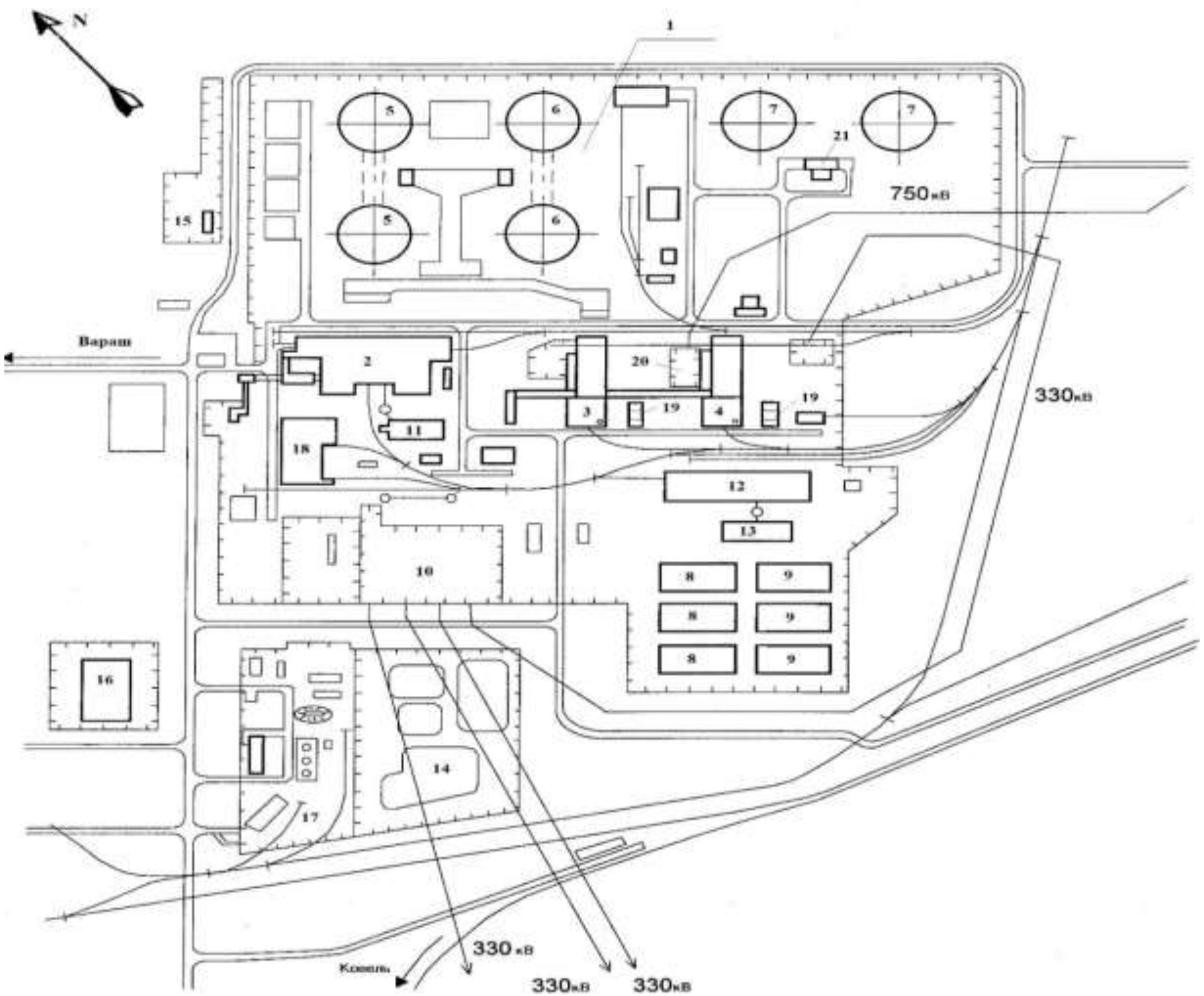


Fig.1.4. Layout of Rivne NPP site

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.

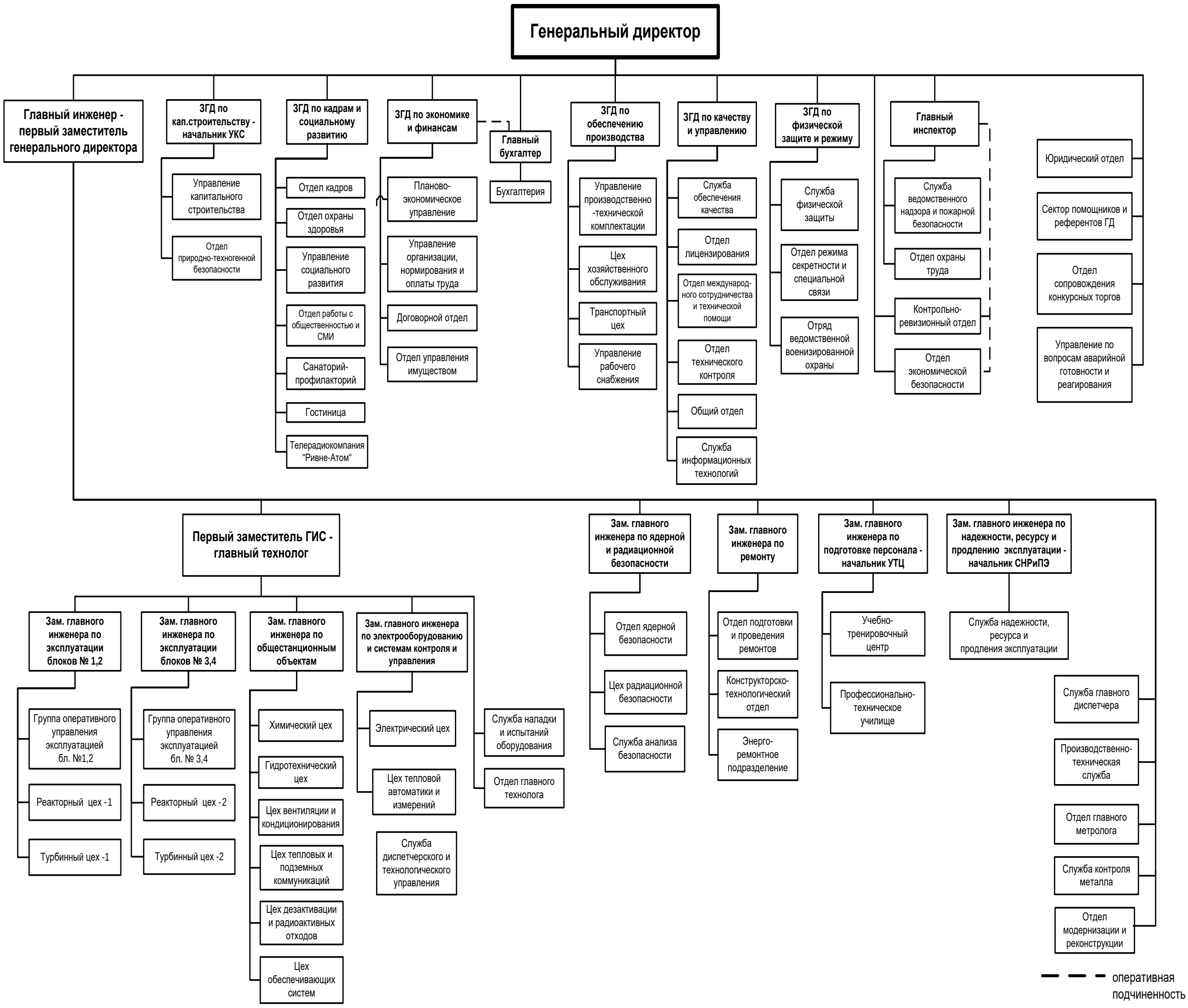


Figure.1.5. Organizational structure of Rivne NPP

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 (0.7m^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 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)

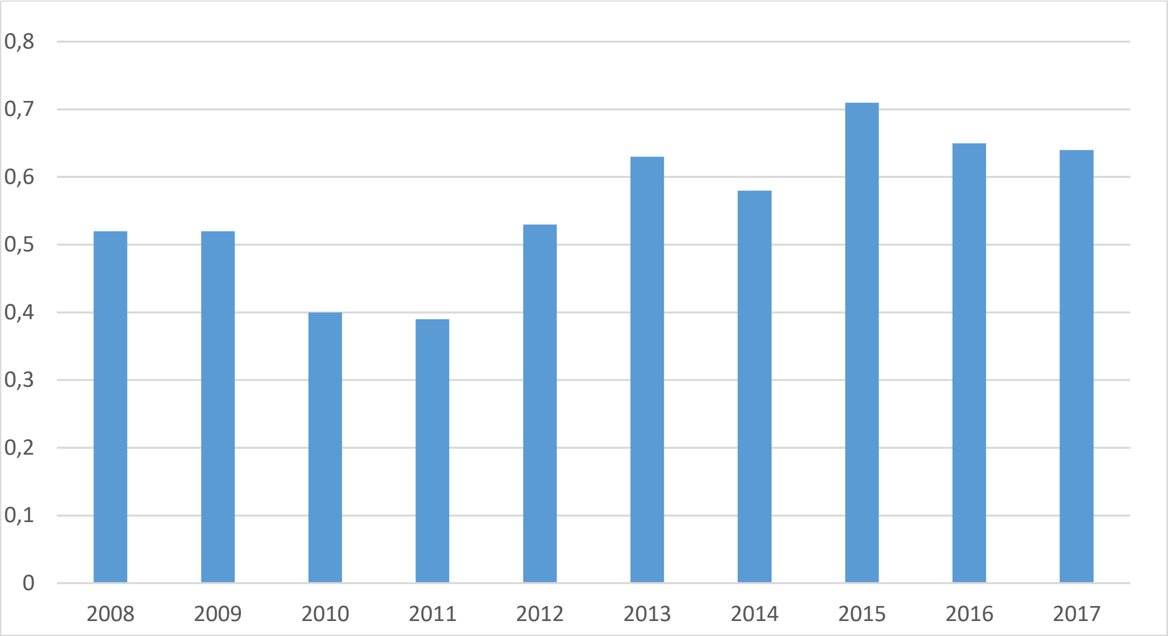


Fig. 1.6. Index of gaseous and aerosol releases of Rivne NPP as related to the allowed release.

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.

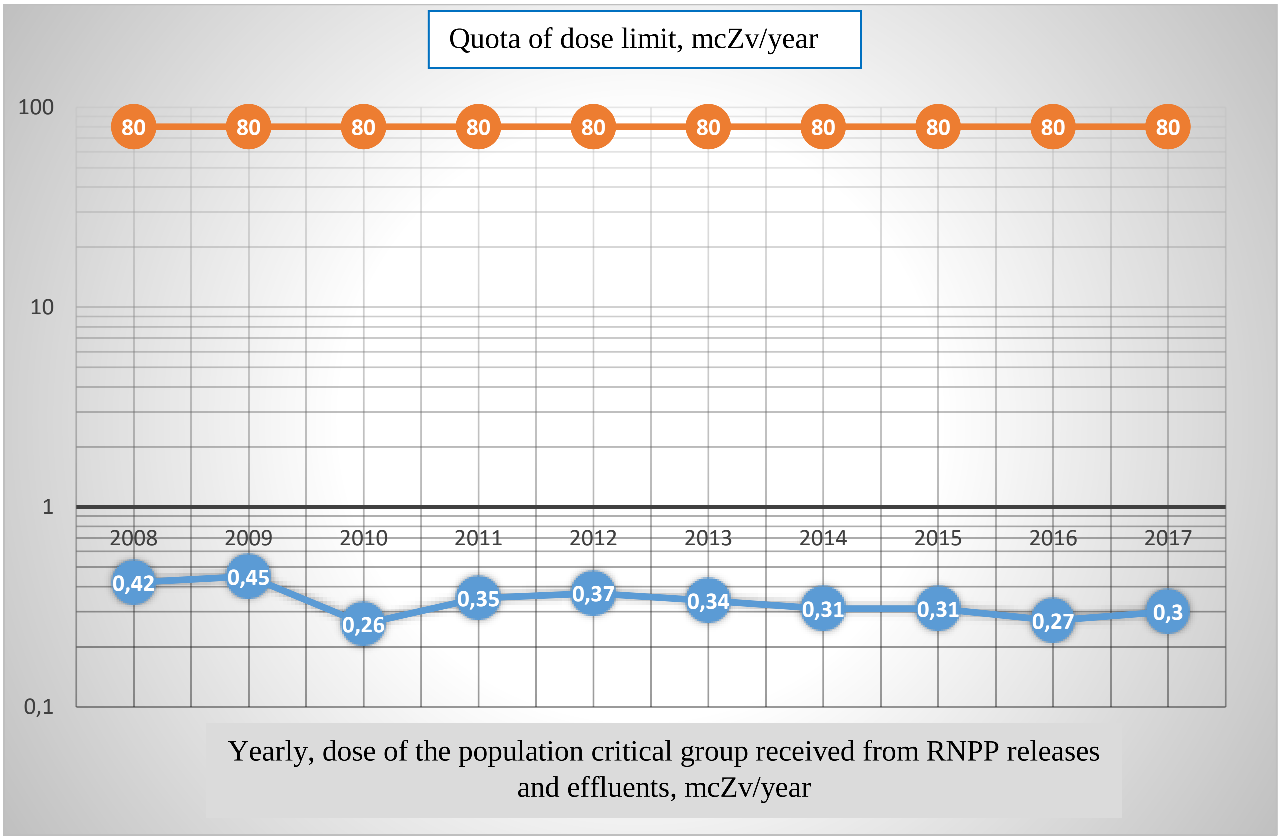


Fig. 1.7. Comparative characteristics of the quota of dose limit and dose of the population critical group from the releases and effluents of Rivne NPP, mcZv/year

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.

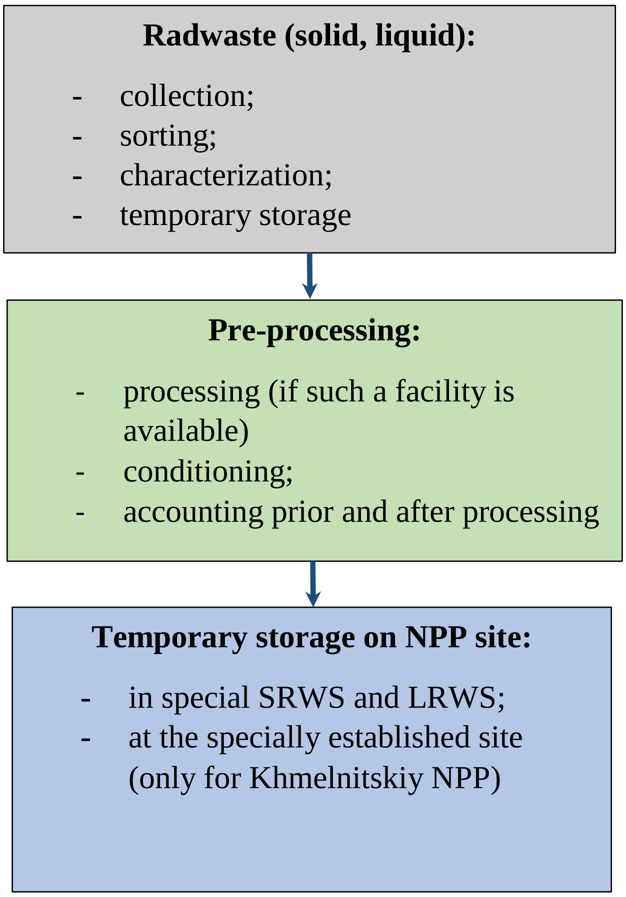


Fig. 2.1. Principal flow chart for radioactive waste management at NPP

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.

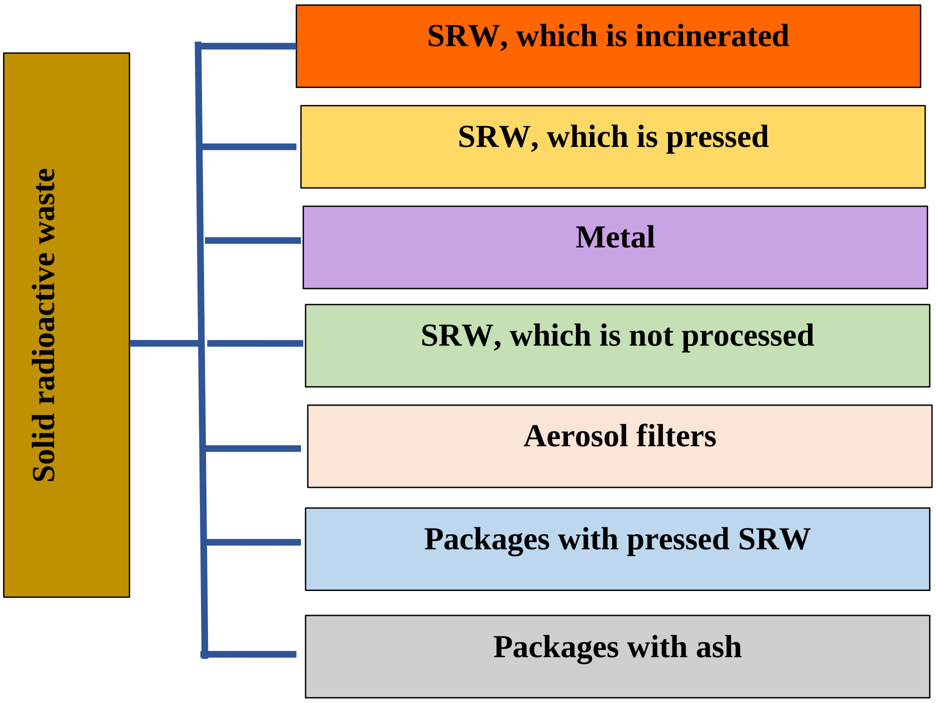


Fig.2.3. SRW distribution by types of treatment

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.

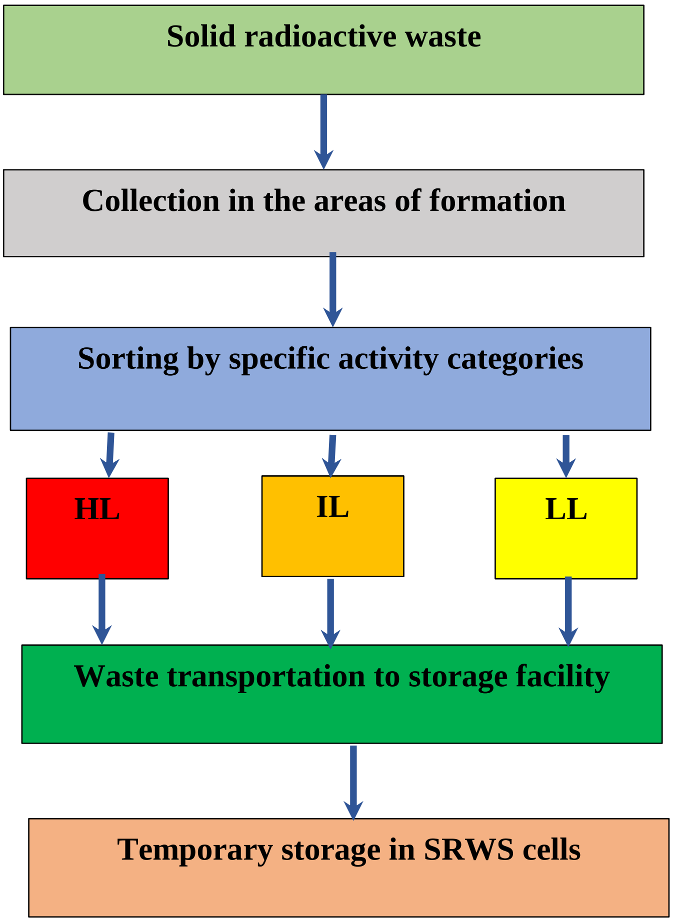


Fig.2.4. Diagram of the SRW management at Rivne NPP

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.

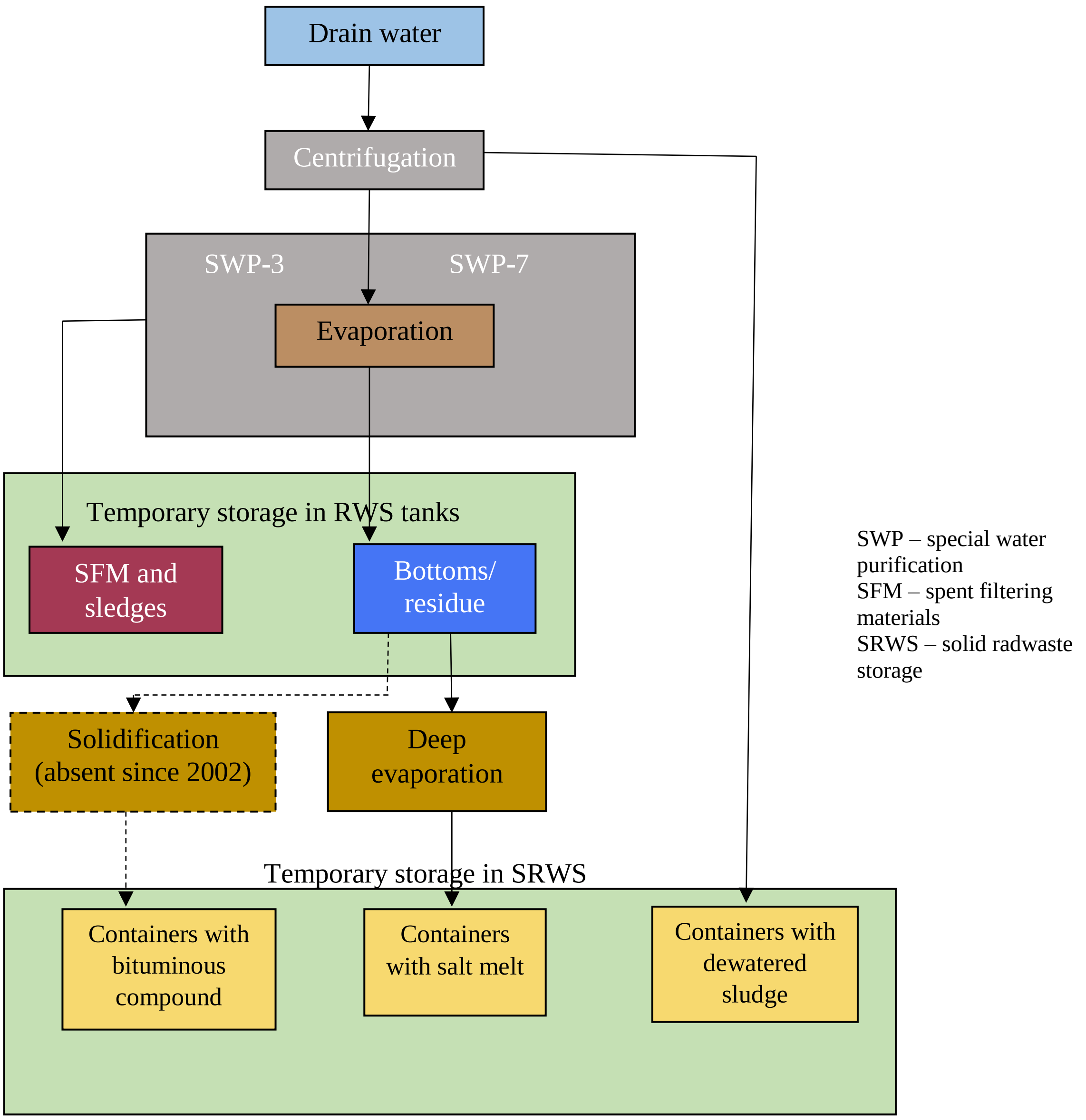


Fig.2.7. Diagram of LRW management system at Rivne NPP.

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/dm^3	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÷2 20; 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/m^3	1100-1450	990-1010	995-1005	n/i	793	2000-2100
Salt content, kg/dm^3	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.

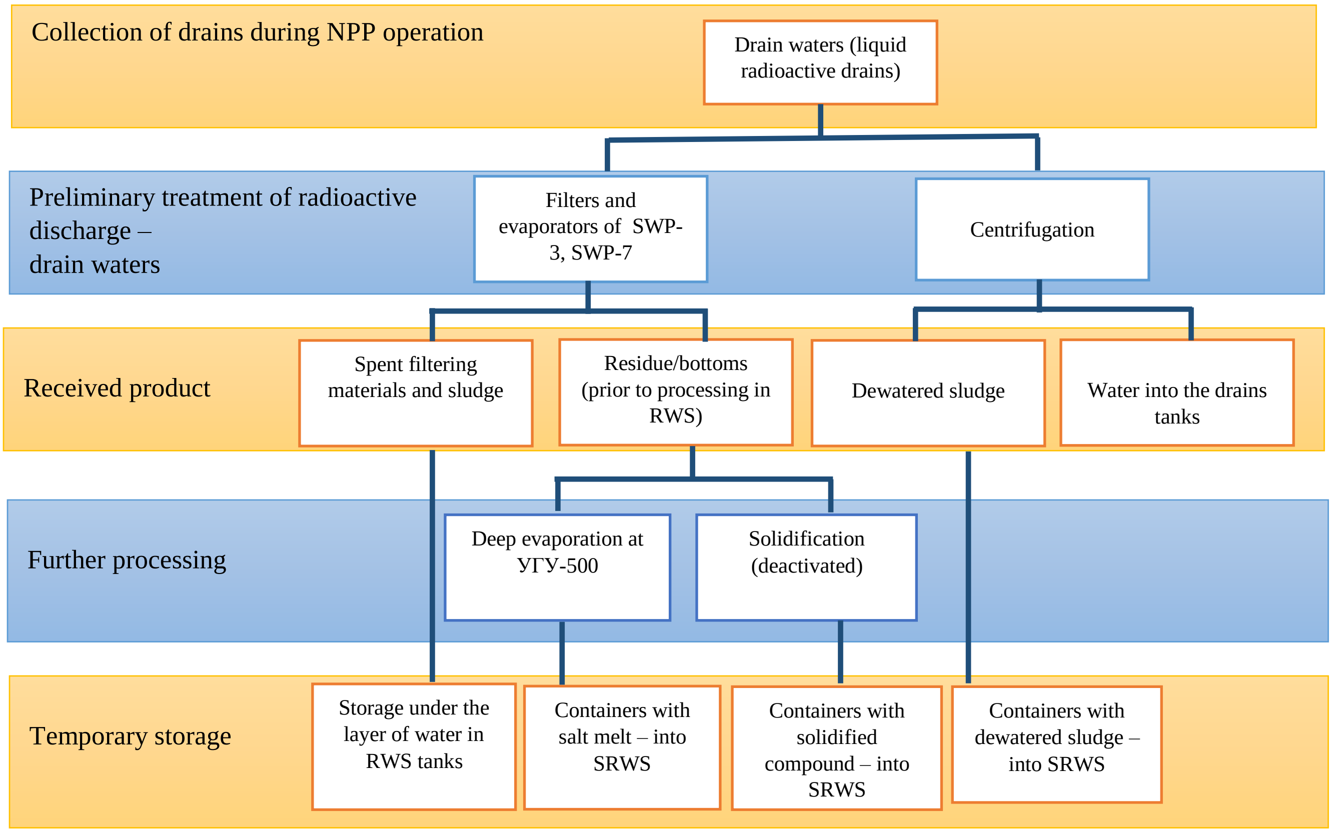


Fig.2.9. Diagram of drain waters and LRW treatment at Rivne NPP

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).

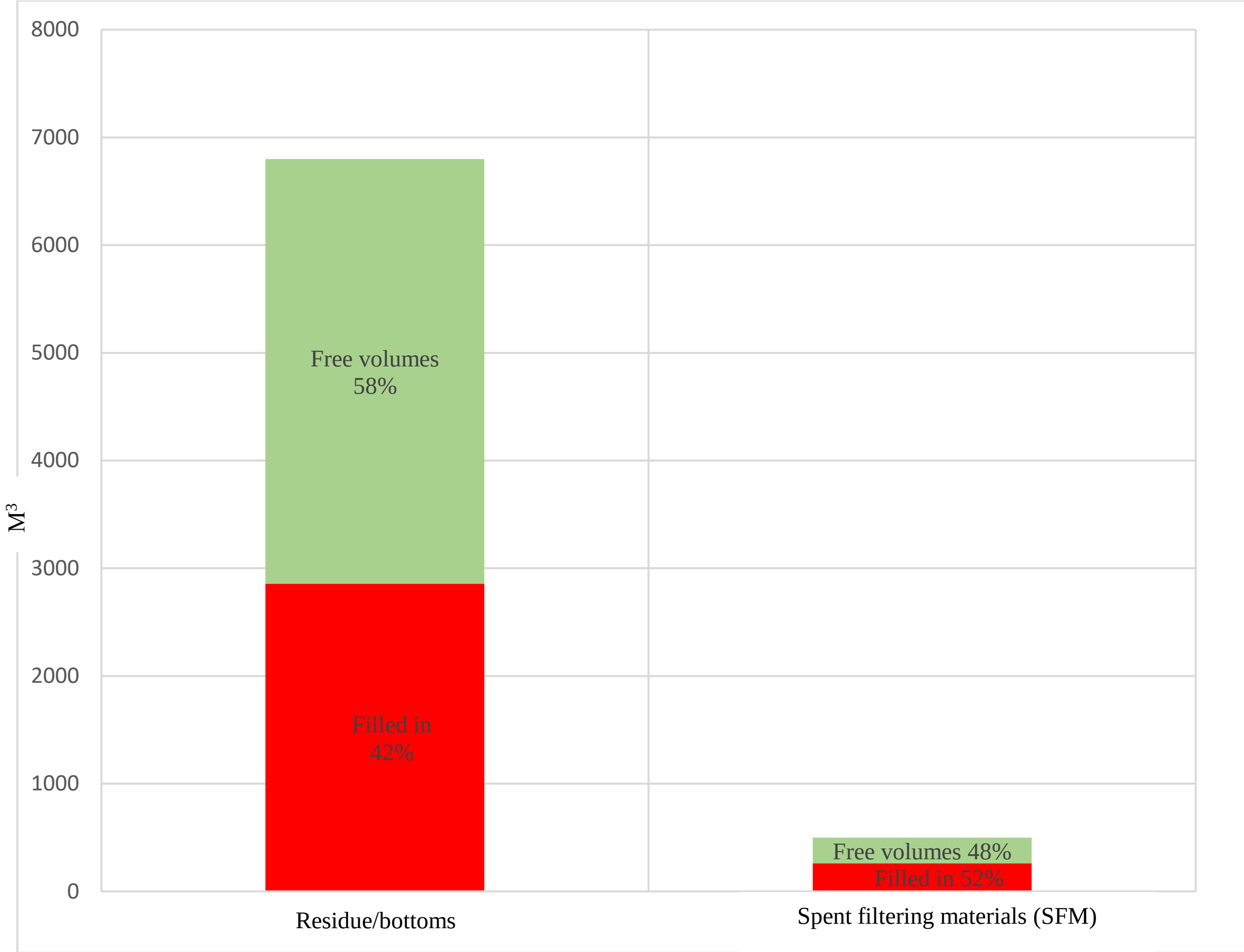


Fig. 2.10. LRW accumulation in RWS at Rivne NPP

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 IУ030163421149 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).

[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

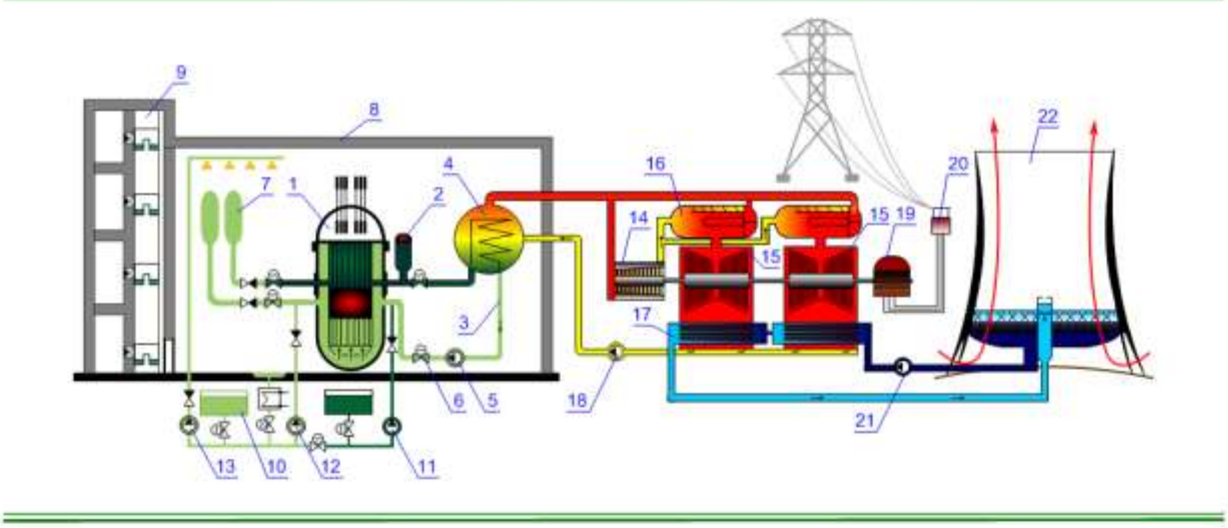
Flow chart of the power unit with VVER-440 reactor type.

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.

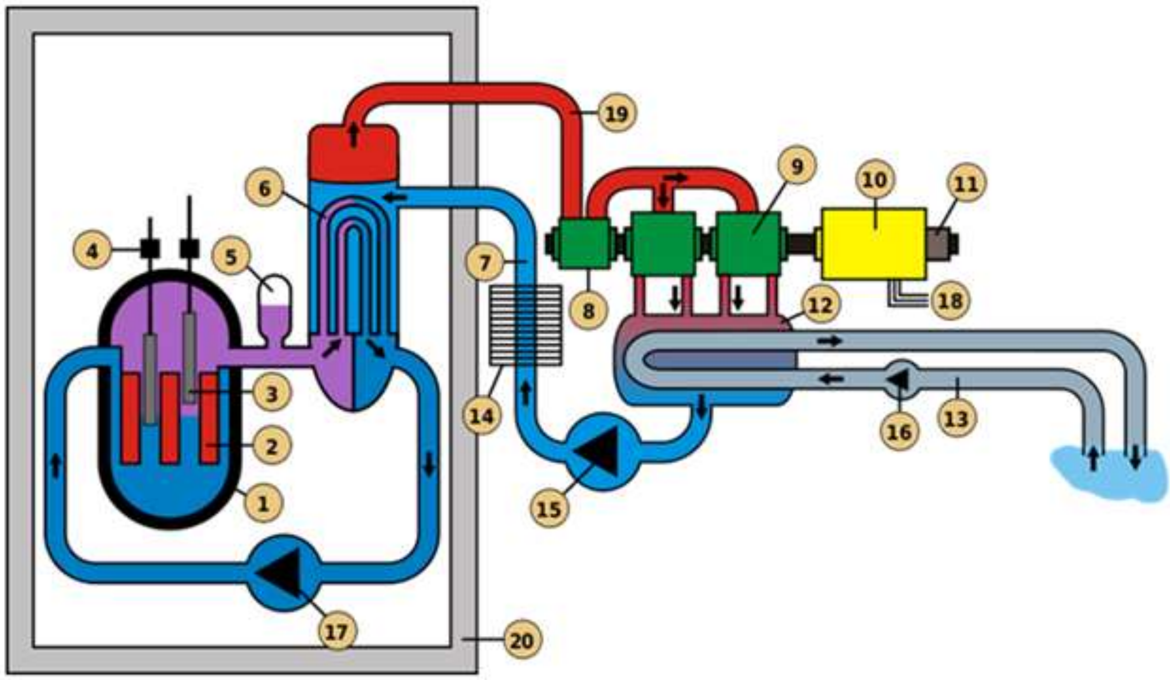


Fig. 1. Diagram of power unit with VVER reactor. 1- reactor, 2 – fuel, 3 – control rods, 4 – control rod driving mechanisms, 5 – pressurizer, 6 – steam generator heat exchange tubes, 7 – feedwater supply to steam generators, 8 – turbine high pressure cylinder, 9 - turbine low pressure cylinder, 10 – 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.

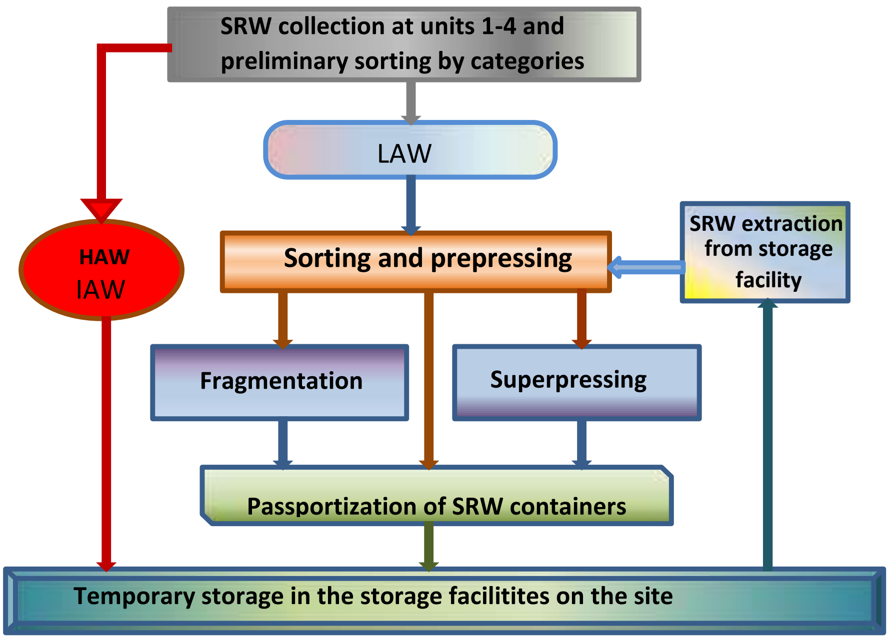


Fig. 1. Perspective diagram of SRW management system at Rivne NPP.

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.

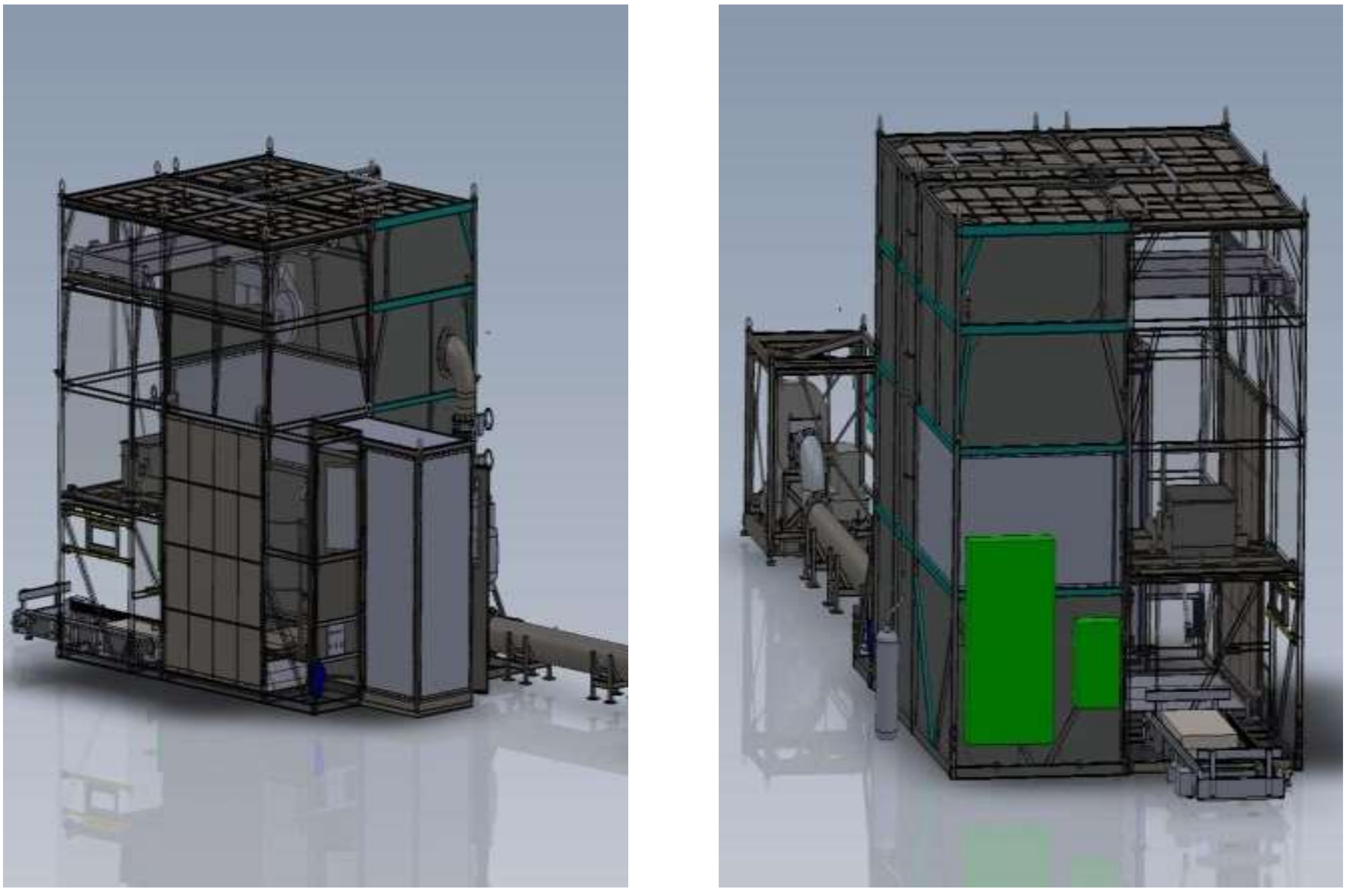


Fig.2. Solid radwaste extraction installation.

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.

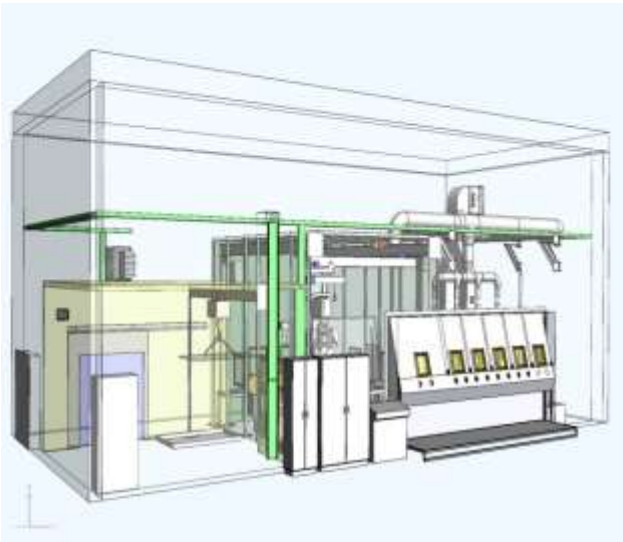


Fig. 4 Fragmentaiton and sorting intallation

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.

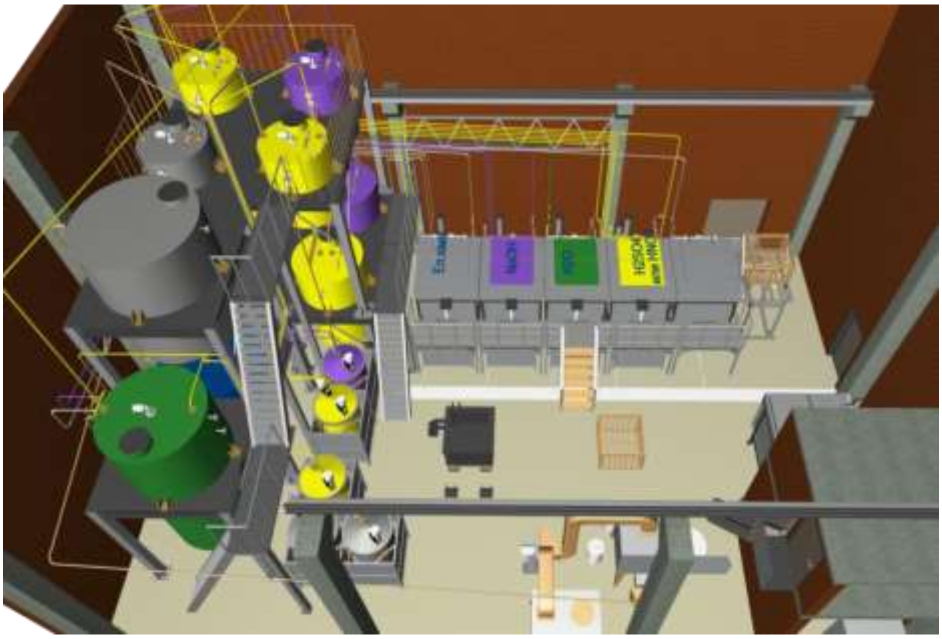


Fig. 7. Equipment layout of the metal decontamination installation (top view).

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.

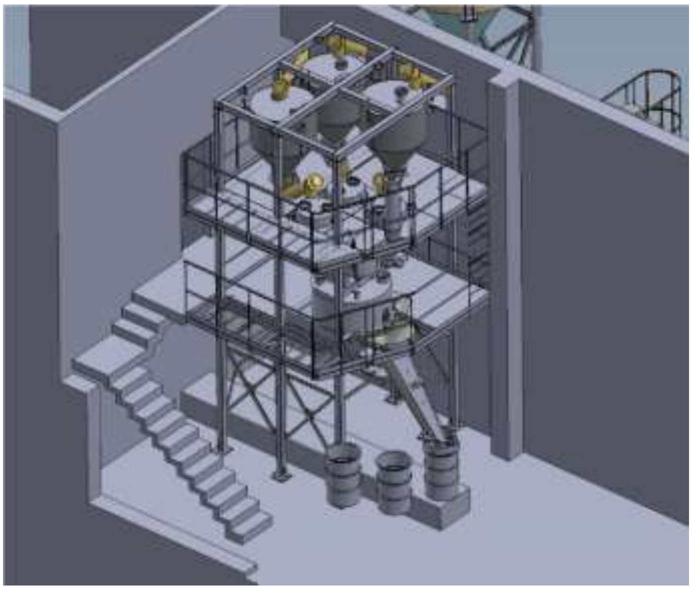


Fig. 9. Equipment layout of the cementation facility in the CRWP building

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.

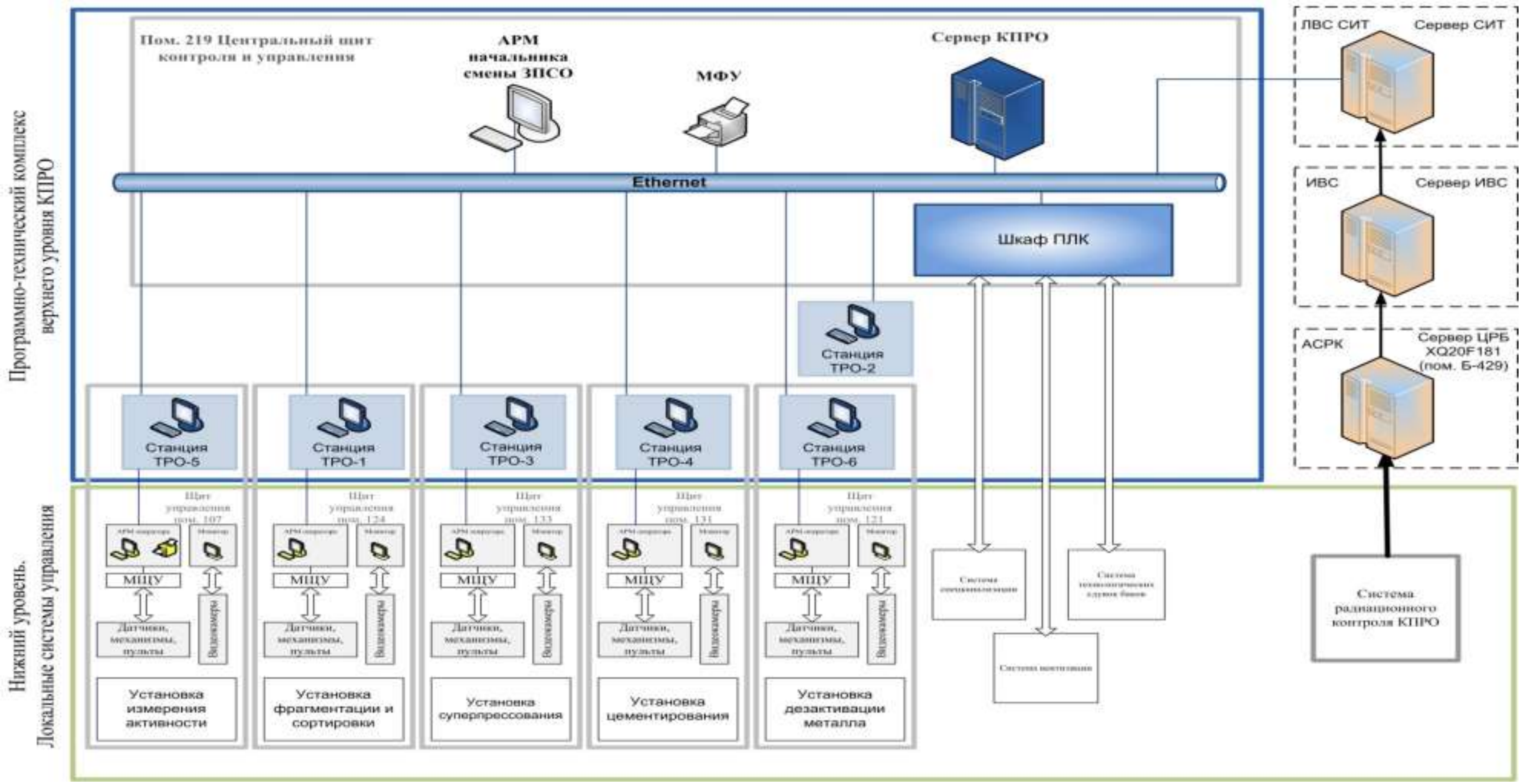


Fig.11. Flow chart of the software and hardware complex for managing CRWP activity (high-level equipment is highlighted).

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.

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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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.

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TABLE OF CONTENTS

SCOPE OF REPORT

SS "Rivne NPP" Environmental Impact Assessment

Book	Section	Title	Notes
1		Grounds for EIA. Physical and geographical features of the area of the Rivne NPP location	
2		General description of the Rivne NPP	
3		Environmental impact assessment of the Rivne NPP site	
	1	Climate and microclimate. Air environment. Chemical pollution of air environment. Attachments	
	2	Air environment. Radiation impact on air environment	
	3	Geological environment	
	4	Water environment	
	5	Soils. Flora and fauna, protected areas	
4		Impact assessment on social and manmade environment	
5		Integrated regulatory measures on environment protection	
6		Non-technical summary of SS Rivne NPP site environmental assessment	
7		Transboundary environmental impact of production activity	

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.

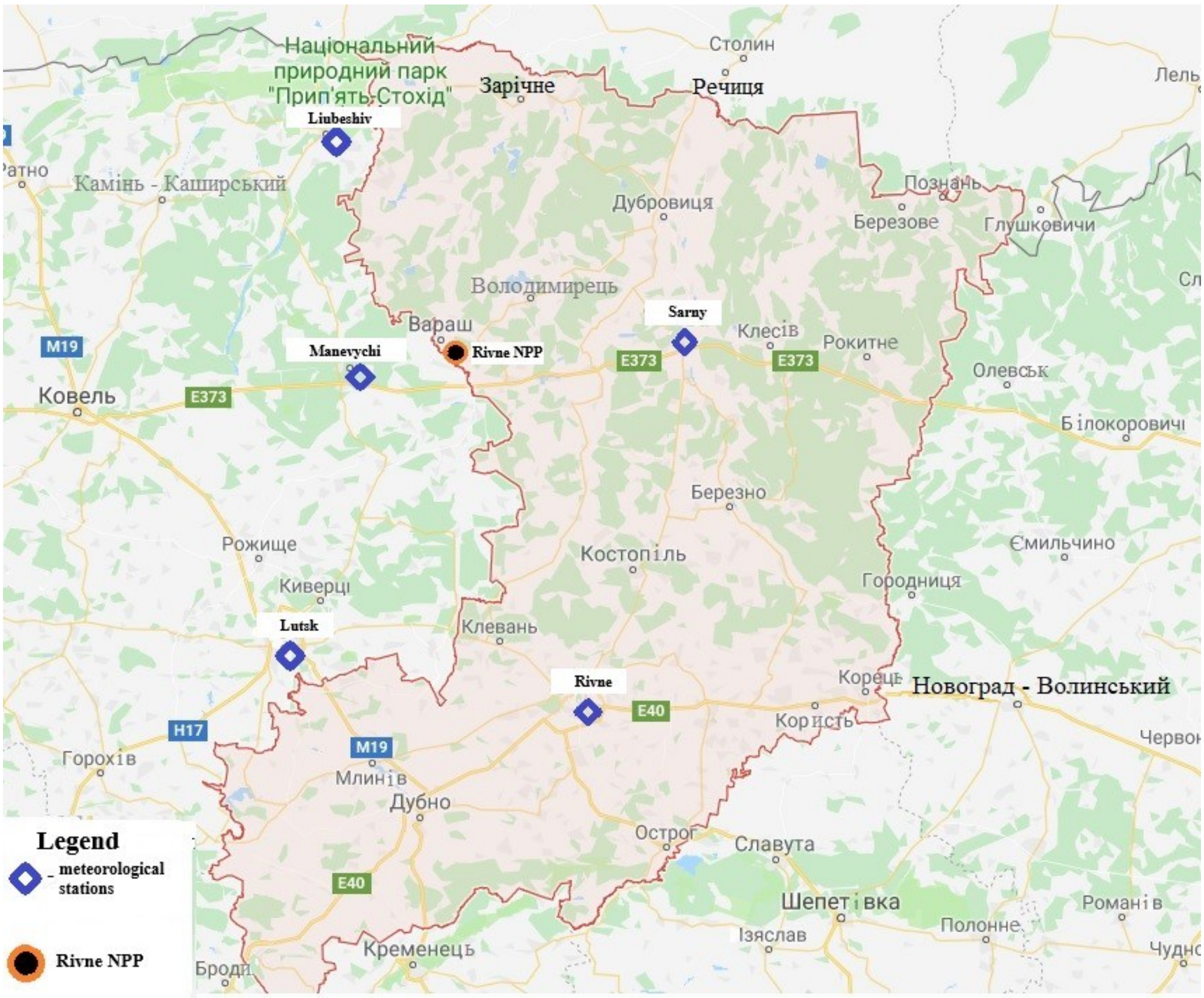


Fig. 1.1. The meteorological stations (Hydrometerological Committee of Ukraine) of the Rivne and Volyn Oblasts, the nearest to the Rivne NNP

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	Month												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
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												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
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				Hour		
		5	10	20	30	1	12	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

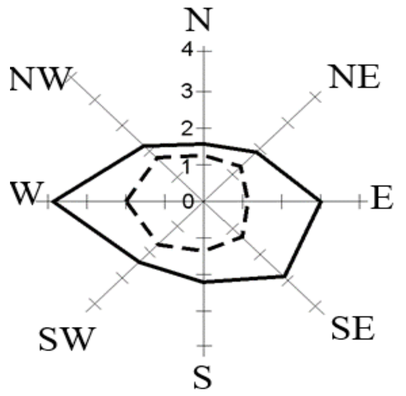
Year	8,3	5,6	12,3	14,0	11,4	12,1	24,6	11,7	8,9
b) Wind speed by direction indicator, m/s									
January	3,7	3,1	3,9	3,9	4,2	5,0	5,8	5,6	0,0
February	4,4	3,7	4,1	4,4	4,3	4,7	5,3	4,9	0,0
March	3,9	3,8	4,2	4,2	4,2	4,6	5,5	5,3	0,0
April	4,5	4,2	4,0	4,2	4,3	4,7	5,1	5,1	0,0
May	4,3	3,8	3,7	3,8	3,8	3,8	4,2	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.

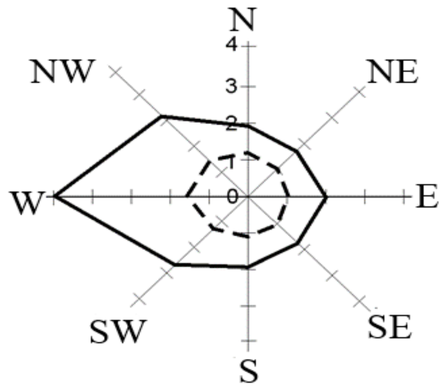
Month, season, year	Direction (rhumb)								Calmness
	N	NE	E	SE	S	SW	W	NW	
a) Frequency of wind direction, (%)									
January	3,1	3,9	11,9	11,7	13,7	17,7	27,4	10,6	3,3
February	4,7	3,9	14,6	14,1	14,9	13,6	22,9	11,3	3,1
March	5,5	6,0	18,5	18,8	14,8	11,0	16,7	8,7	3,2
April	7,3	5,9	19,5	16,8	13,3	8,1	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

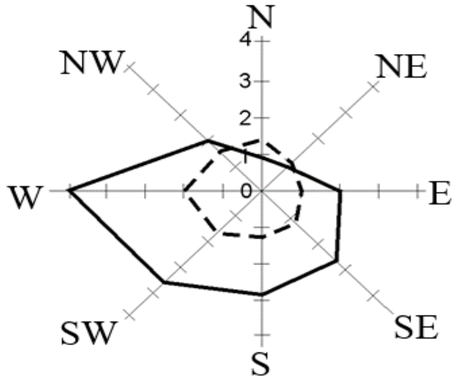
Spring (calmness 17,8 %)



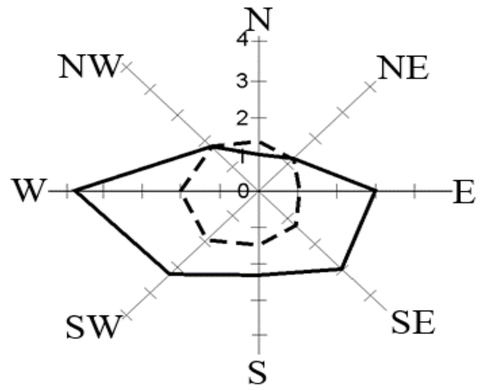
Summer (calmness 26,5 %)



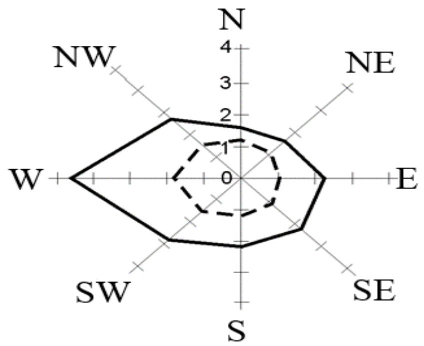
Autumn (calmness 18,5 %)



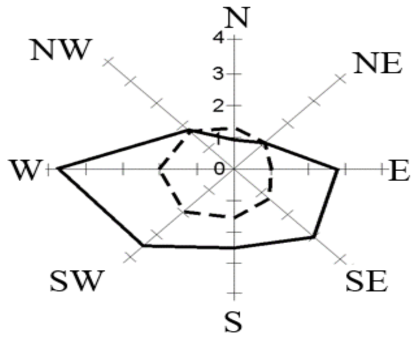
Winter (calmness 14,7 %)



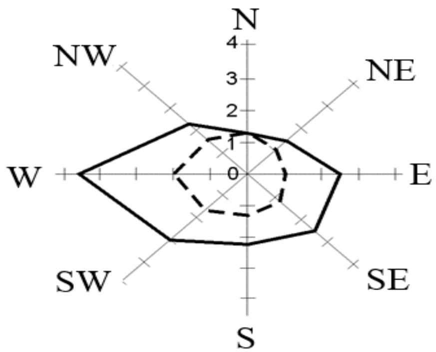
Warm period (calmness 21,8 %)



Cold period (calmness 14,6 %)



Year (calmness 19,4 %)



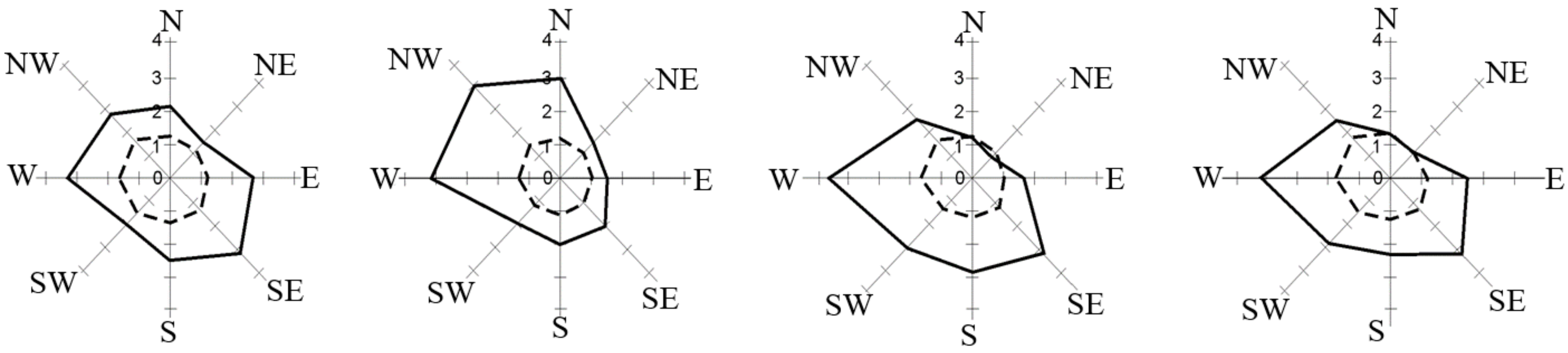
Conventional symbols

frequency, %
(1 graduation line = 5 %)

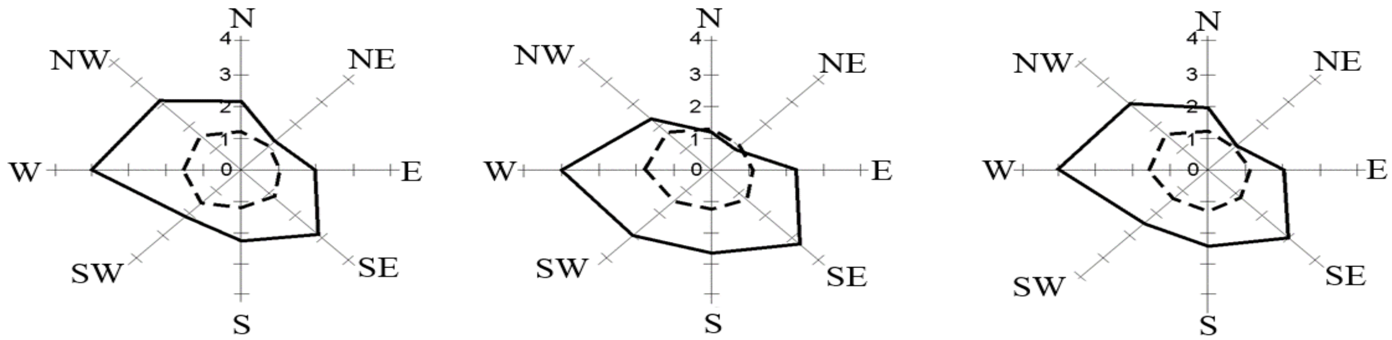
wind speed, m/s
(1 gradation line = 2 m/s)

Fig. 1.2. Wind pattern (wind rose) of Lyubeshiv meteorological station (per season, per period and per year)

Spring (calmness 11,8 %) | Summer (calmness 15,8 %) | Autumn (calmness 10,9 %) | Winter (calmness 7,2 %)



Warm period (calmness 13,5 %) | Cold period (calmness 7,3 %) | Year (calmness 11,4 %)



Conventional symbols

frequency, %
(1 graduation line = 5 %)

wind speed, m/s
(1 gradation line = 2 m/s)

Fig.1.3. Wind pattern (wind rose) of Manevichi meteorological station (per season, per period and per year)

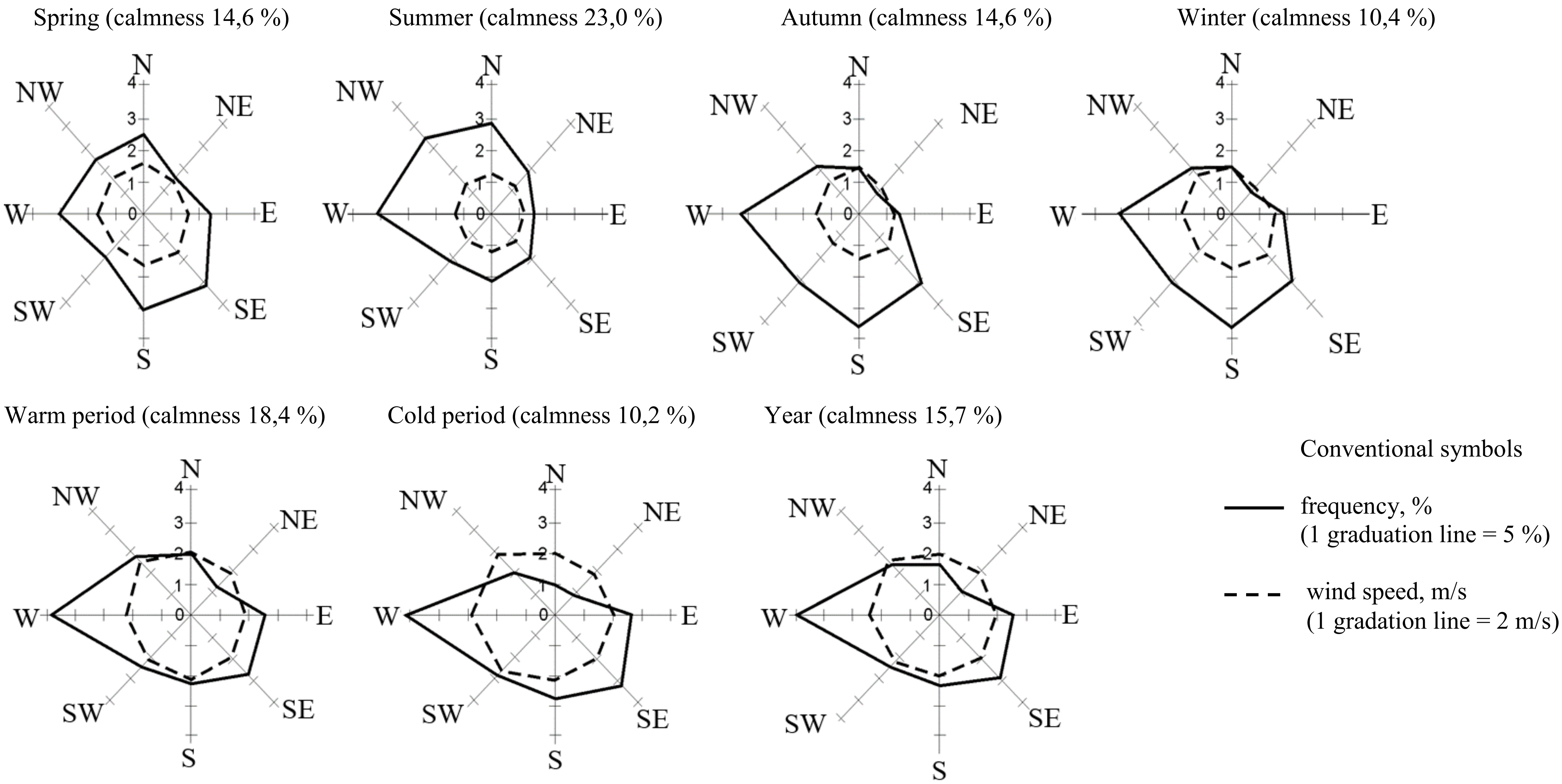


Fig.1.4. Wind pattern (wind rose) of Sarny meteorological station (per season, per period and per year)

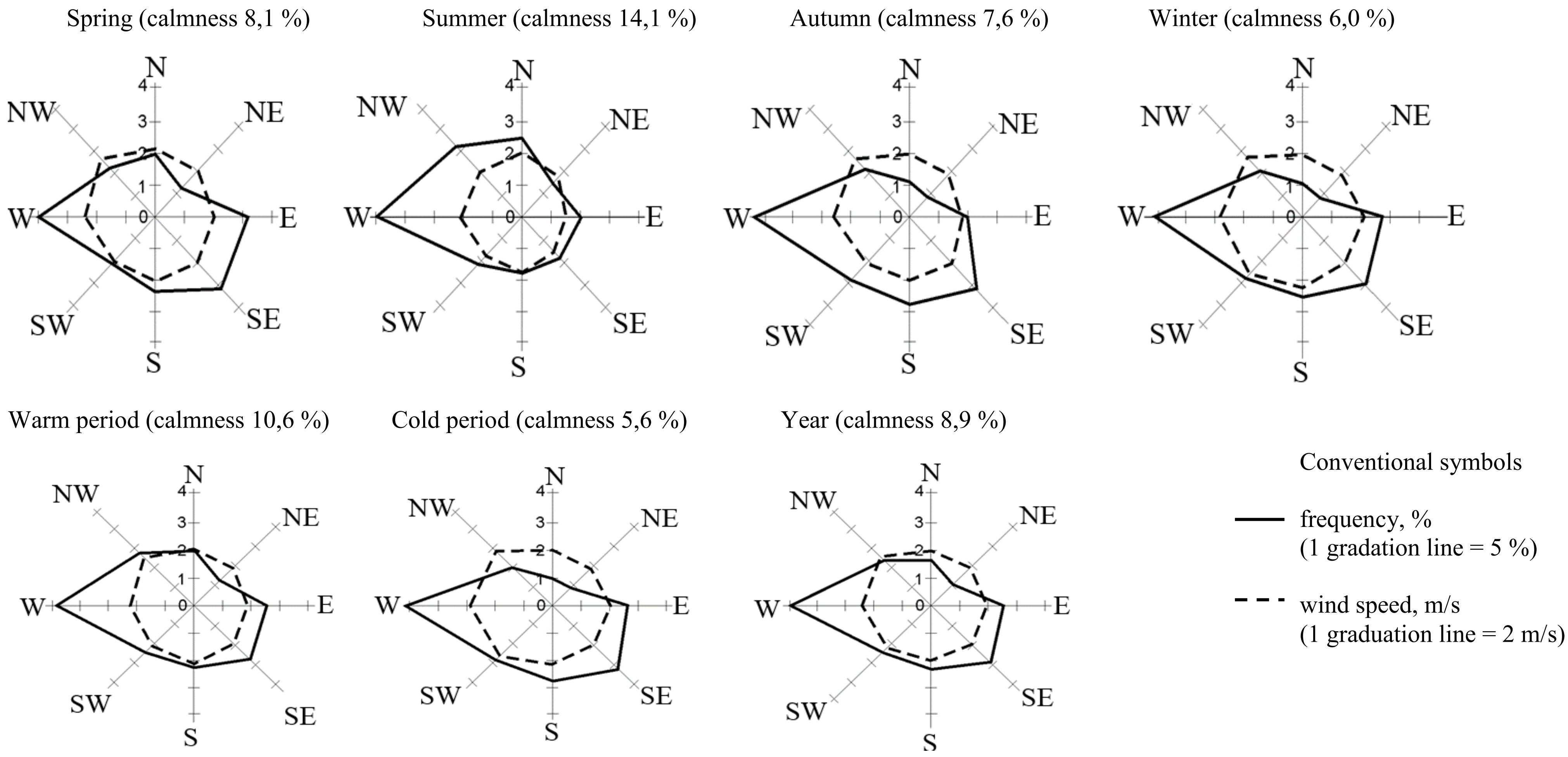


Fig.1.5 Wind pattern (wind rose) of Rivne meteorological station (per season, per period and per year)

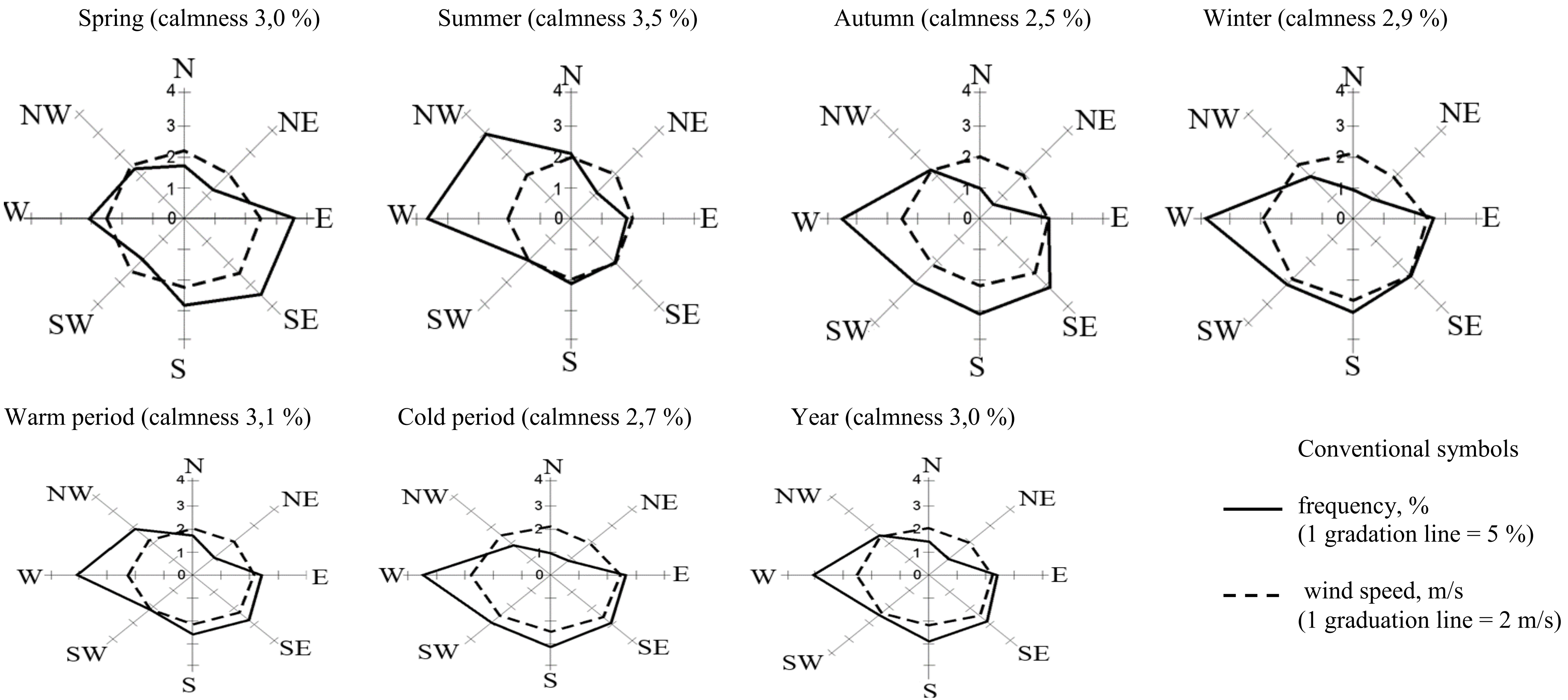


Fig.1.6. Wind pattern (wind rose) of Lutsk meteorological station (per season, per period and per year)

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	-

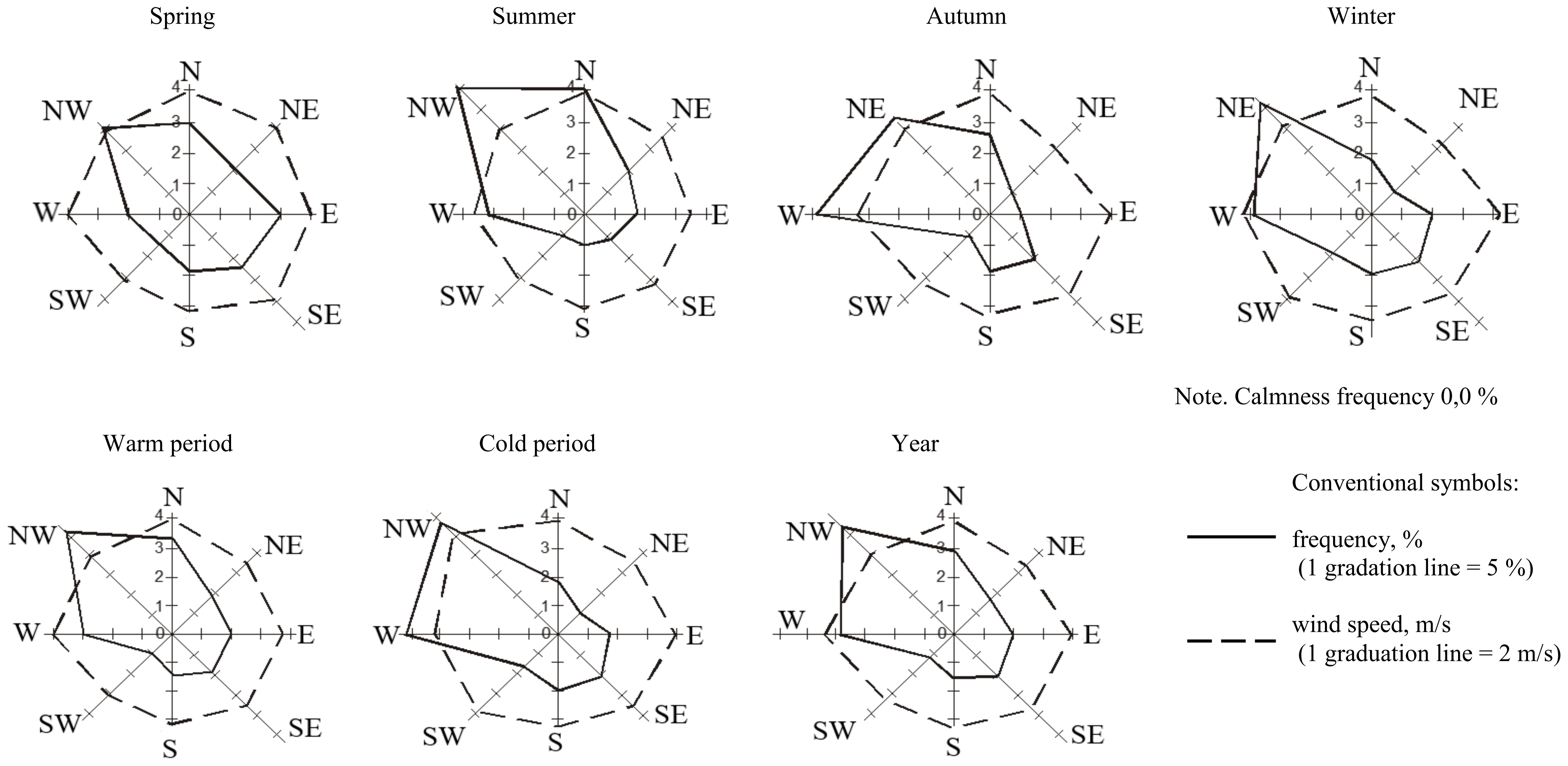


Fig. 2.1. Wind pattern (wind rose) at an altitude of 100 m. The Shepetivka aerological station.

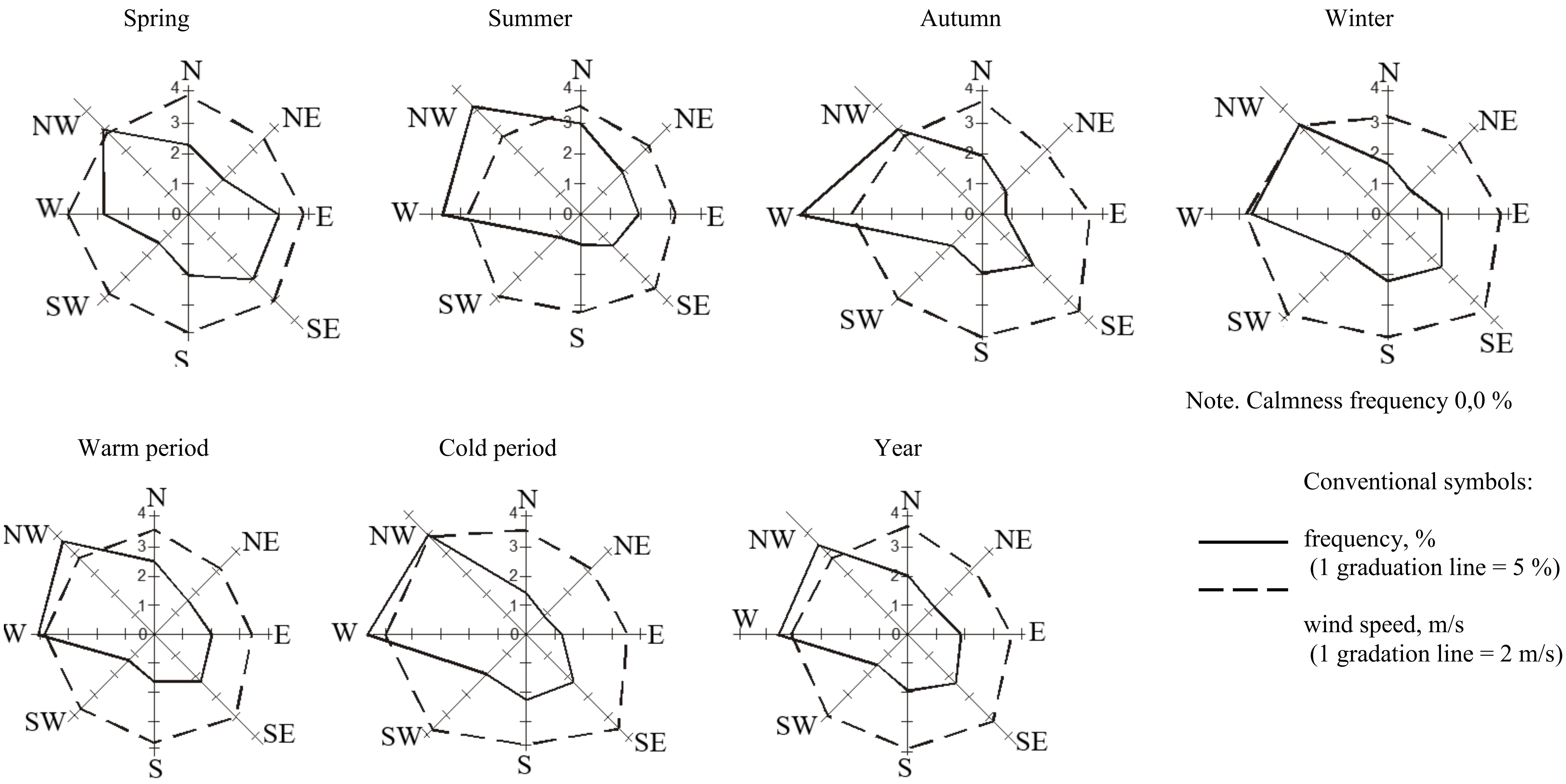


Fig.2.2. Wind pattern (wind rose) at an altitude of 200 m. The Shepetivka aerological station

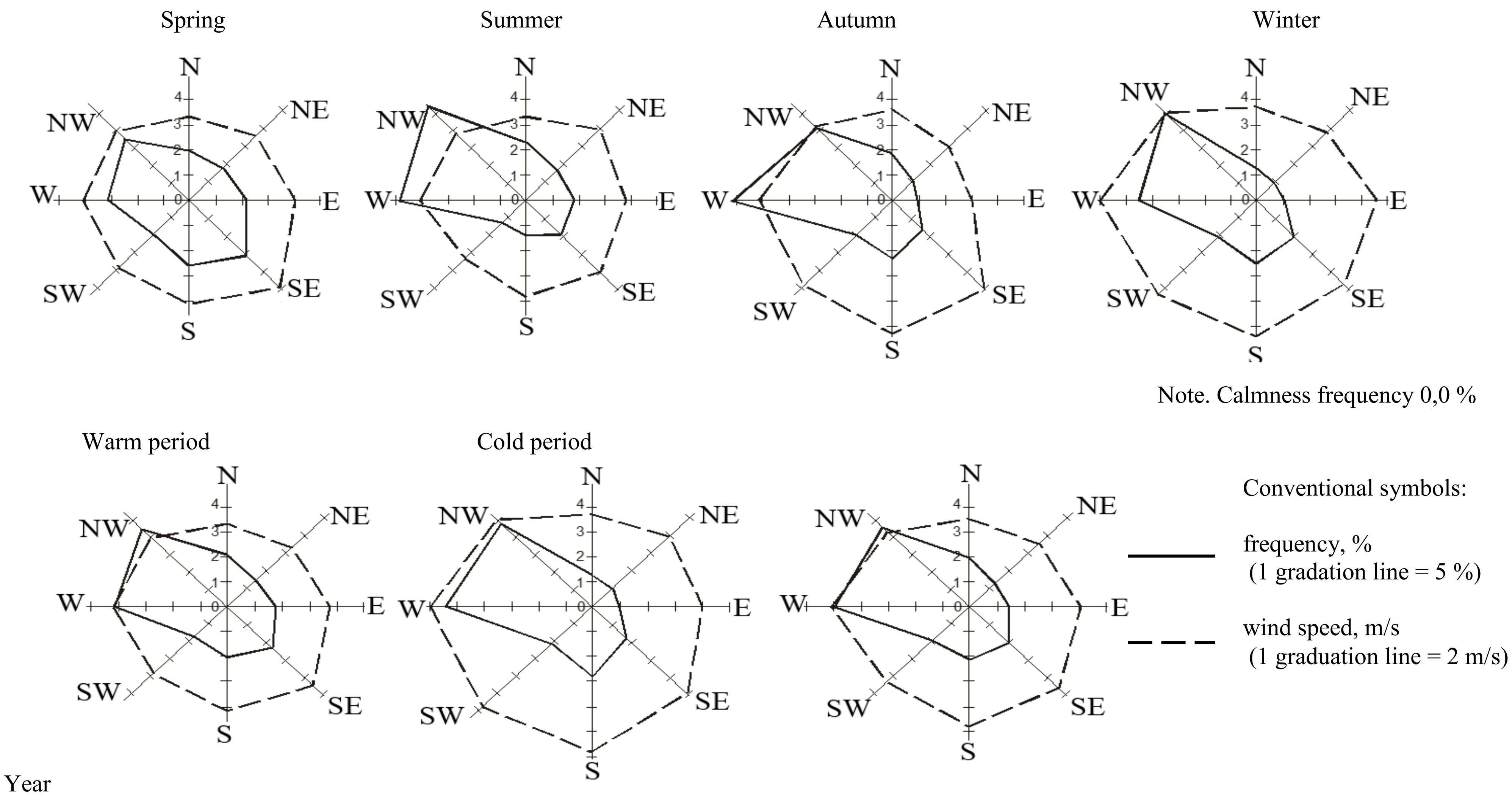


Fig. 2.3. Wind pattern (wind rose) at an altitude of 500 m. The Shepetivka aerological station.

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	$0{,}9\times10^9$ Kcal/per year
4. Liquid spray area		10000 m^2
5. Liquid spray rate	nominal	9,5 $m^3/m^2 \times$ 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 ^0C 5 – 33 ^0C
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.

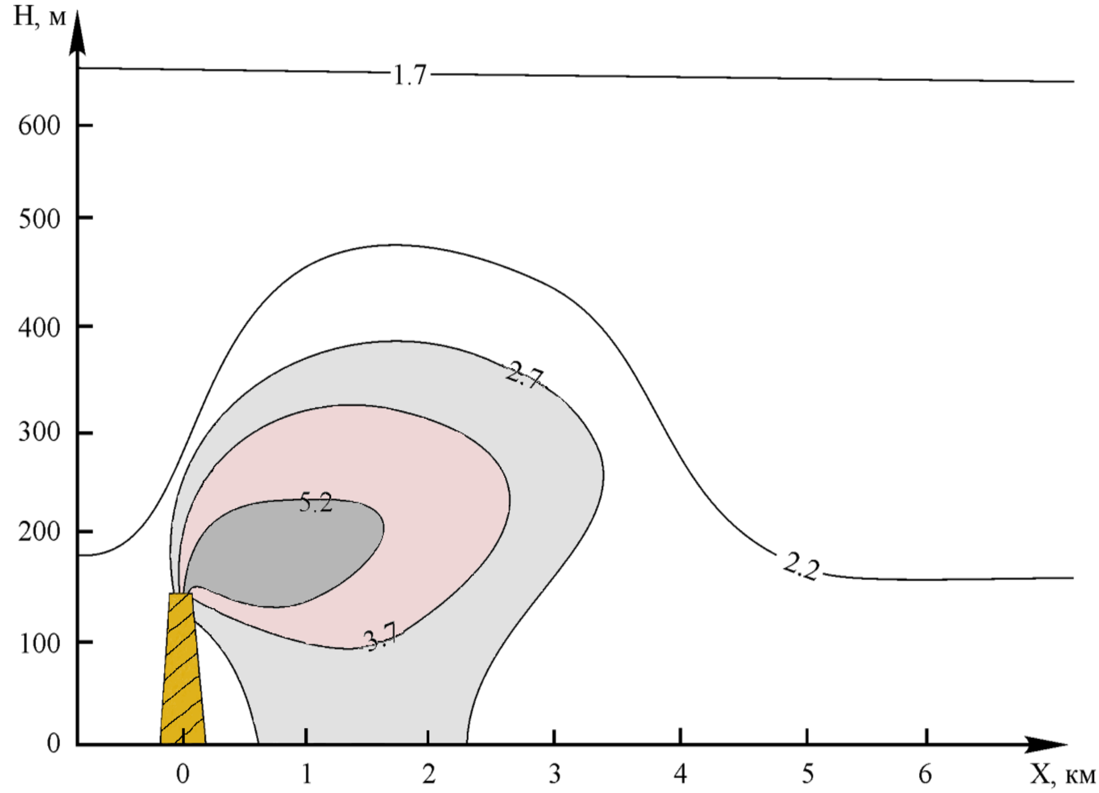


Fig. 3.1. Vertical cross-sections of specific humidity near the cooling towers, g/kg. Winter

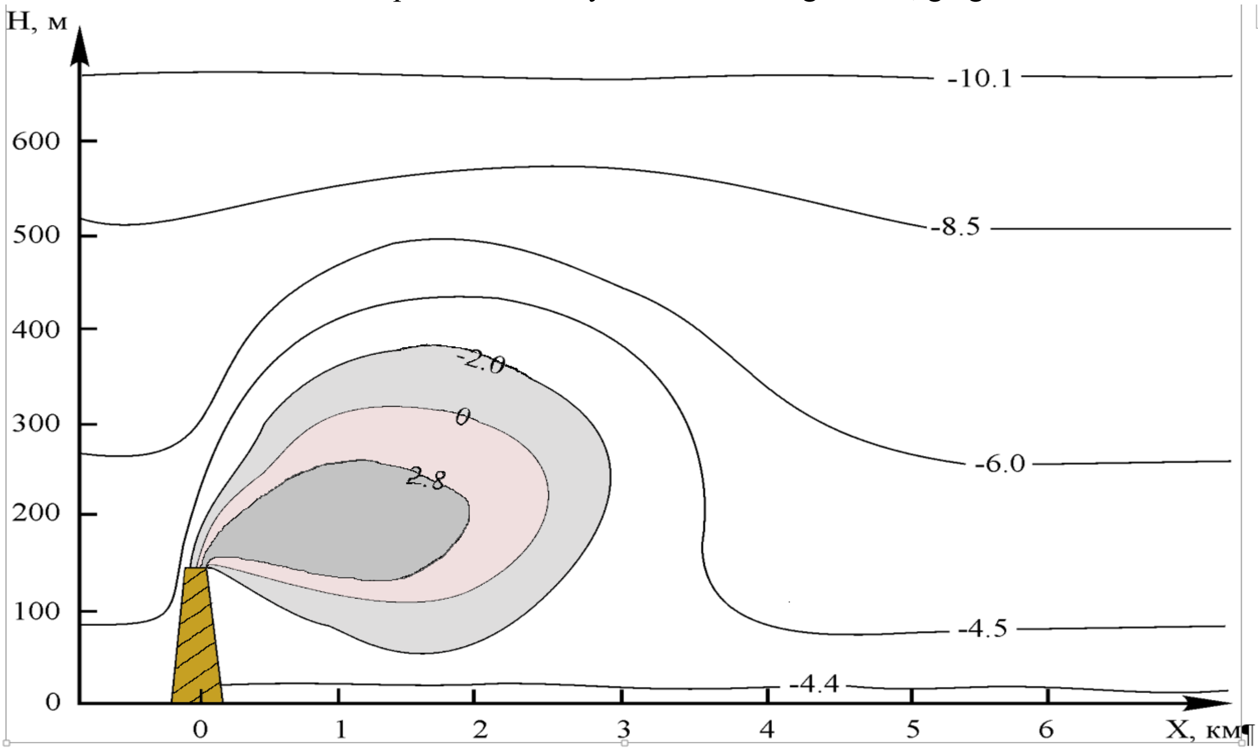


Fig. 3.2. Vertical cross-sections of air temperature near the cooling towers, ^{0}C. Winter

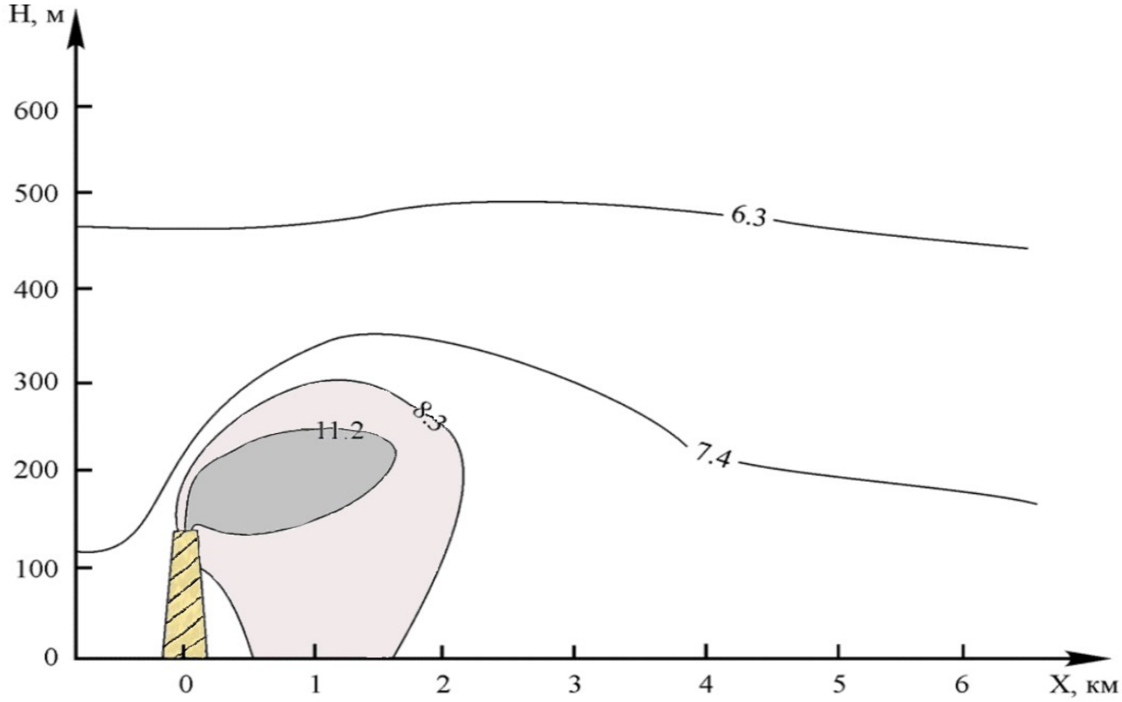


Fig. 3.3. Vertical cross-sections of specific humidity near the cooling towers, g/kg. Summer

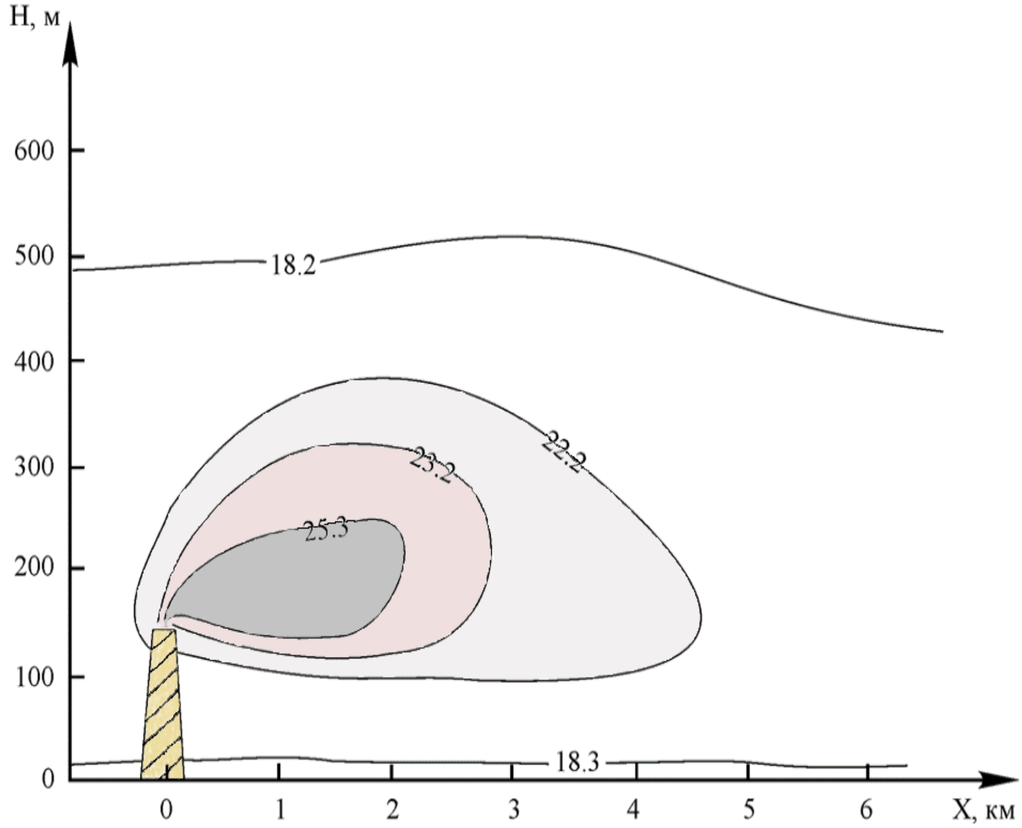


Fig.3.4. Vertical cross-sections of air temperature near the cooling towers, ^{0}C. Summer

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.

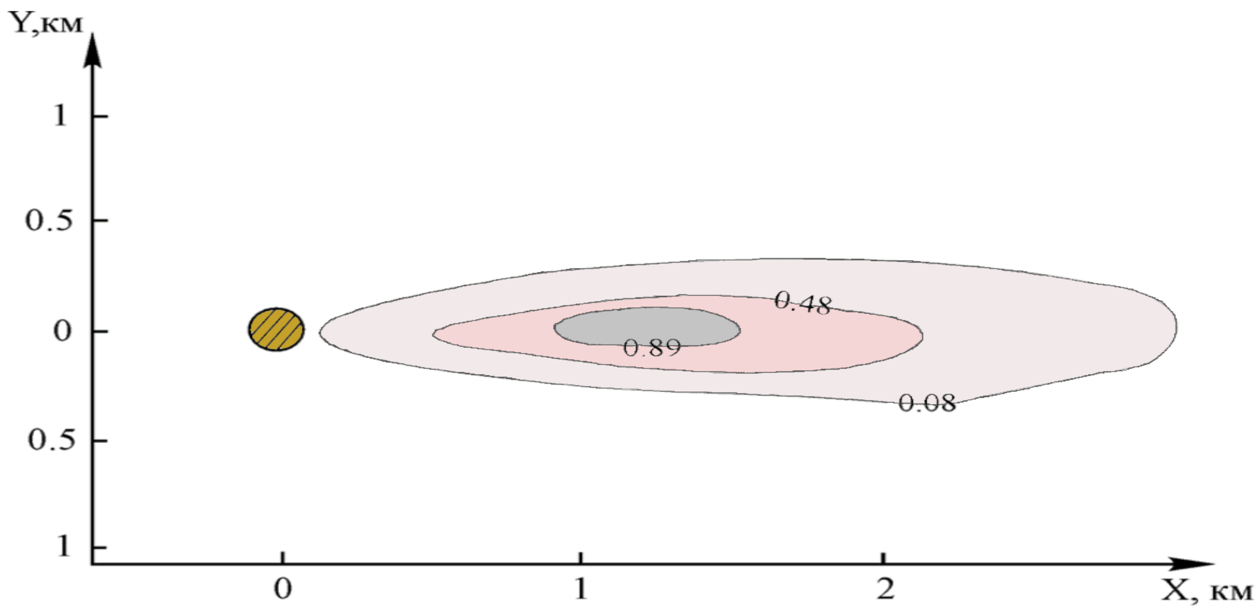


Fig. 3.5. Horizontal cross-sections of perturbation temperature fields, ΔT ^{0}C, at the land surface under effect of emissions from cooling tower. Winter.

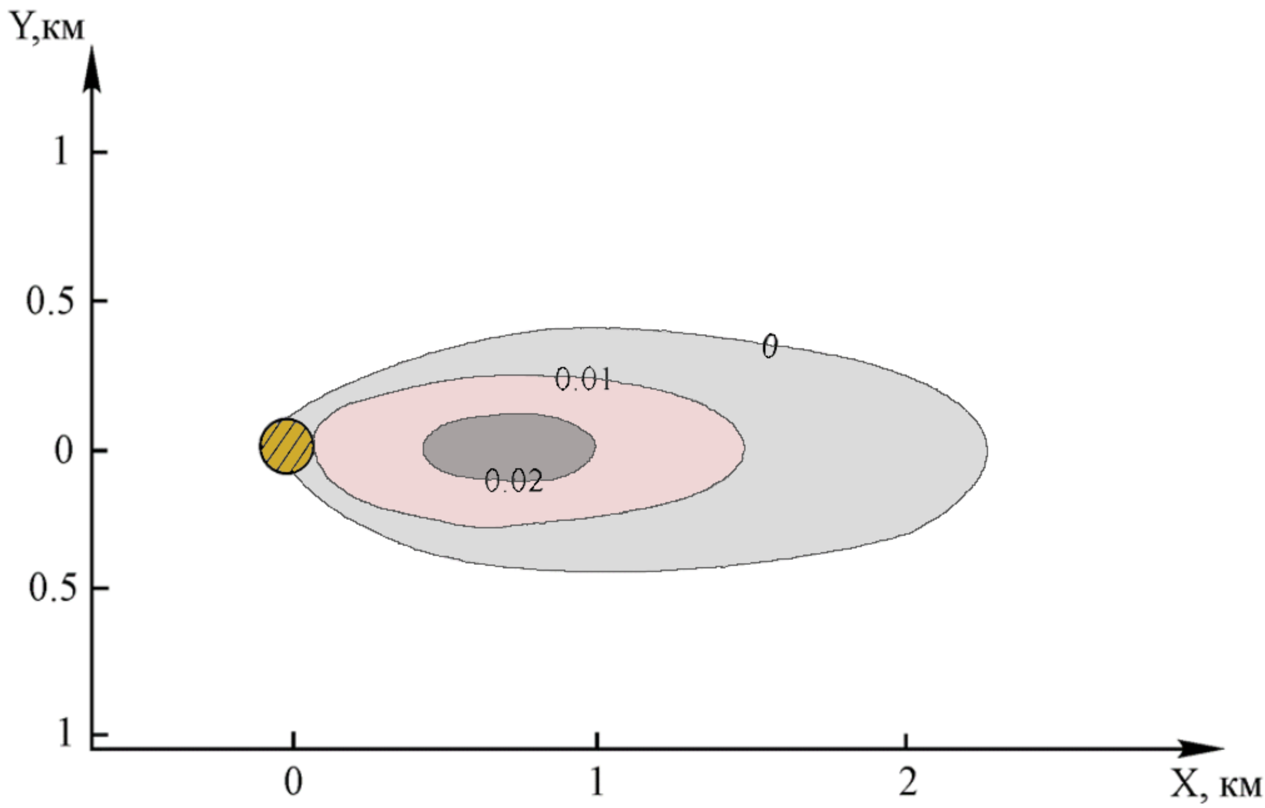


Fig. 3.6. Horizontal cross-sections of specific air humidity fields, ΔR g/kg, at the land surface under effect of emissions from cooling tower. Winter.

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].

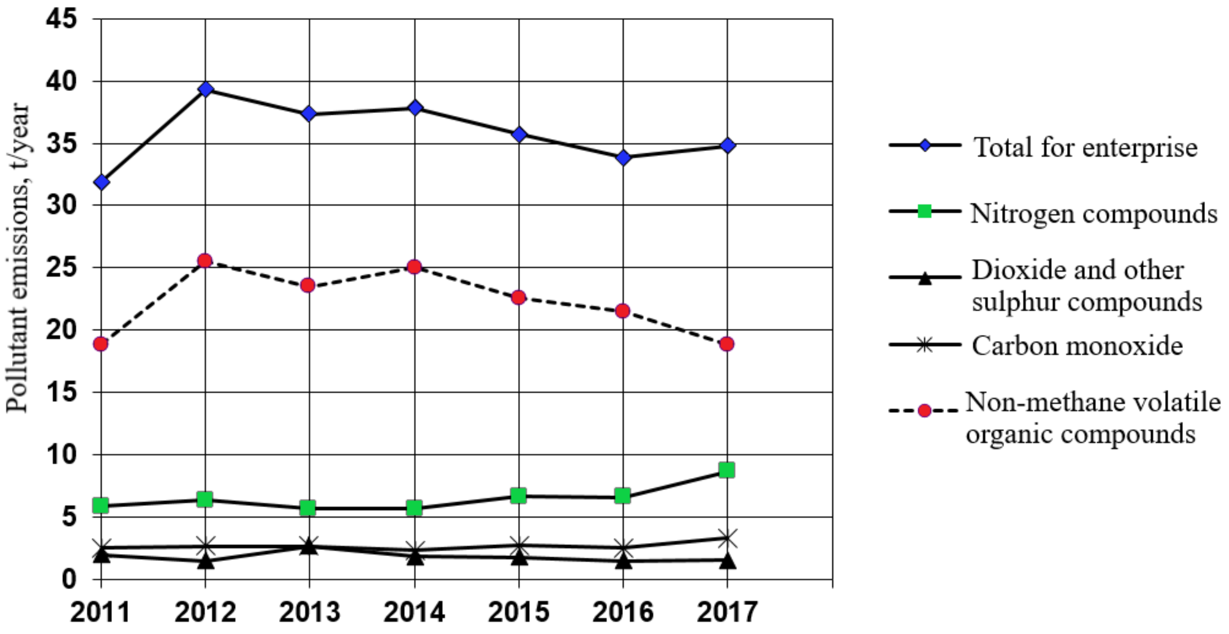


Fig. 3.7. Dynamics pattern of air pollution emissions from stationary sources

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

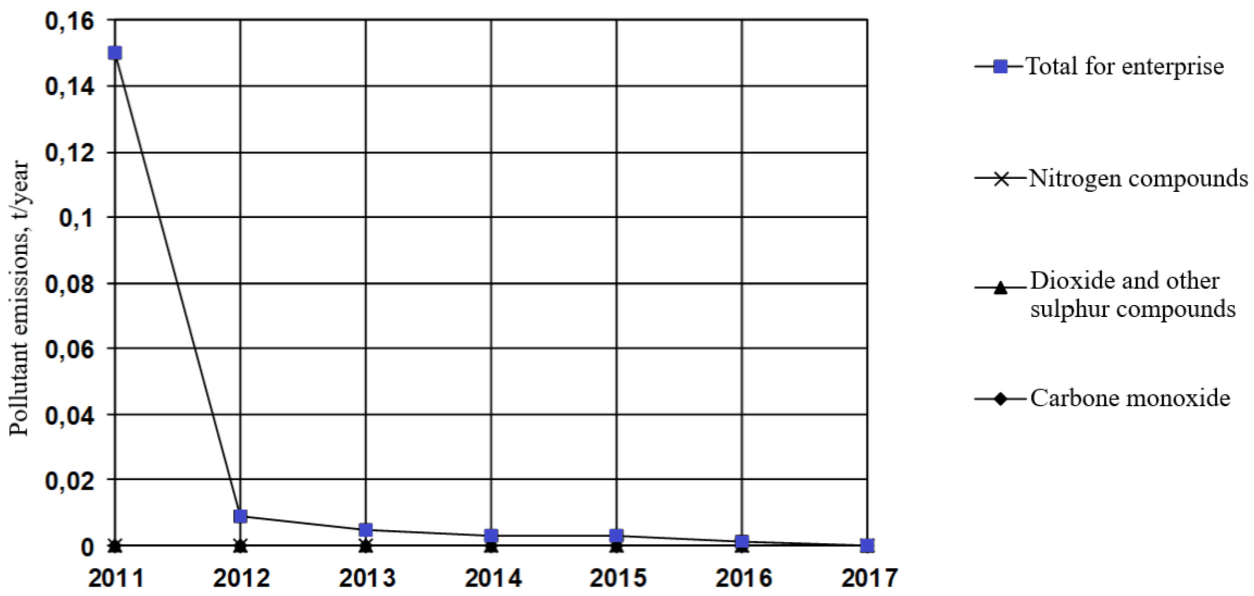


Fig.3.8. Dynamics pattern of air pollution emissions from stationery source of RHC “Bile ozero”, SS “Rivne NPP”

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:

$$\frac{M}{MPC} < 0{,}01\ H \text{ at } H > 10\ м$$

$$\frac{M}{MPC} < 0{,}1\ H \text{ at } H < 10\ м$$

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.

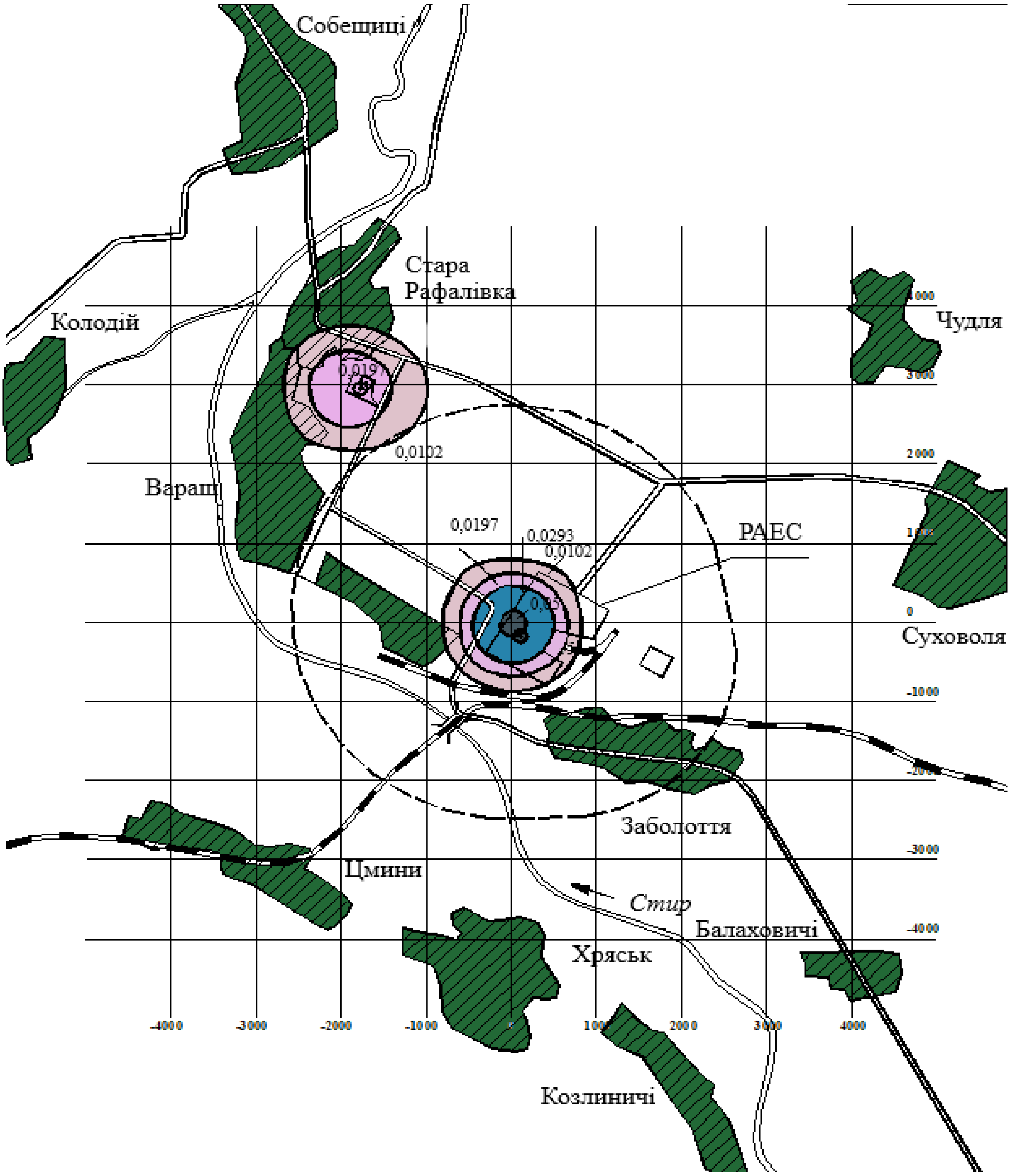


Fig. 3.9. Dispersion modelling of SO_2 emissions

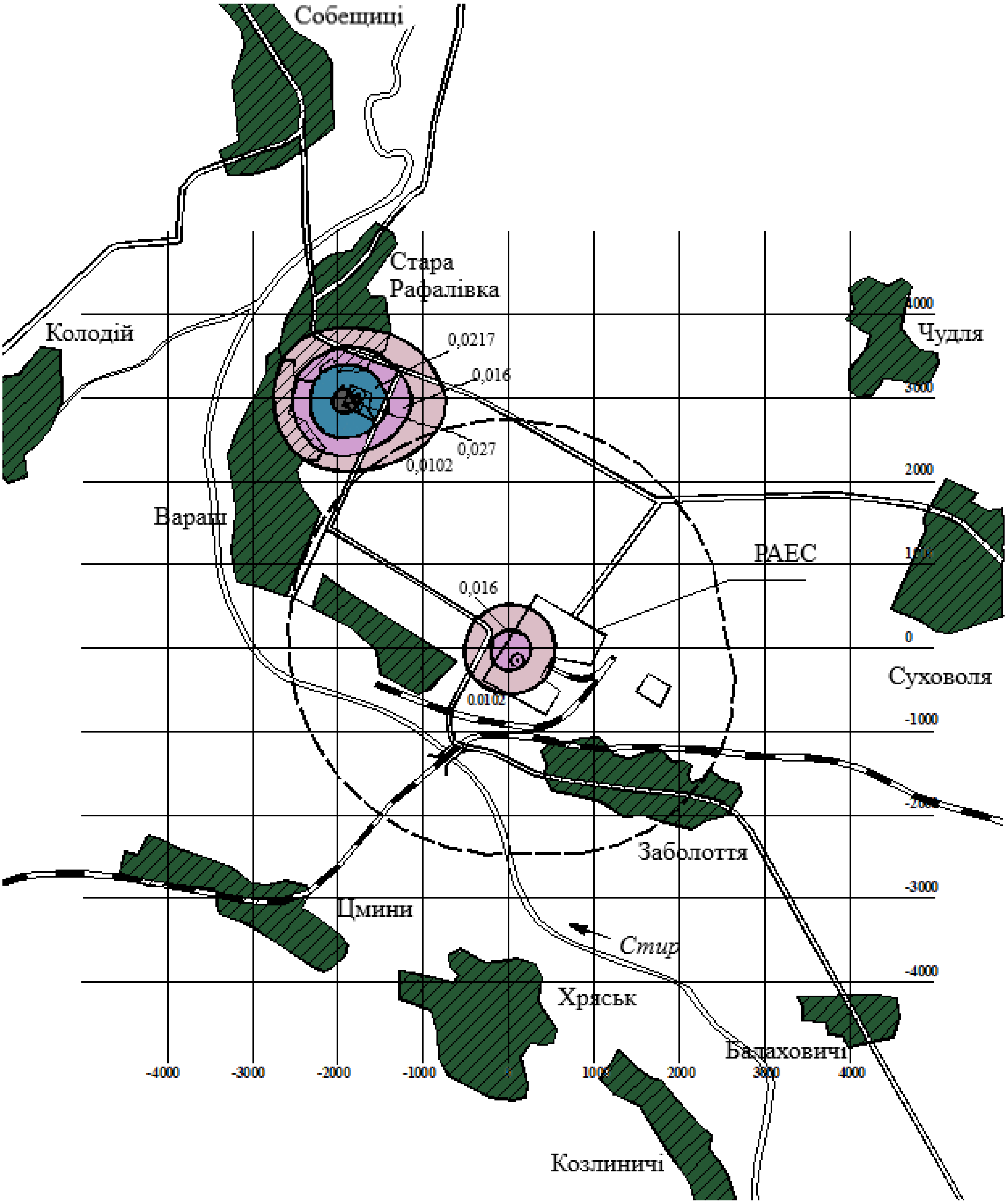


Fig. 3.10. Dispersion modelling of NO_2 emissions

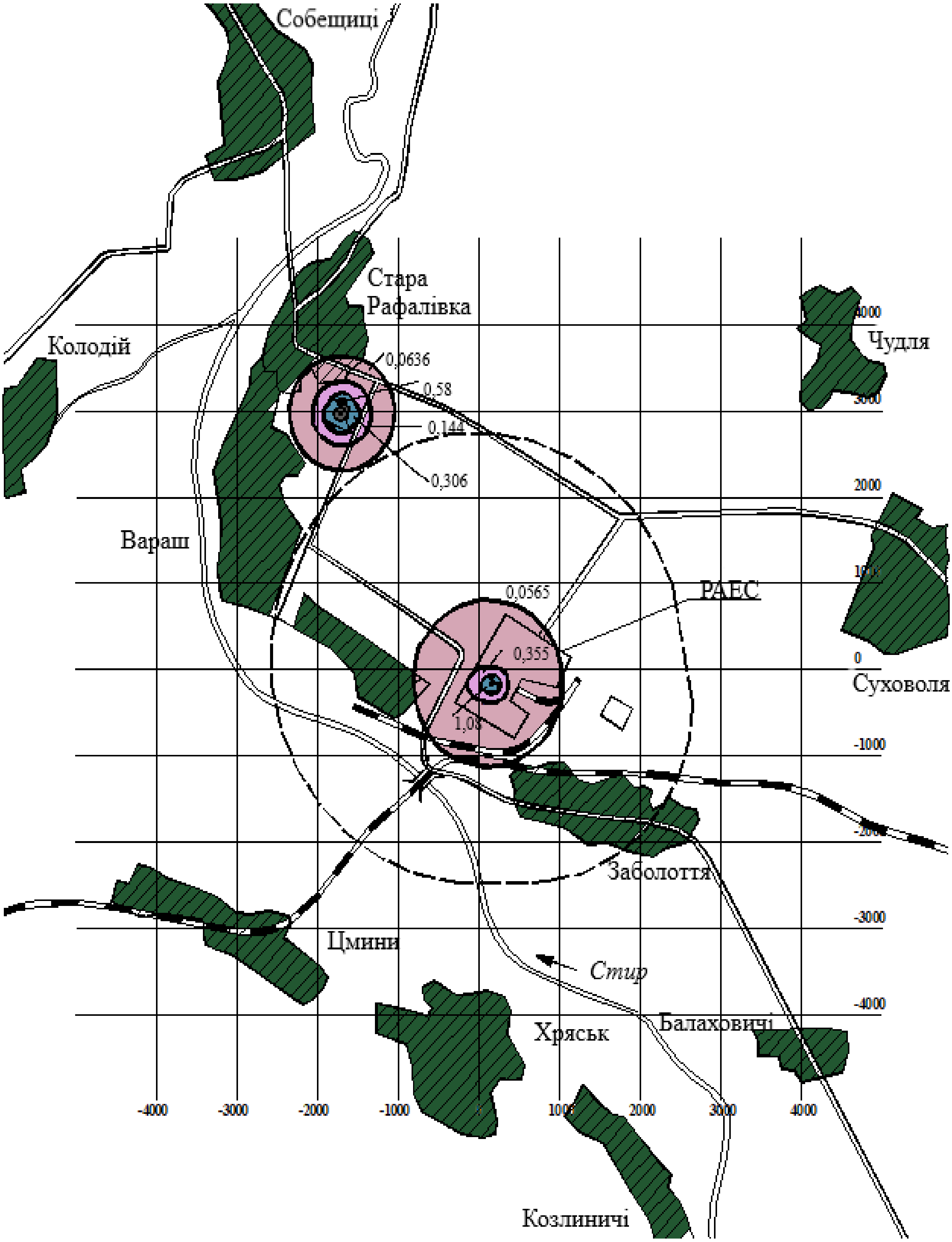


Fig. 3.11. Dispersion modelling of ashes emissions

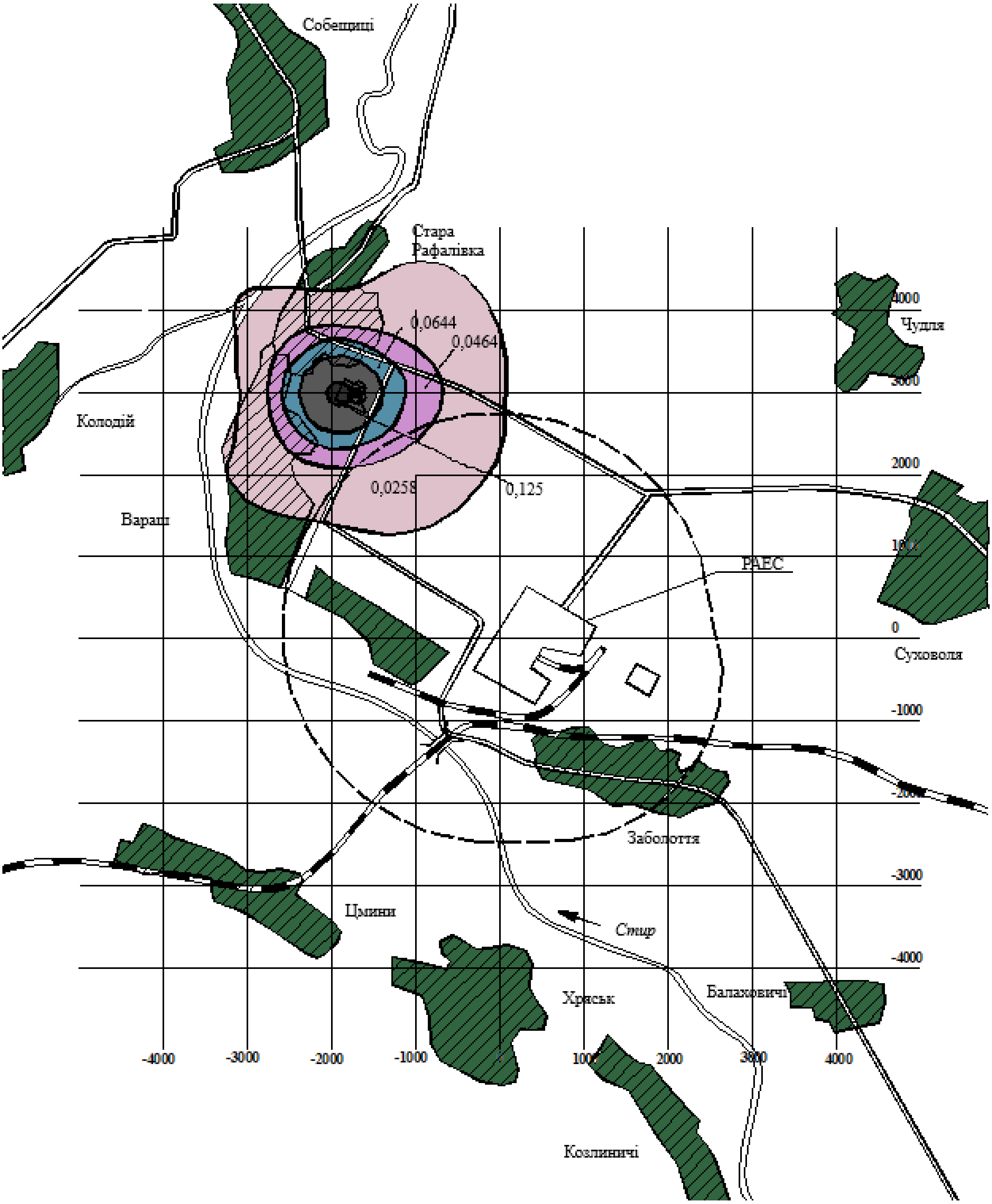


Fig. 3.12. Dispersion modelling of butanol emissions

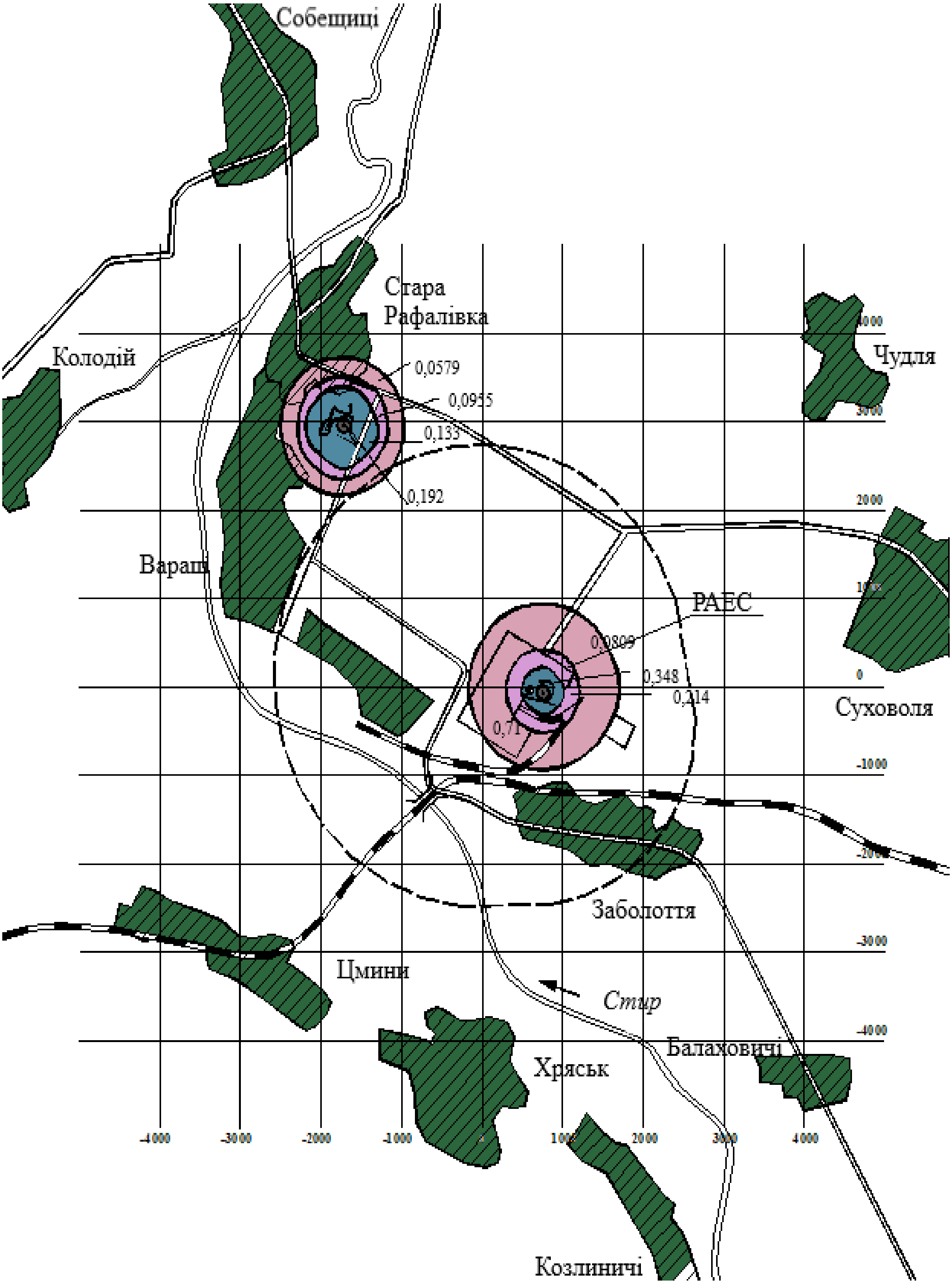


Fig. 3.13. Dispersion modelling of wood dust emissions

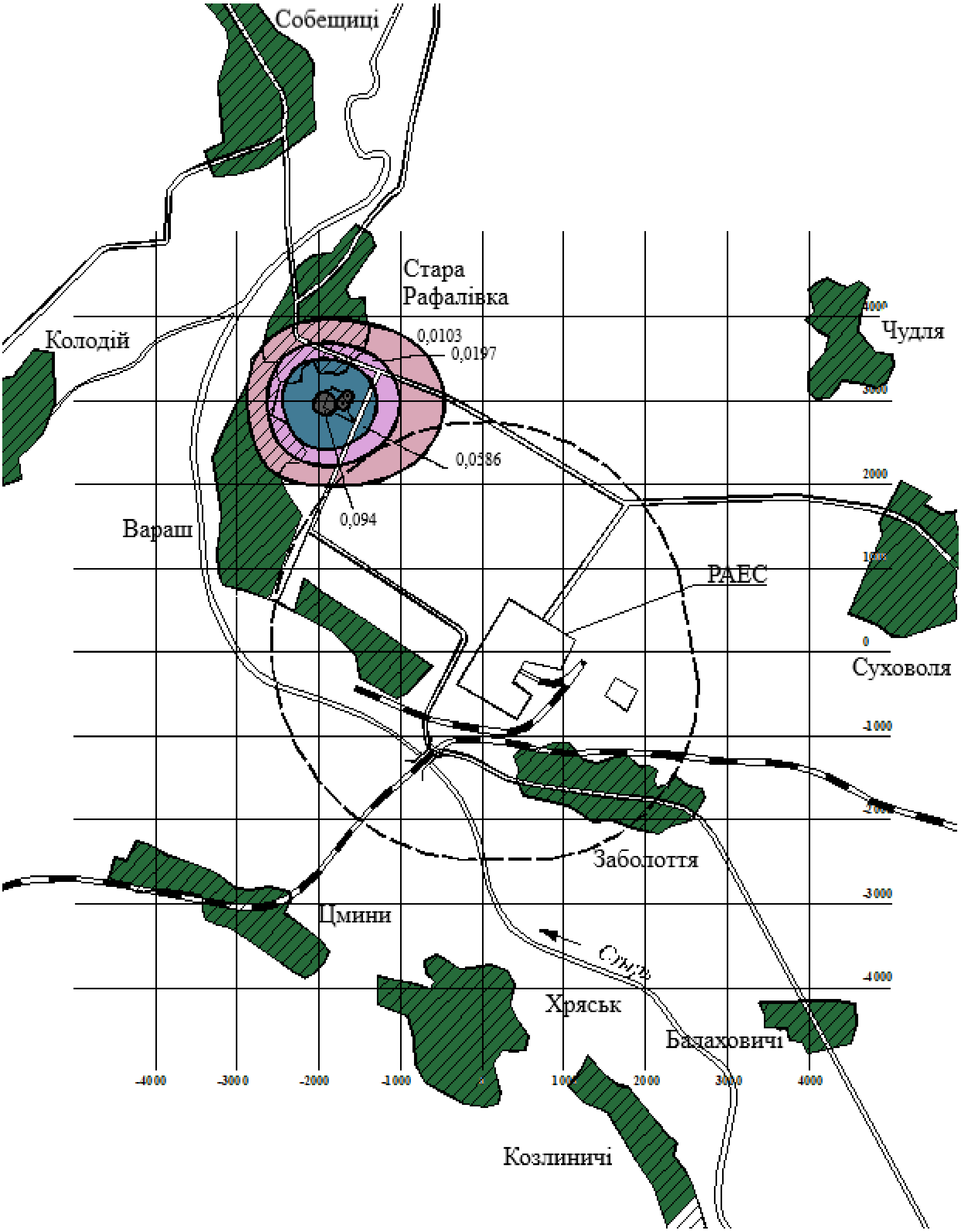


Fig. 3.14. Dispersion modelling of toluene emissions

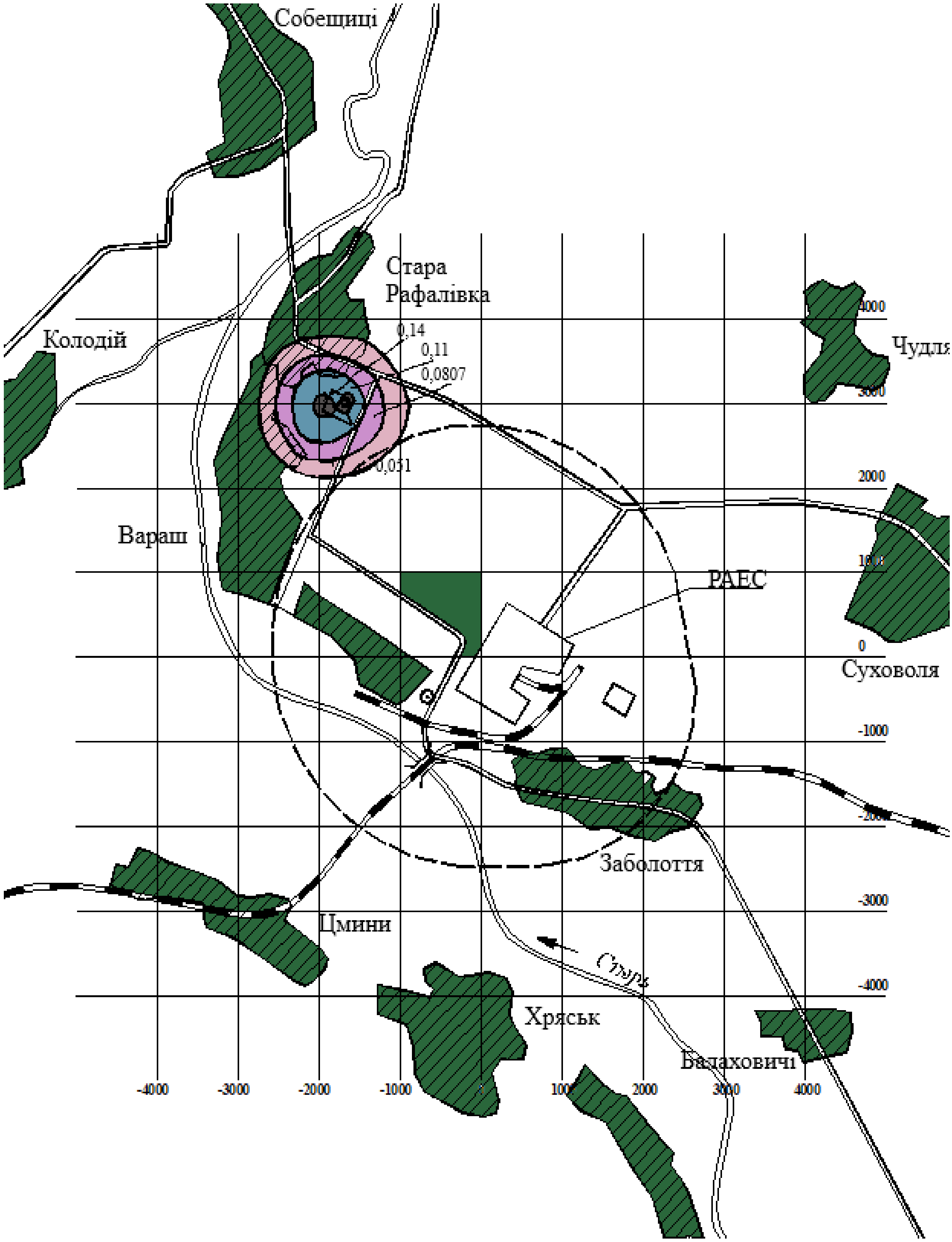


Fig. 3.15. Dispersion modelling of butyl acetate emissions

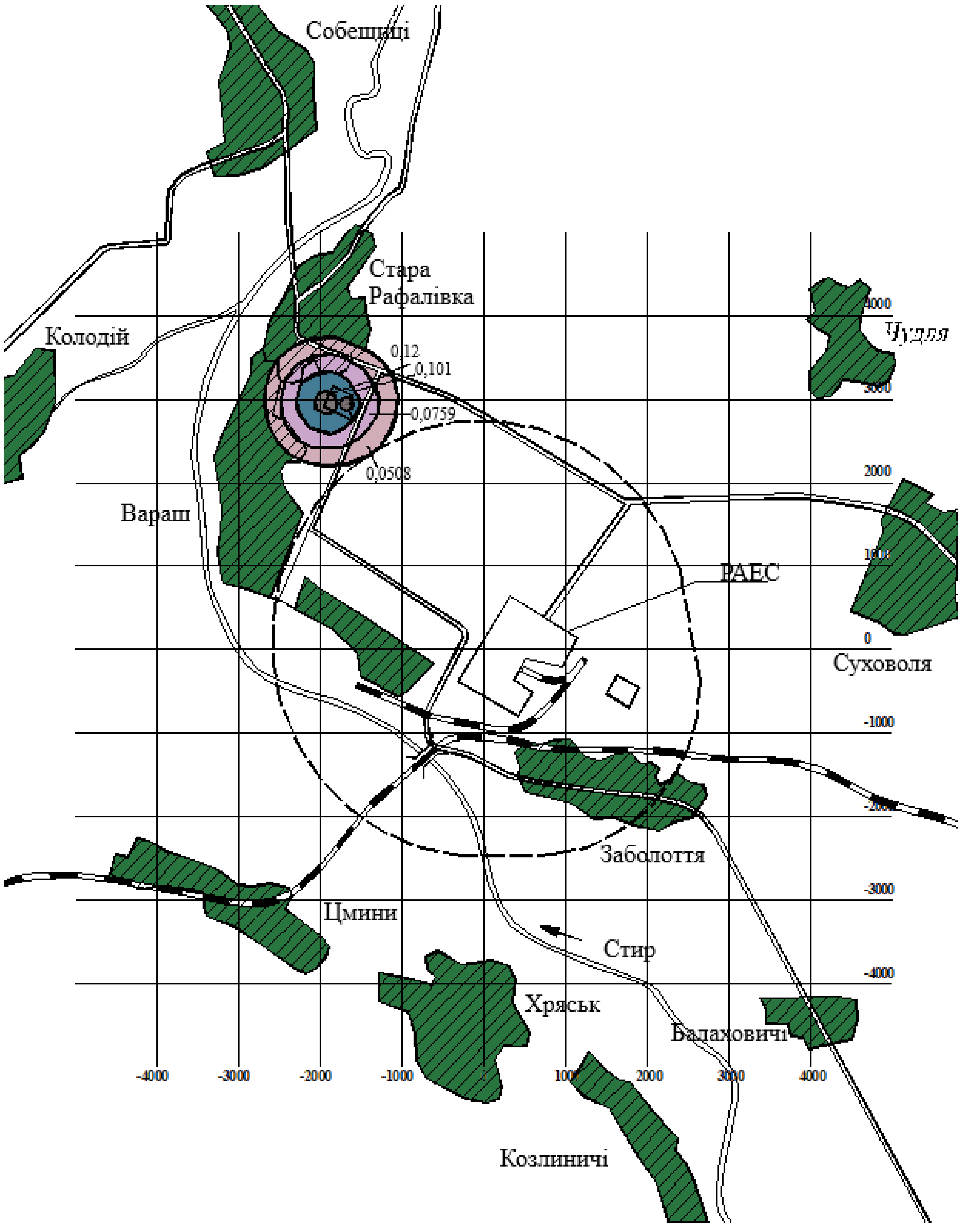


Fig. 3.16. Dispersion modelling of ethyl acetate emissions

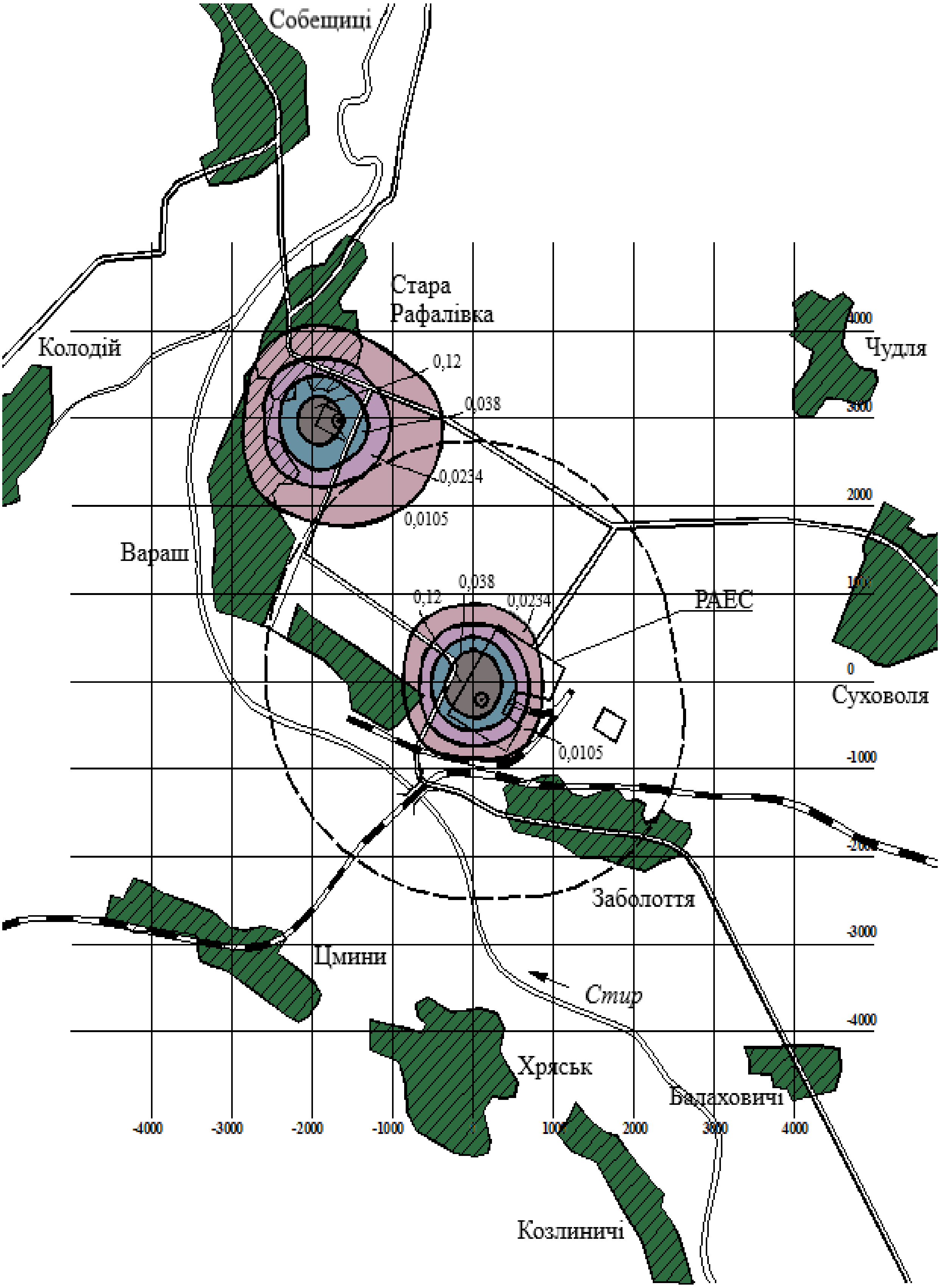


Fig. 3.17. Dispersion modelling of SO_2+NO_2 (total chemical reactivity) emissions

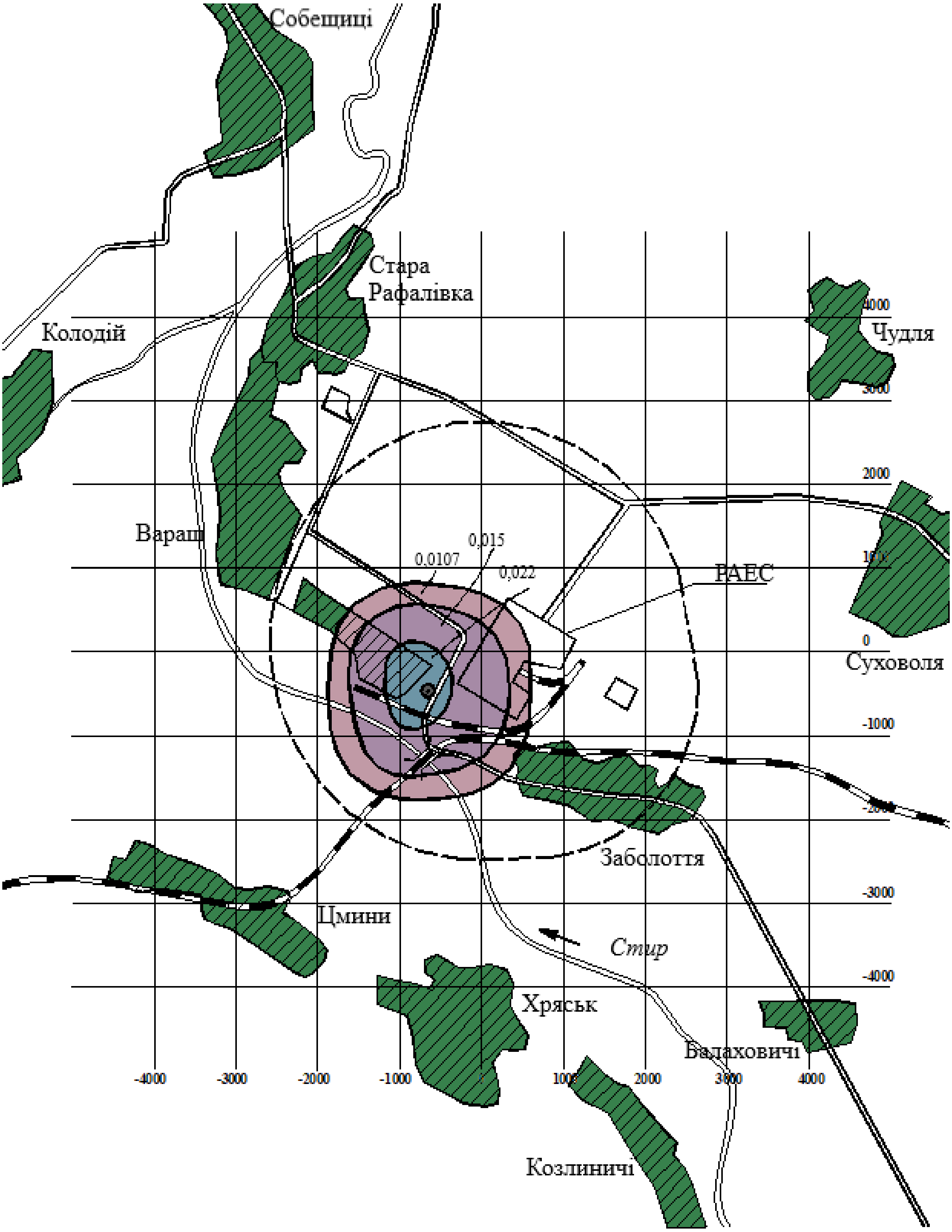


Fig. 3.18. Dispersion modelling of CaO emissions

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

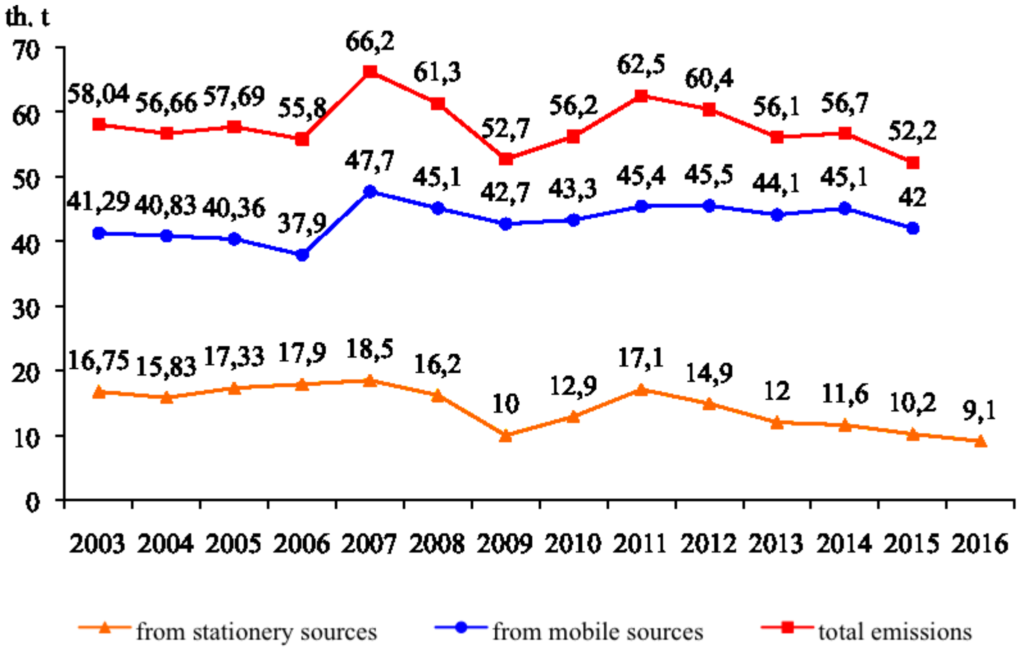


Fig. 3.19. Dynamics of air pollution emissions from stationary and mobile sources

The chemical composition of pollutant emissions from stationary sources in 2016 is shown in Figure 3.20 [6].

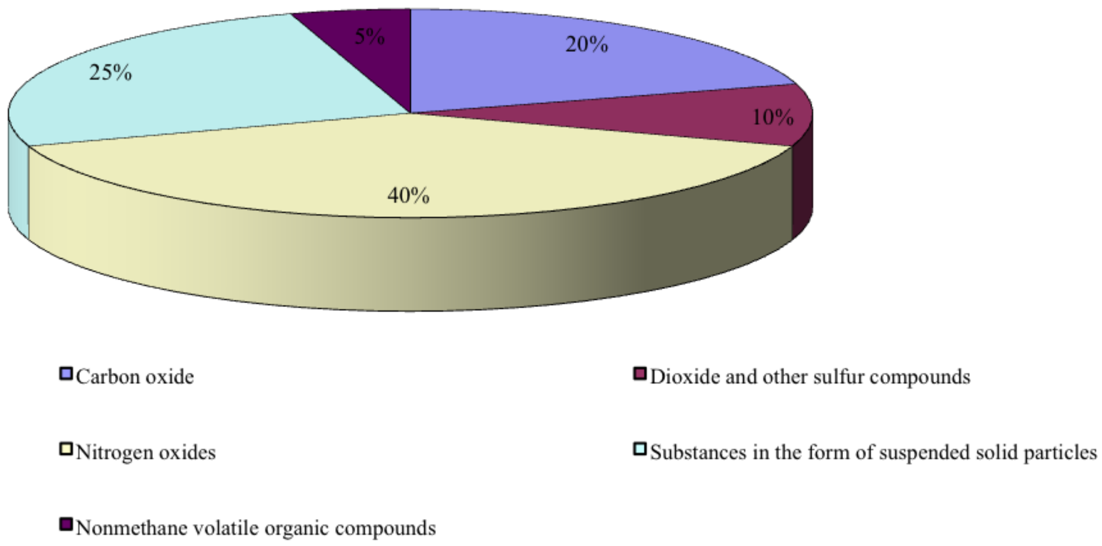


Fig. 3.20. The chemical composition of pollutant emissions from stationary sources in 2016

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					
	total	including						total	including						total	including				
		stationary source					mobile source		stationary source					mobile source		stationary source				
		total	including						total	including						total	including			
			dust	sulphur dioxide	nitrogen dioxide	carbon oxide				dust	sulphur dioxide	nitrogen dioxide	carbon oxide				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

Meteorological 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.

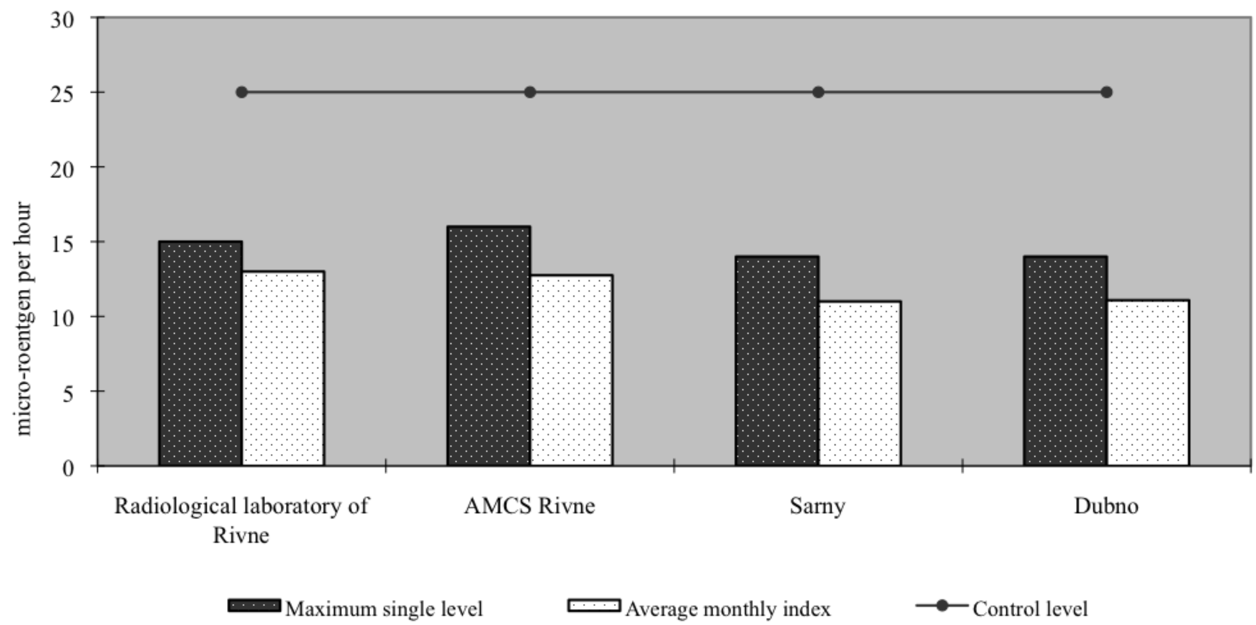


Fig. 3.20. Radiation pollution of air environment in the Rivne Oblast in 2016

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	
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	Letter of Department of Ecology and Natural Resources of Rivne Oblast State Administration №2754/04/1-09/16 dated 06.12.2016
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:

$$\sigma_z = \frac{ax^b}{1+cx^d} F(z_0, x), \qquad (1.2)$$

$F(z_0, x)$ is correction for ruggedness:

$$F(z_0, x) = \ln\left(fx^g \left[1 + \frac{1}{hx^j} \right] \right), \text{ at } z_0 > 0.1 \text{ m}, \qquad (1.3)$$

$$F(z_0, x) = \ln\left(fx^g \left[\frac{1}{1 + hx^j} \right] \right), \text{ at } z_0 \leq 0.1 \text{ m}, \quad (1.4)$$

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:

$$\mathrm{R_{wet}} = \frac{\Phi Q'_{wet}(t)}{x\alpha\mu},$$

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):

$$Q'_{вл}(t) = \frac{Q_0 f_{wet}}{m_1 - m_2}\left[(m_1 + \Phi)e^{m_2 t} - (m_2 + \Phi)e^{m_1 t}\right],$$

$$2m_1 = -(\Phi + P_{dry} + \mathrm{P_{wet}}) - \sqrt{(\Phi + P_{dry} + P_{wet})^2 - 4\Phi P_{dry}},$$

$$2m_2 = -(\Phi + P_{dry} + \mathrm{P_{wet}}) + \sqrt{(\Phi + P_{dry} + P_{wet})^2 - 4\Phi P_{dry}},$$

$$f_{wet} = P_{dry}/(P_{dry}+P_{wet}),$$

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:

$$F_{cyy} = \left[\exp F_{0dry}(x)\right]^{V_g/\mu},$$

$$\text{where } F_{0cyx}(\mathrm{x}) = -\sqrt{\frac{2}{\pi}}\int_0^x \frac{1}{\sigma_z}\left\{\exp\left[-\frac{h_{eff}^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(h_{eff}+2L)^2}{2\sigma_z^2}\right]\right\}dx$$

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:

$$R_д = \frac{\lambda_д}{\lambda_м - \lambda_д}\left[\exp\left\{-\lambda_д \frac{x}{\mu}\right\} - \exp\left\{\lambda_м \frac{x}{\mu}\right\}\right],$$

λ_d, λ_m here are decay constants for daughter and mother radionuclides, respectively.

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.

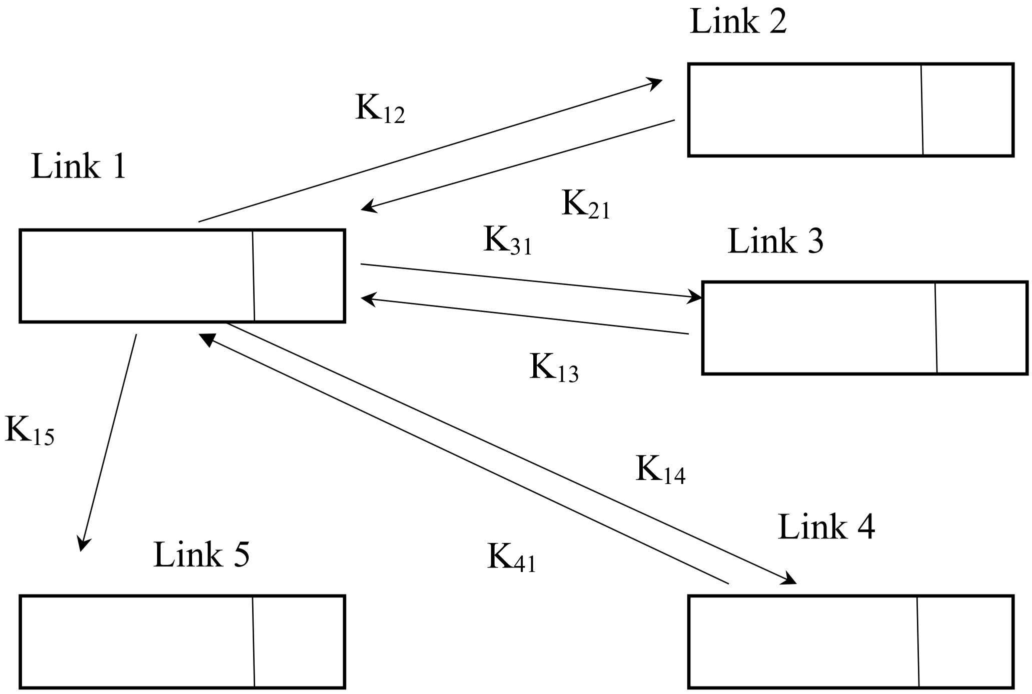


Fig. 1.1 - Radionuclide migration scheme for agricultural plants

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:

$$B_{a\gamma} = 2.13 \cdot E \ \mu\text{Sv}\cdot\text{m}^3/(\text{year}\cdot\text{Bq})$$

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·cm^2/(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×cm^2/(year×Bq)

Nuclide	Epidermis thickness Δx, mg/cm^2			Nuclide	Epidermis thickness Δx, mg/cm^2		
	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/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.

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:

$$A = \left(\frac{Q}{2\pi \sigma_y \sigma_z \mu} \right) \cdot \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y} \right)^2 \right] \cdot \left\{ \exp[-0.5 \cdot (z-H)/\sigma_z)^2] + \exp[-0.5 \cdot (z+H)/\sigma_z)^2] \right\}, \quad (1.13)$$

$\overline{A}$ 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 $3.5 \cdot 10\text{-}^{2}$ m/s for iodine, $1.8 \cdot 10\text{-}^{3}$ 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 $1 \times 10\text{-}^{7}$ 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 $\mu = 1$ 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.

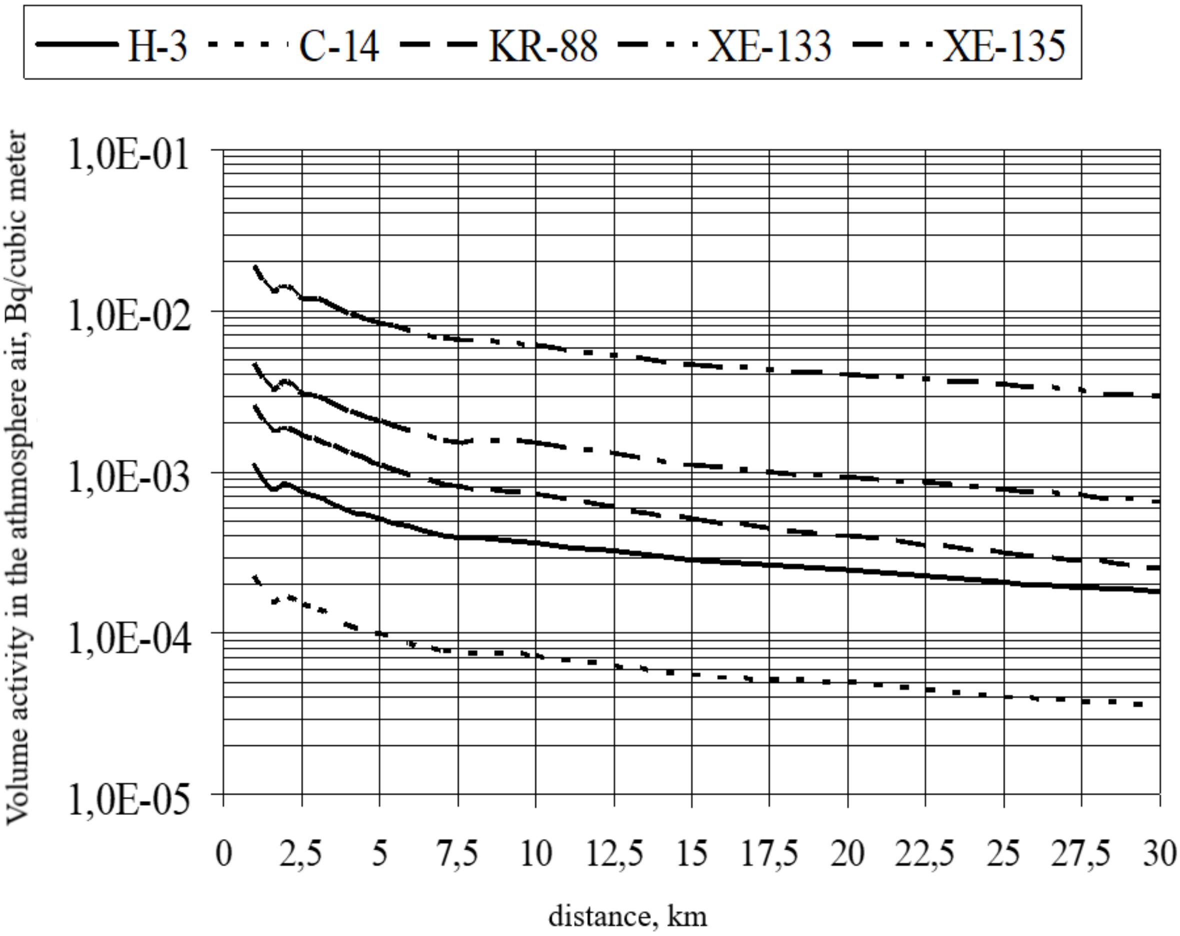


Figure 2.1 - Distance dependence of expected volumetric activity of IRG, hydrogen-3 (H-3) and carbon in surface air

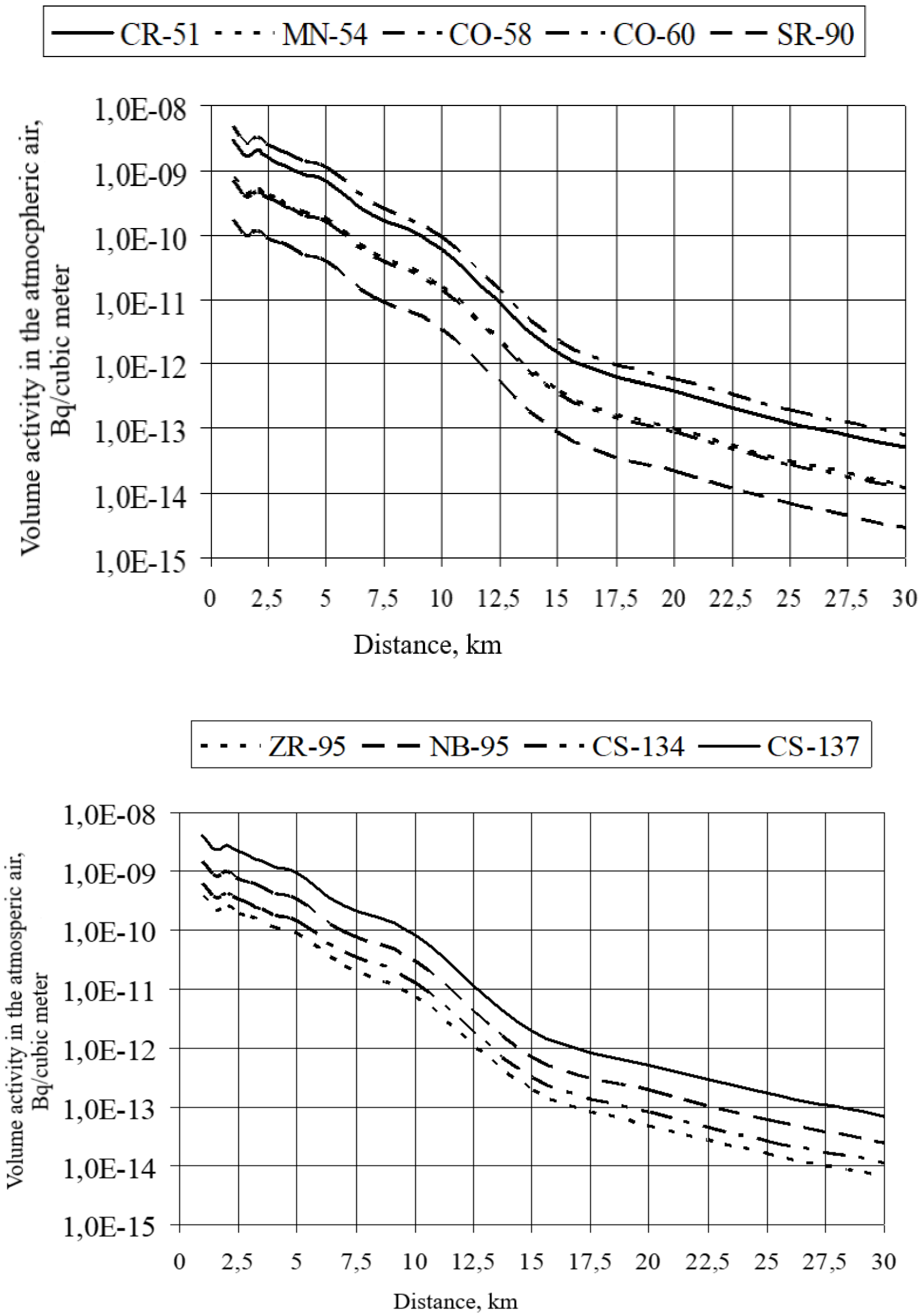


Figure 2.2 - Distance dependence of expected volumetric activity of LLN in surface air

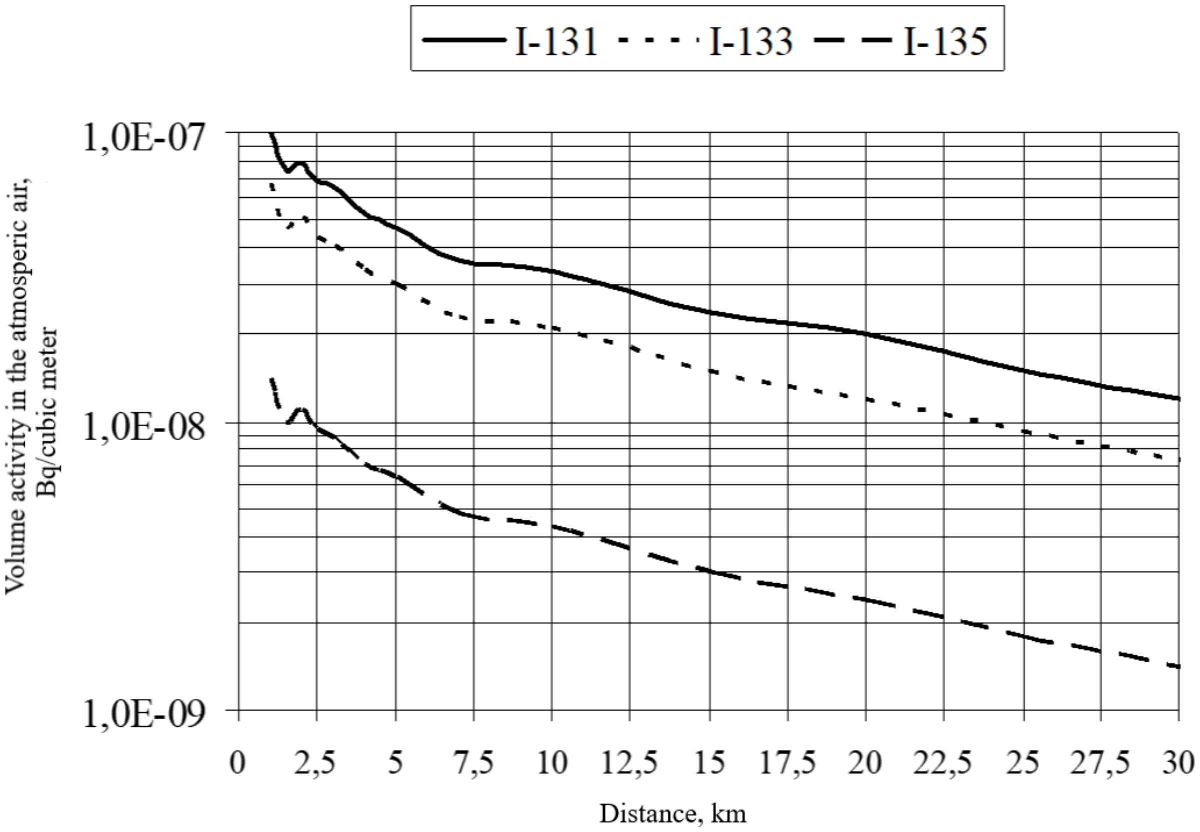


Figure 2.3 - Distance dependence of expected volumetric activity of iodine isotopes in surface air

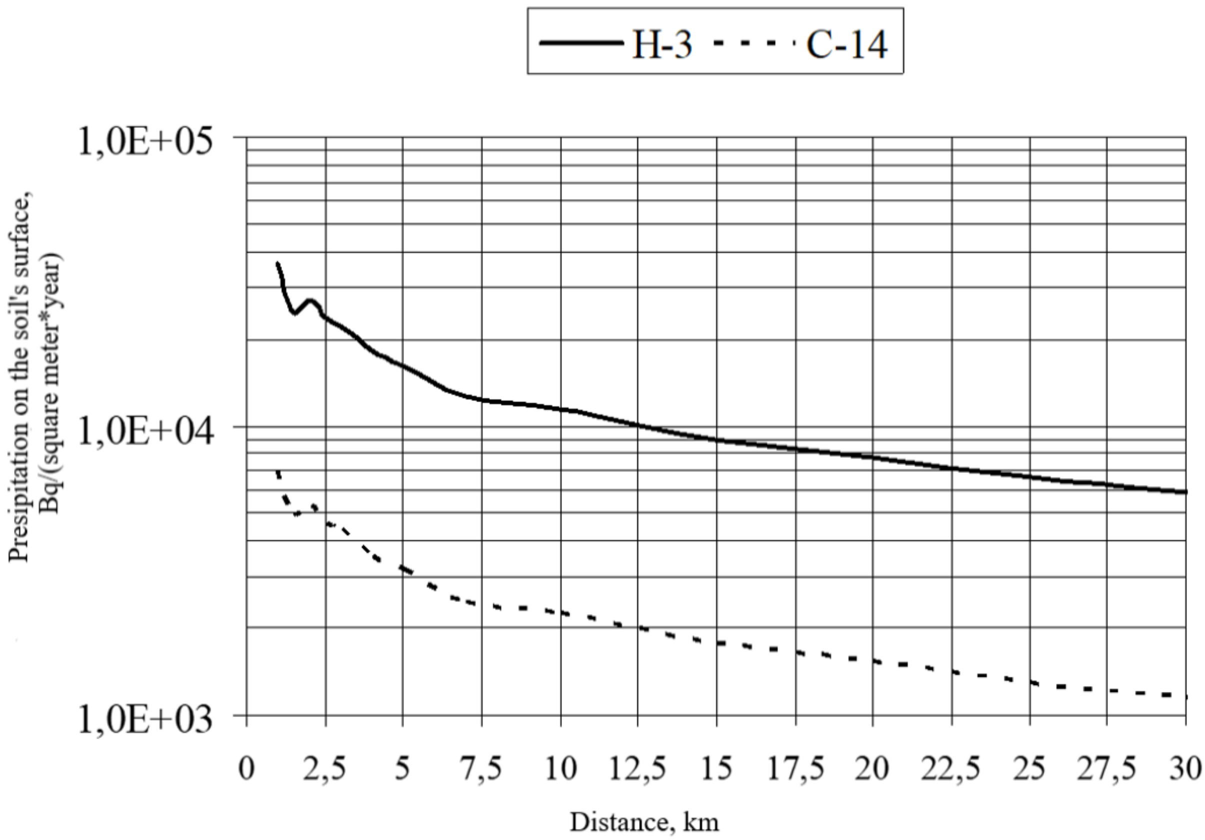
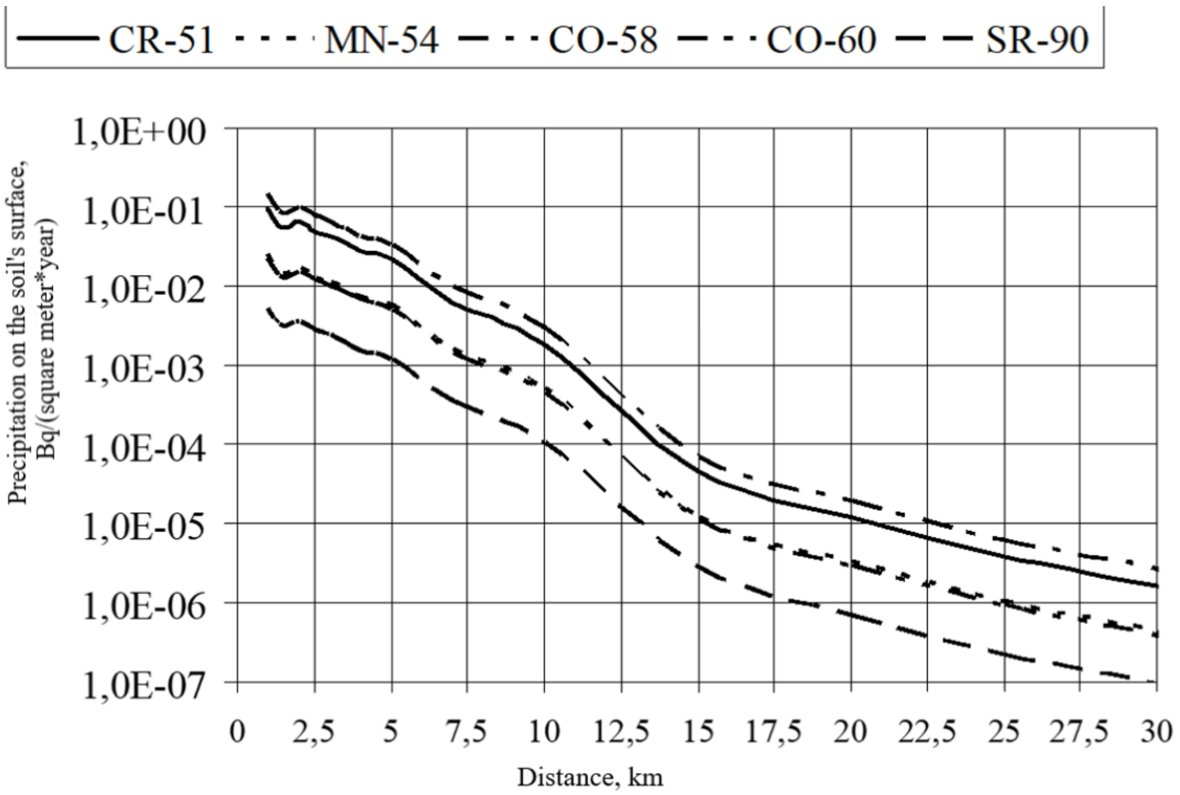


Figure 2.4 - Distance dependence of expected H-3 and carbon soil fallout



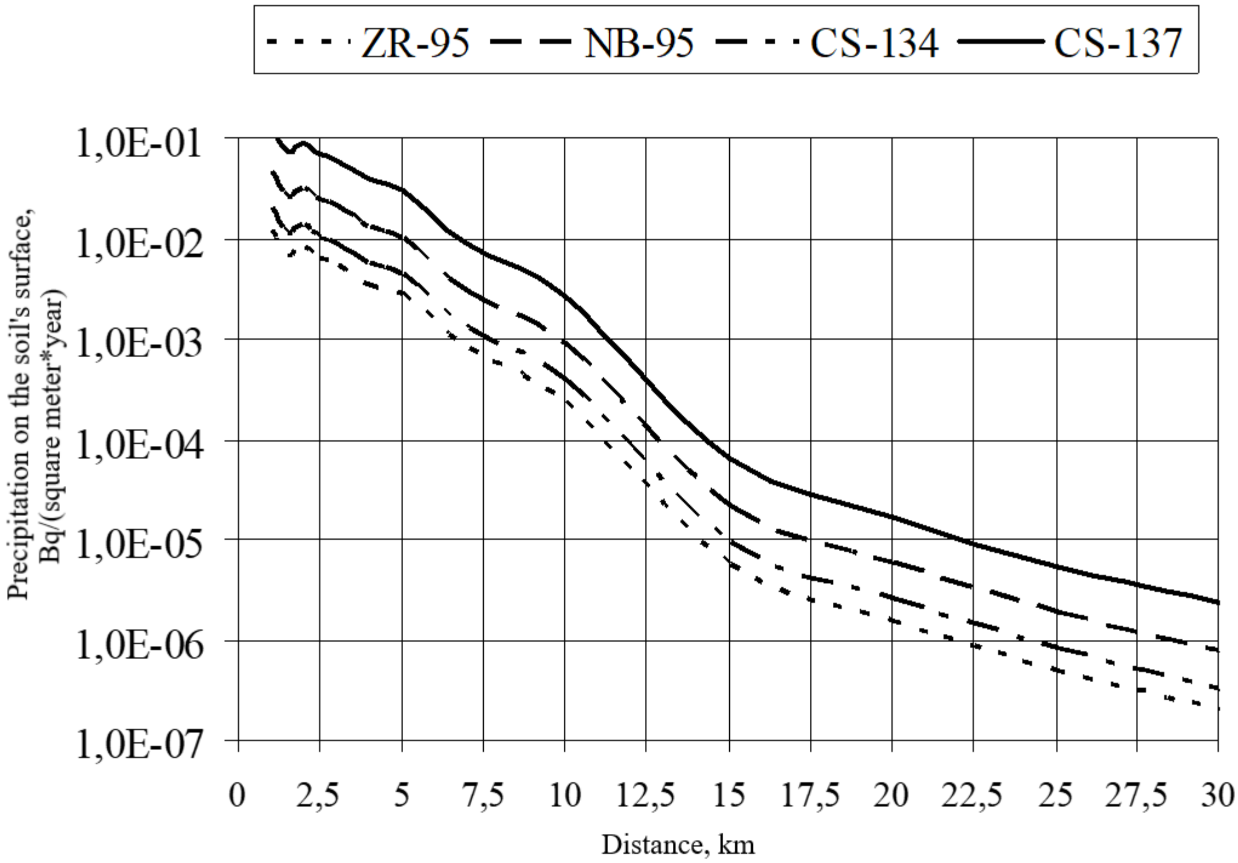


Figure 2.5 - Distance dependence of expected LLN soil fallout

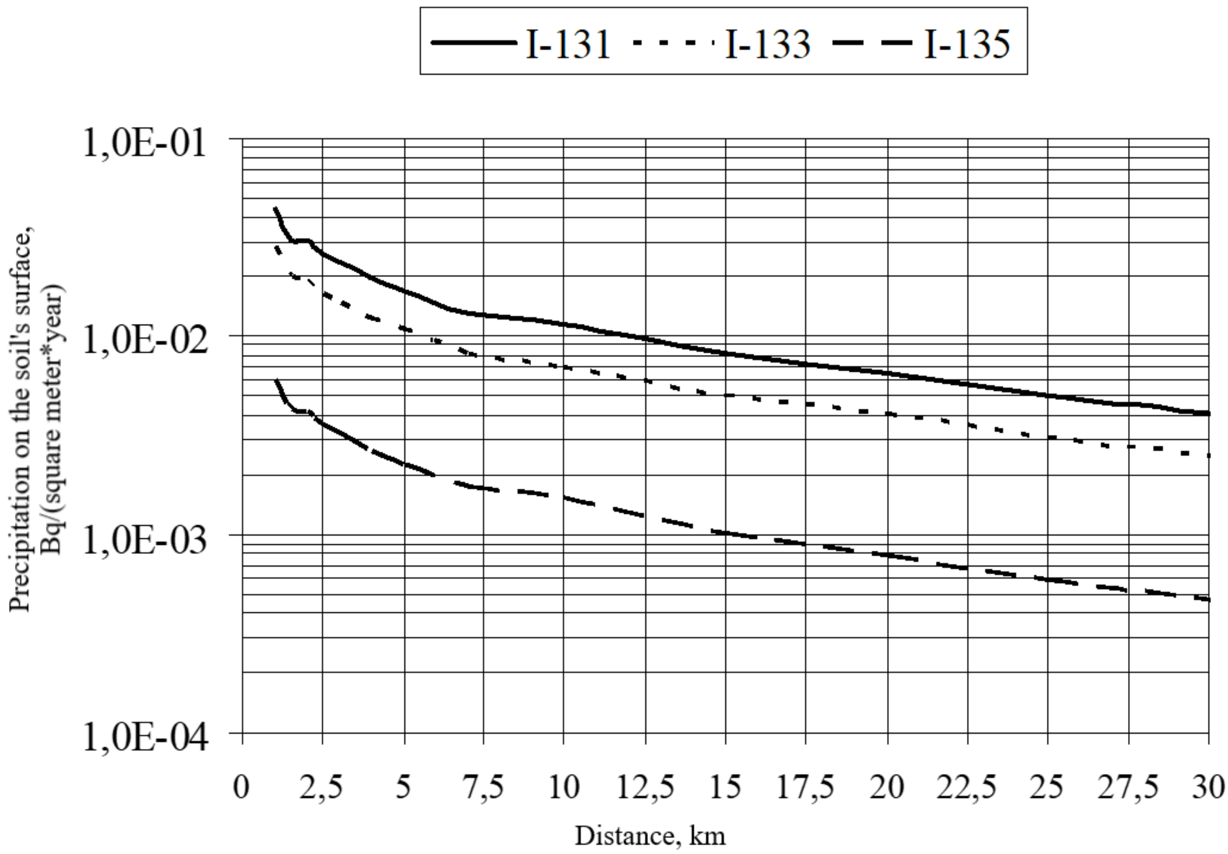


Figure 2.6 - Distance dependence of expected iodine isotopes soil fallout

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.

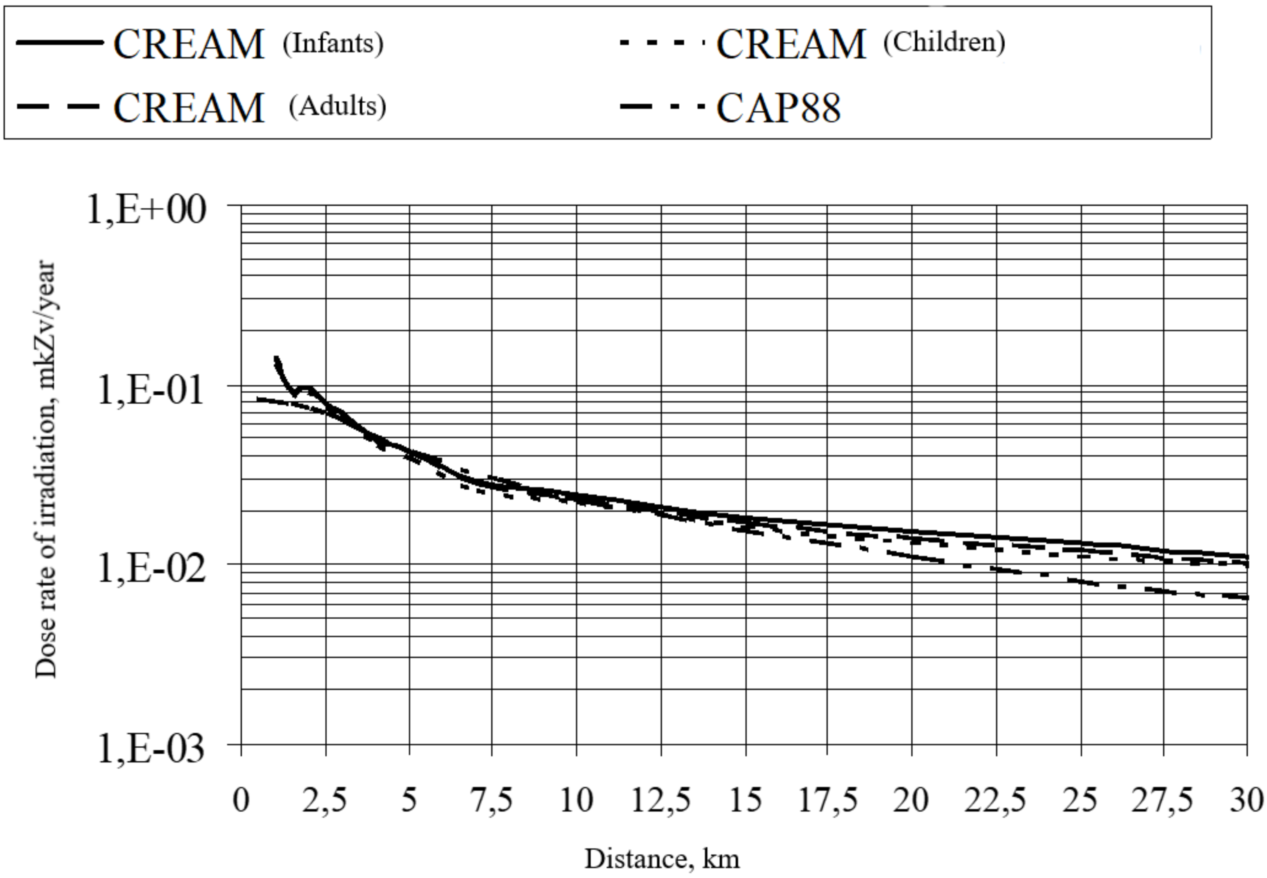


Figure 2.7 - Distance dependence of expected population radiation doses

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.

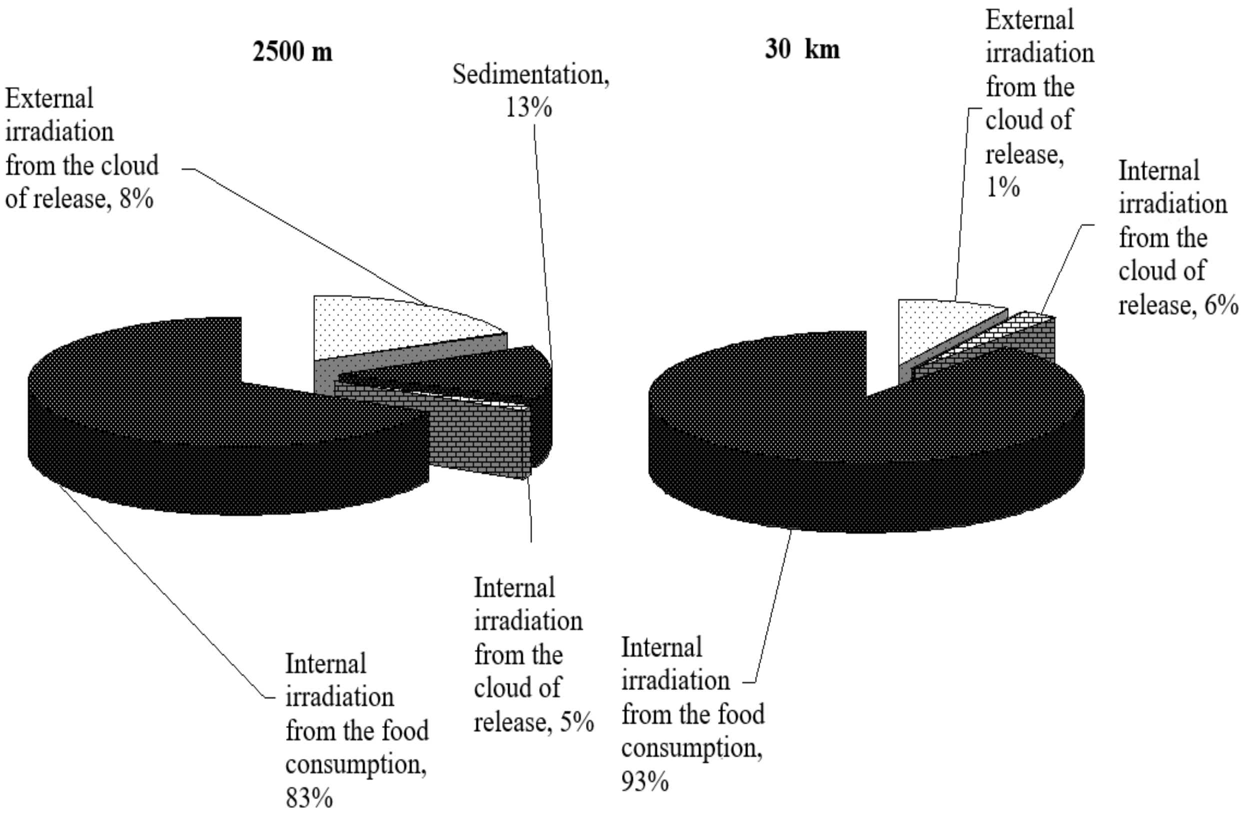
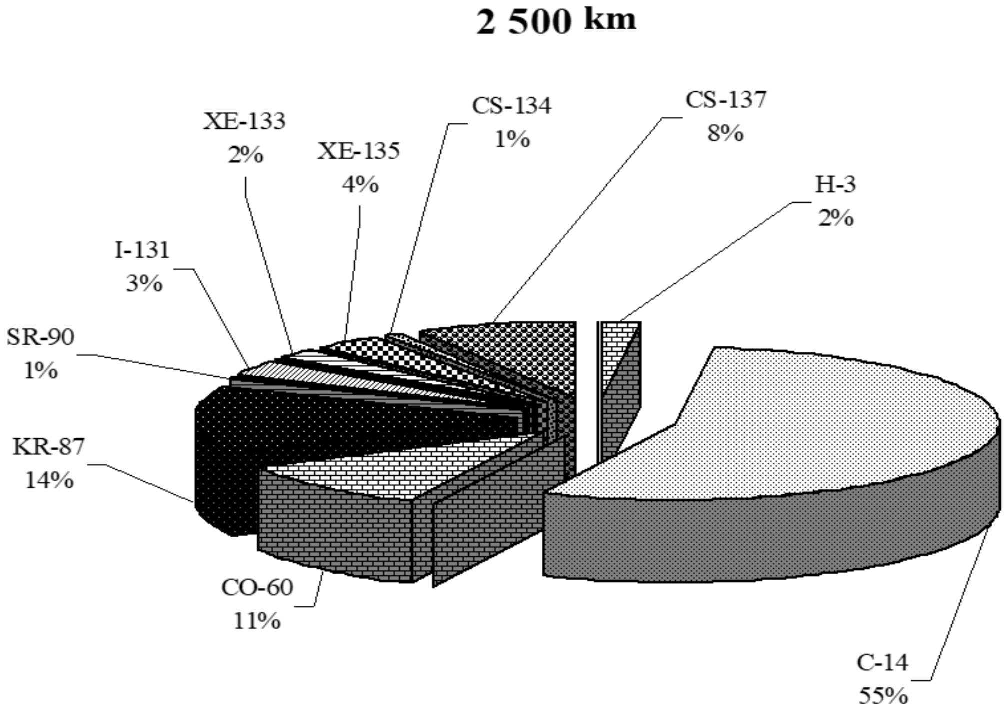


Figure 2.8 - Relative shares of radiation dose formation pathways

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.



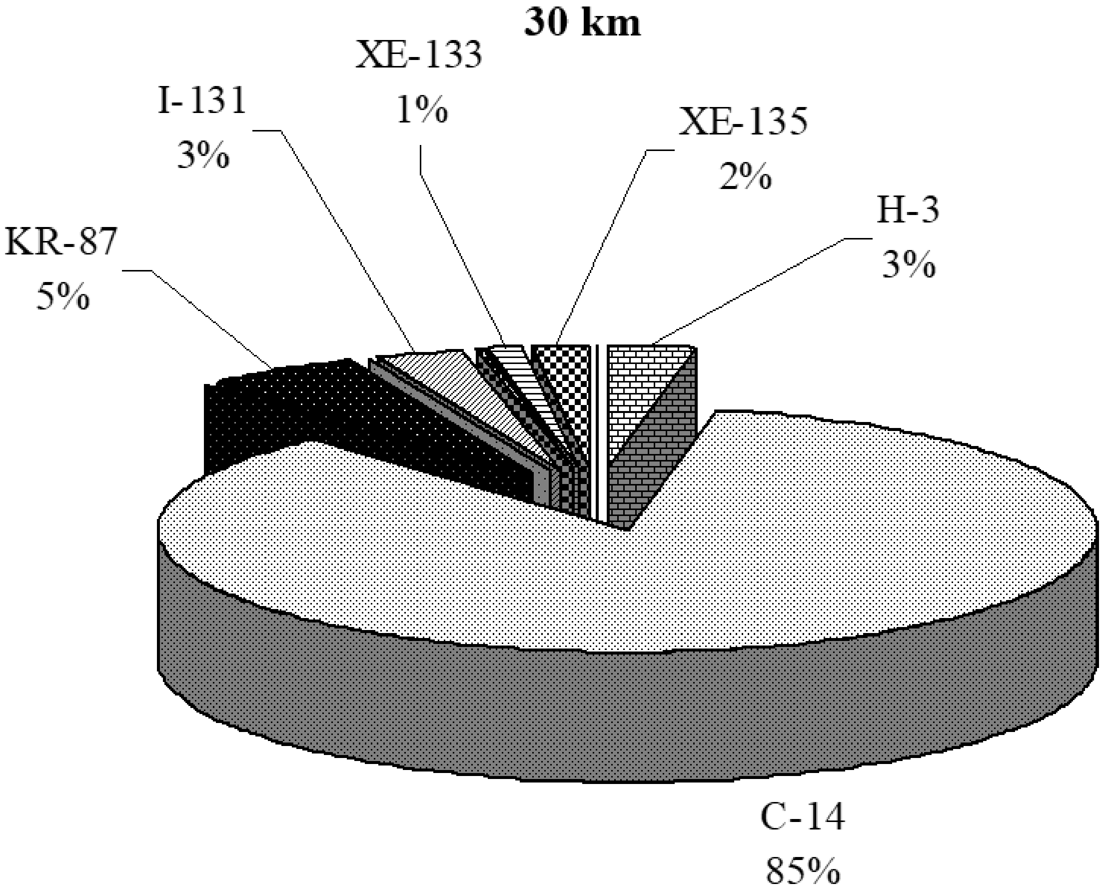


Figure 2.9 - Relative shares of radionuclides in the radiation dose

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**

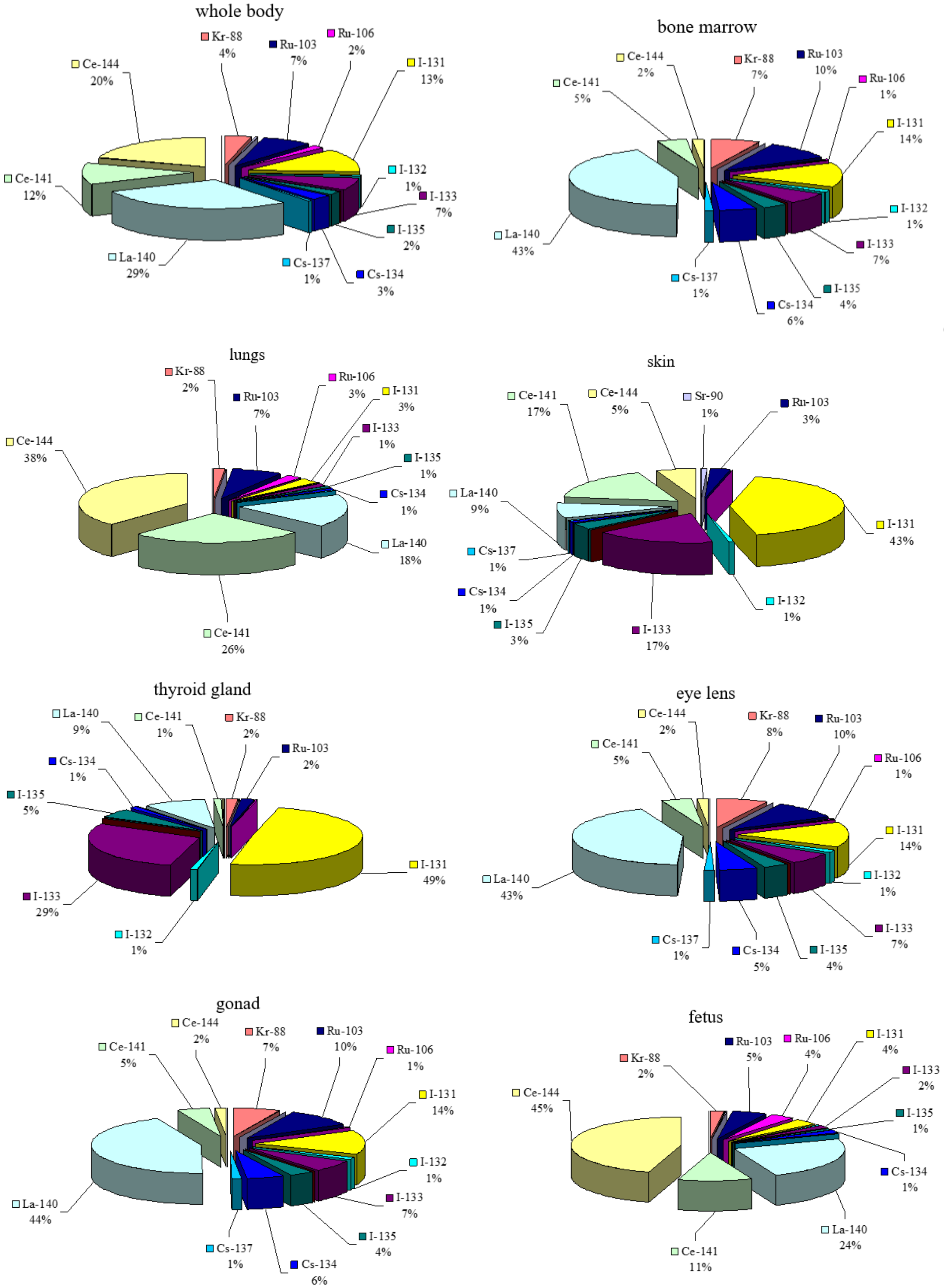


Figure 3.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

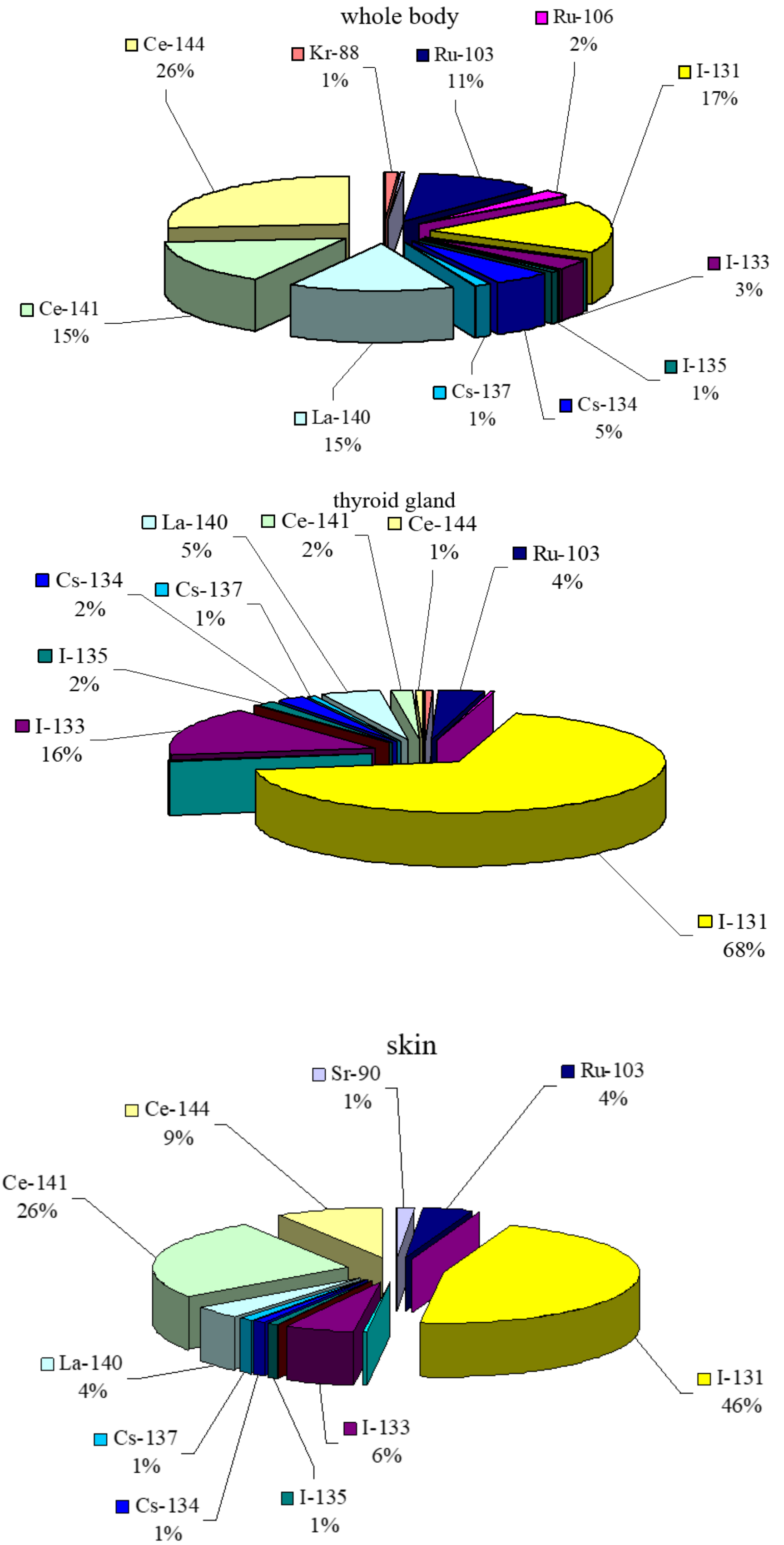


Figure 3.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

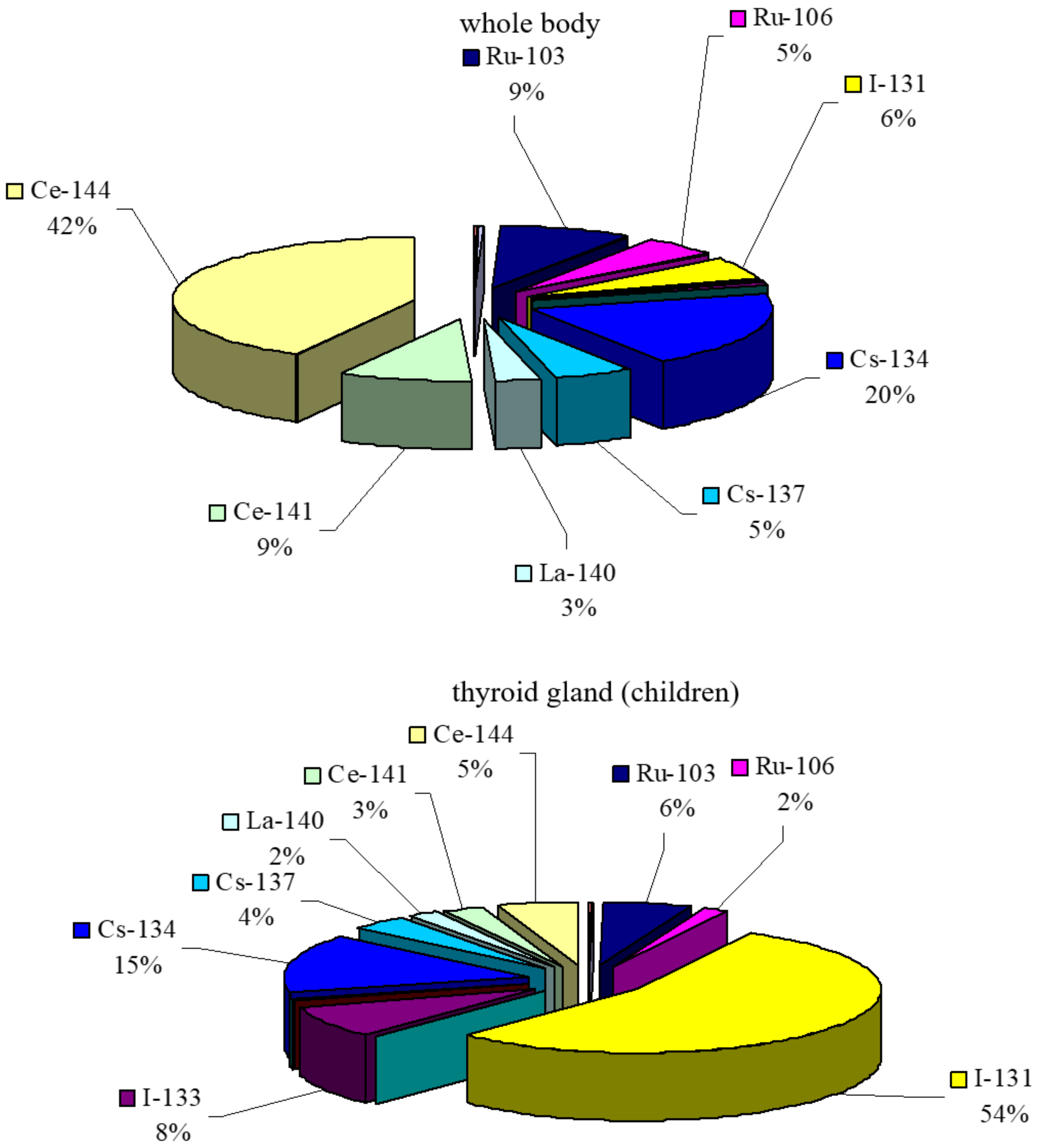


Figure 3.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

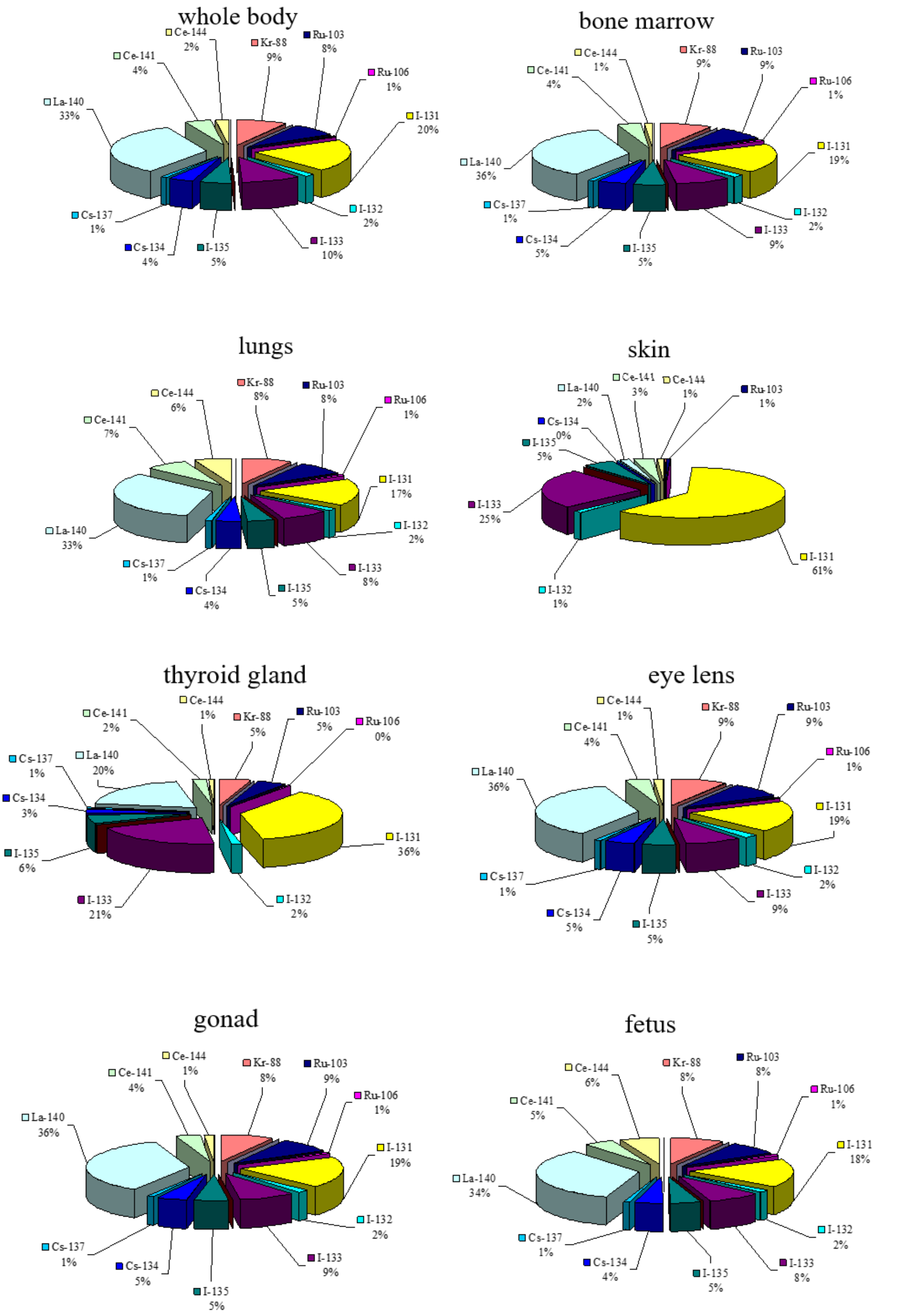


Figure 3.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

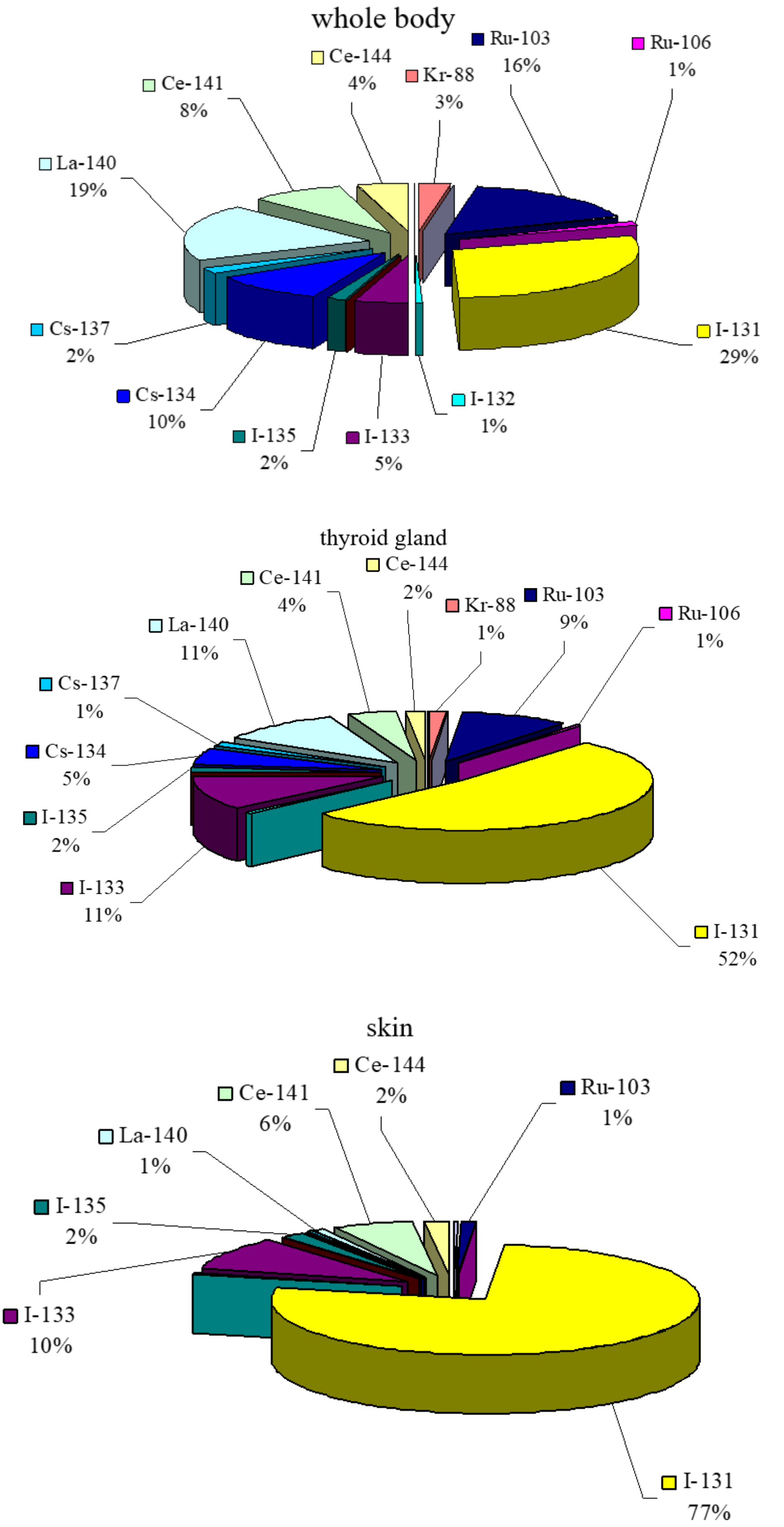


Figure 3.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

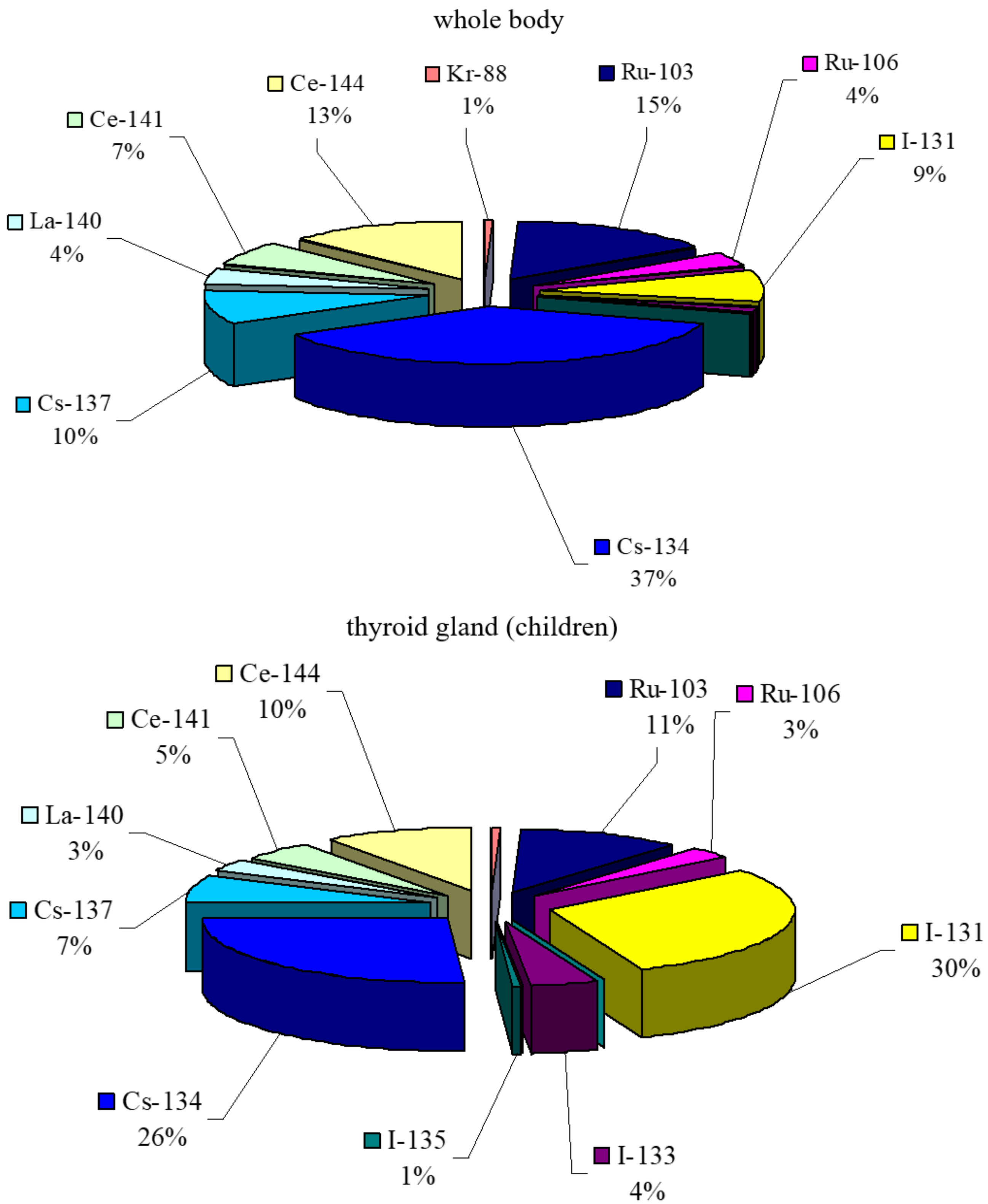


Figure 3.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

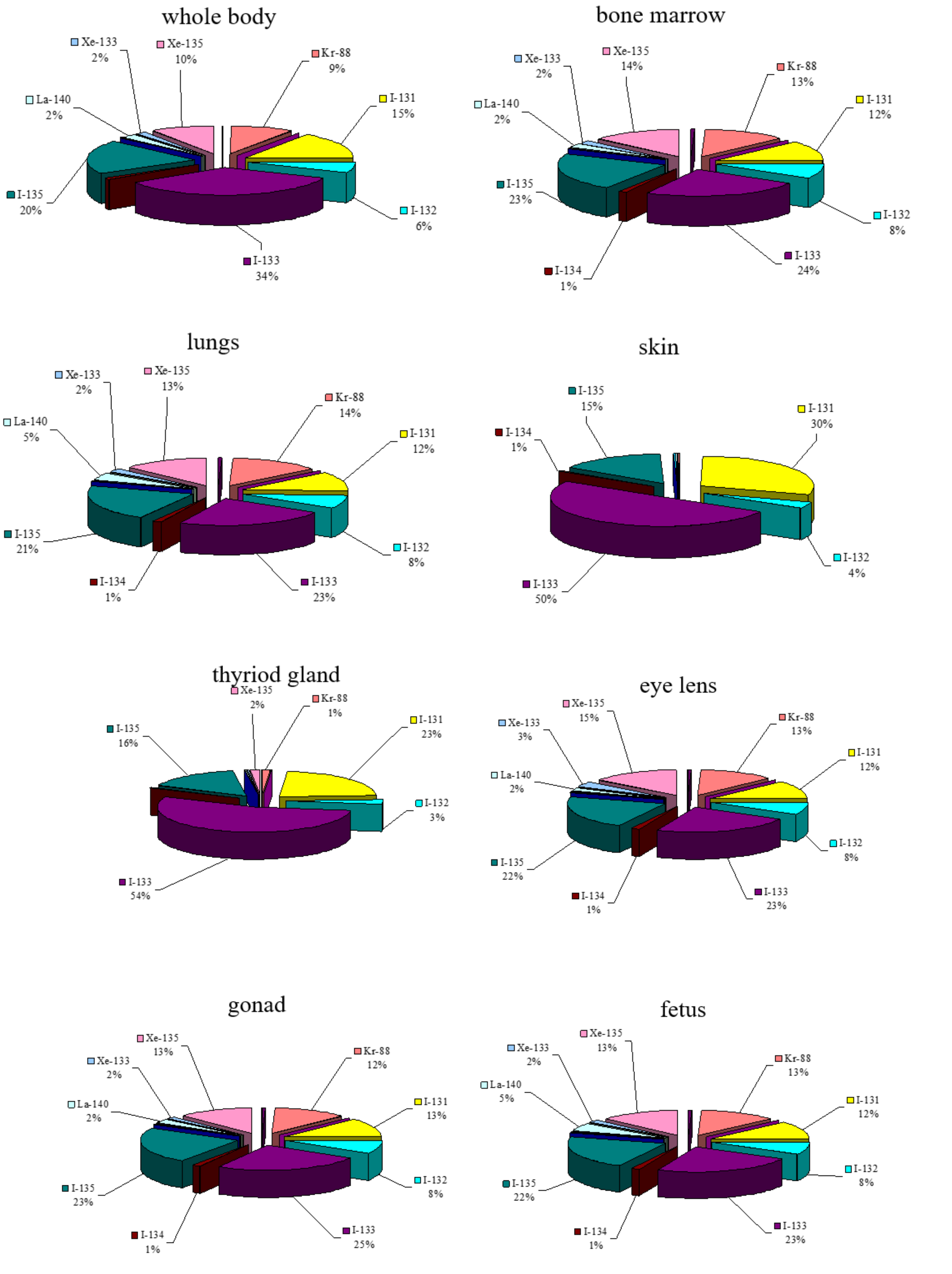


Figure 4.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

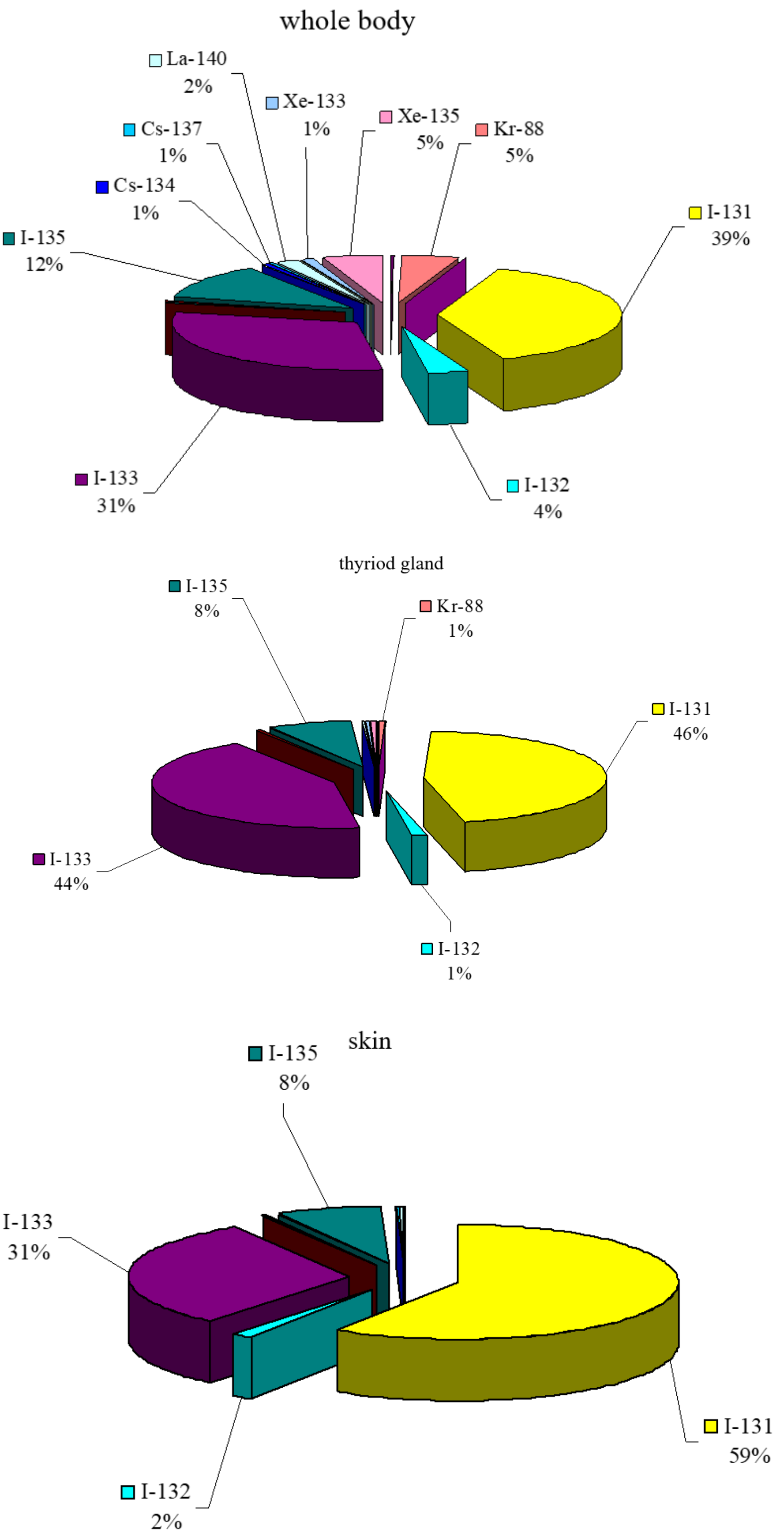
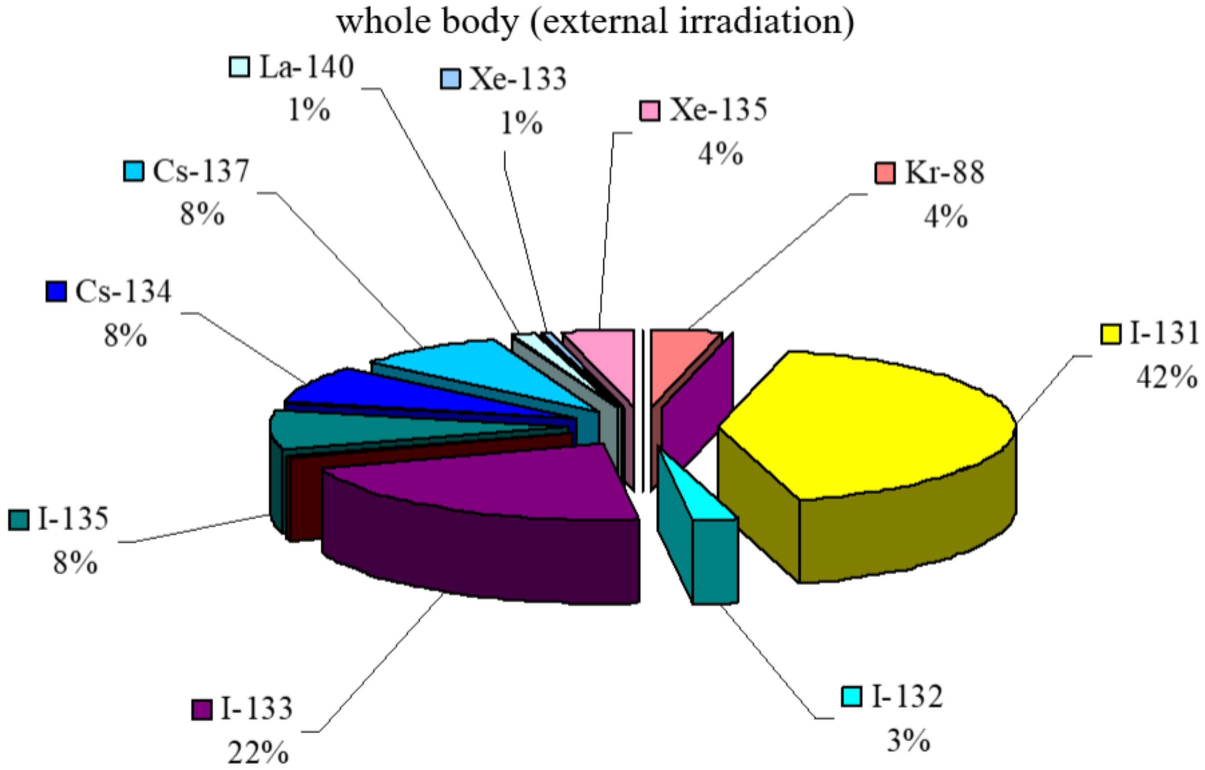


Figure 4.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



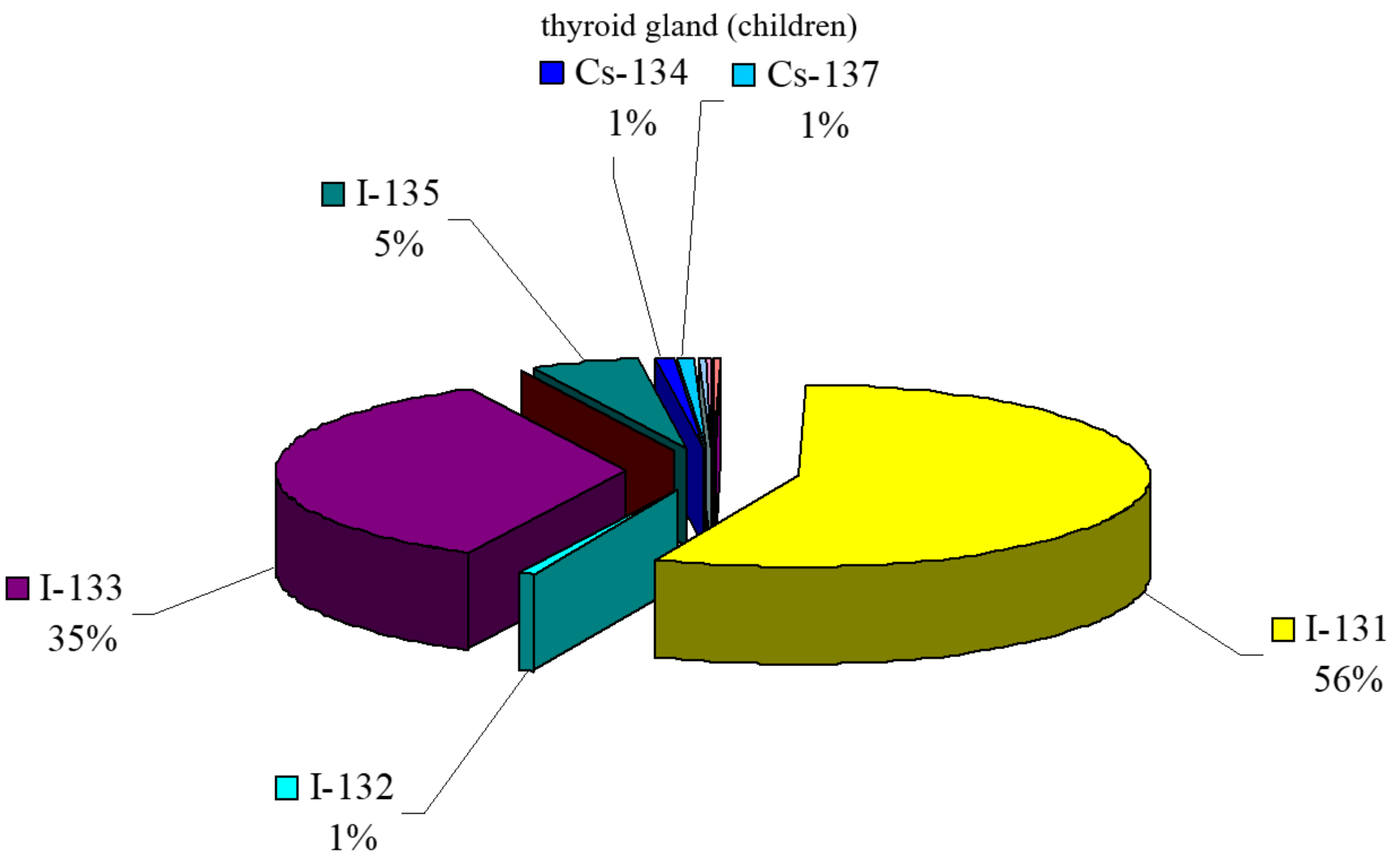


Figure 4.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

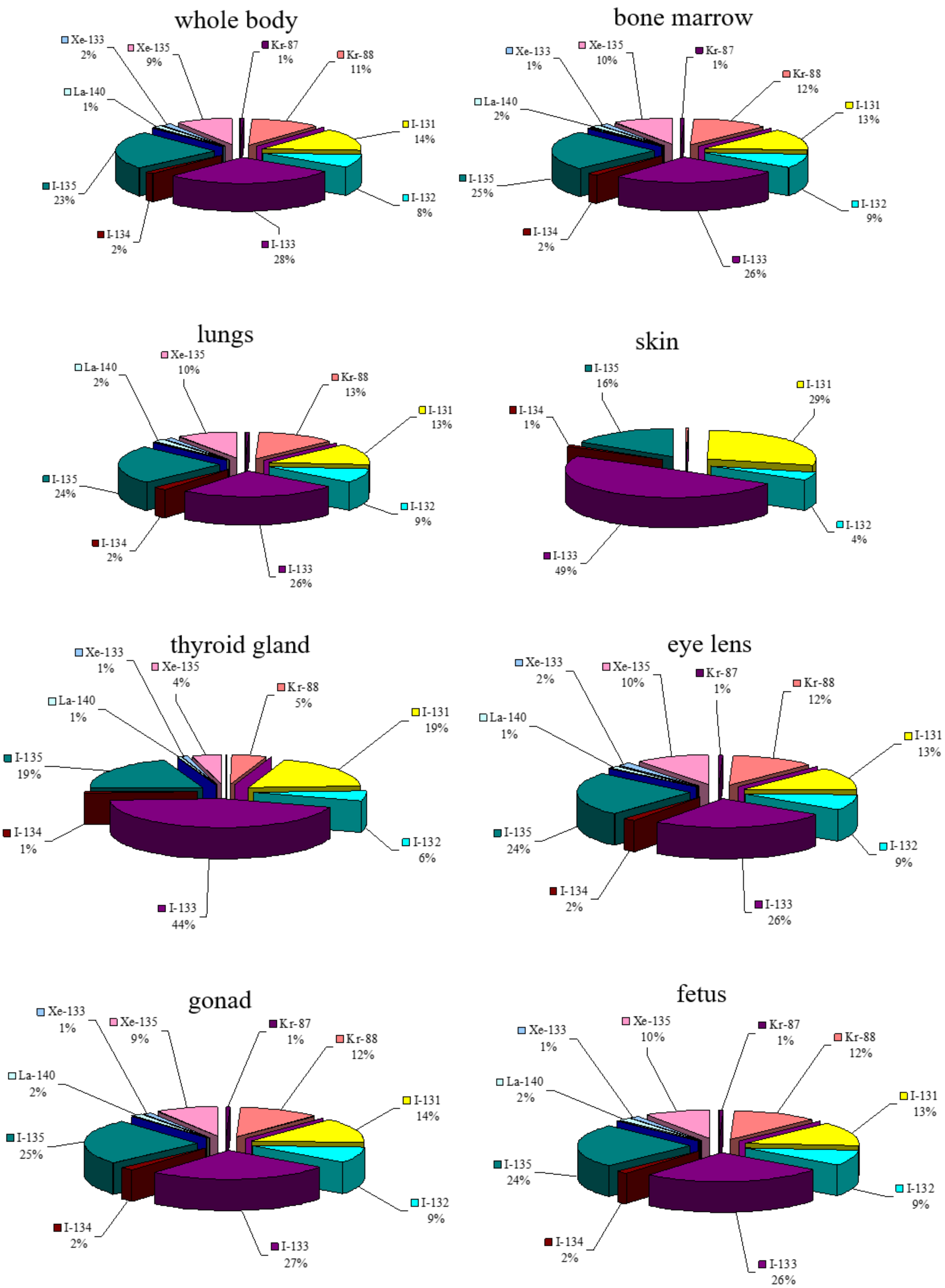


Figure 4.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

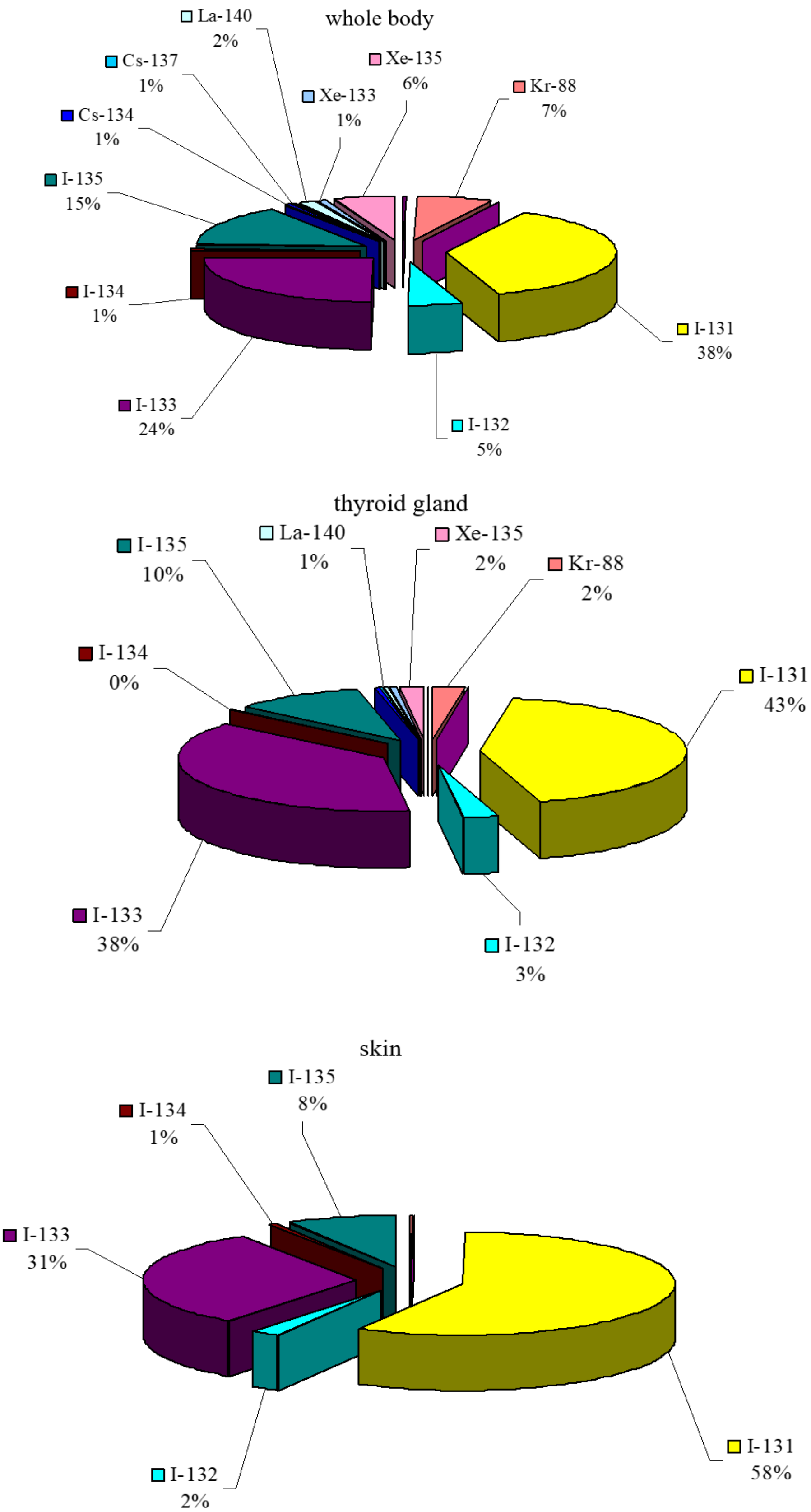
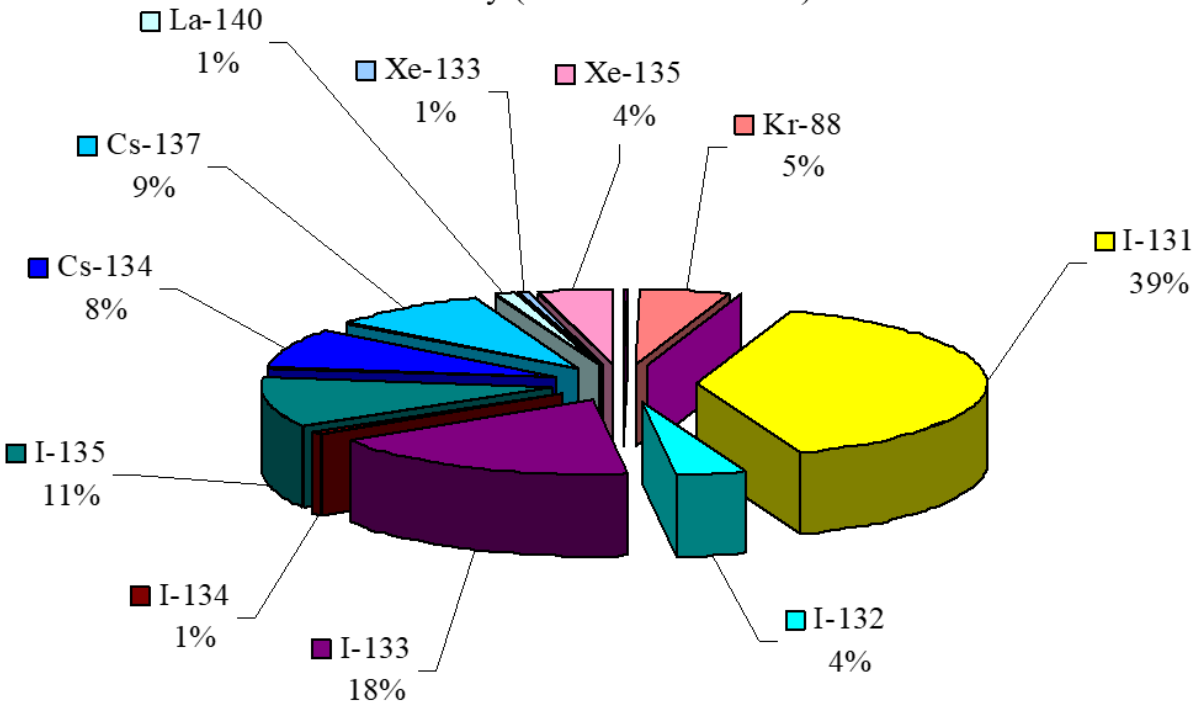


Figure 4.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

whole body (external irradiation)



thyriod gland (children)

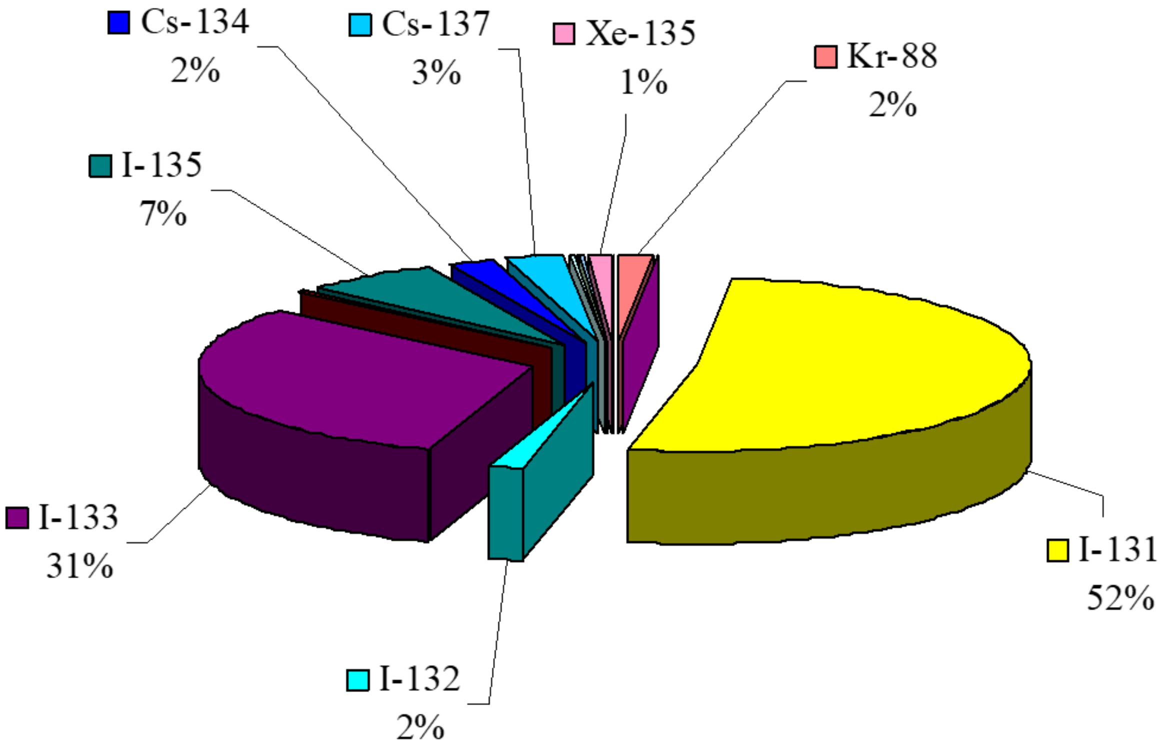


Figure 4.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

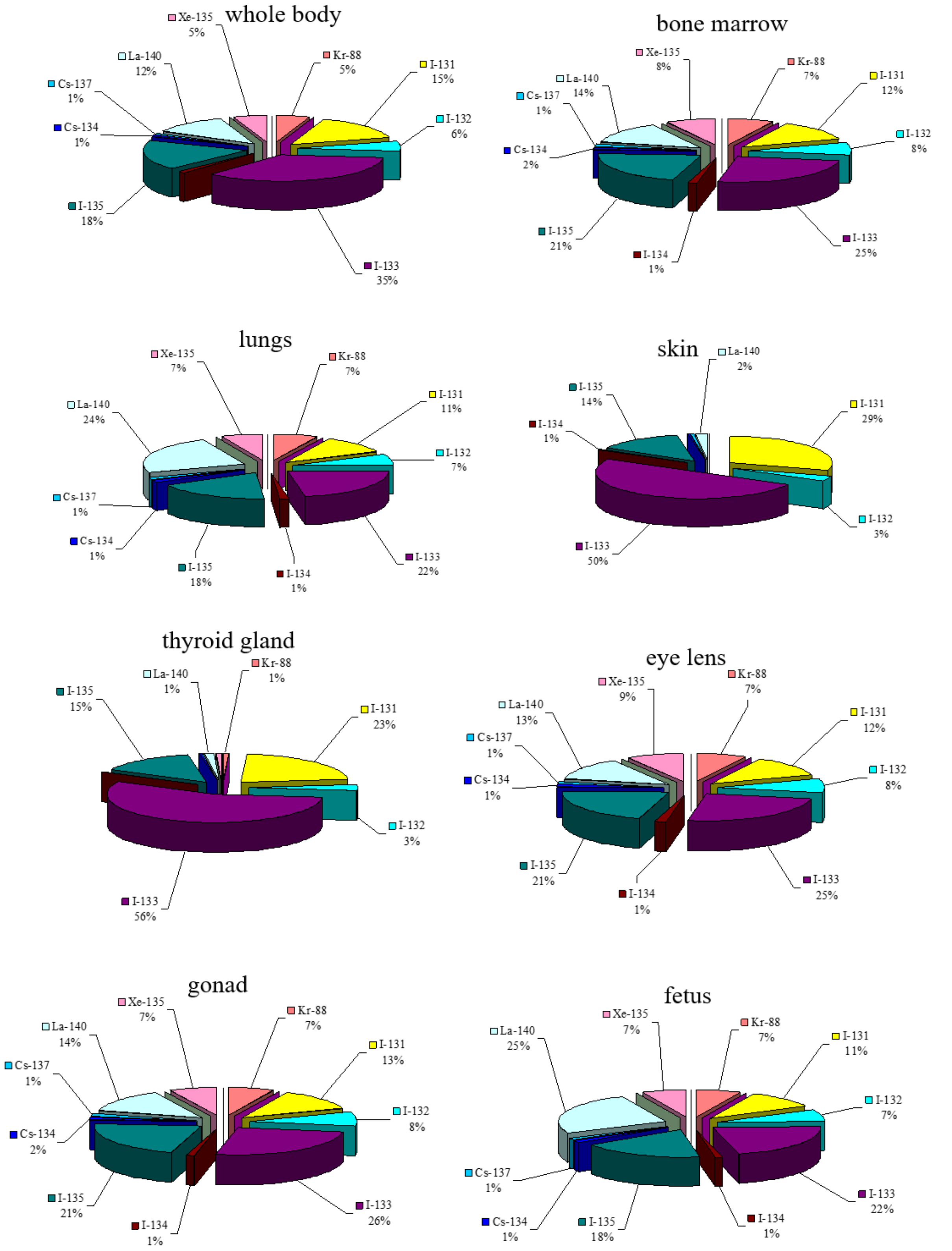


Figure 5.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

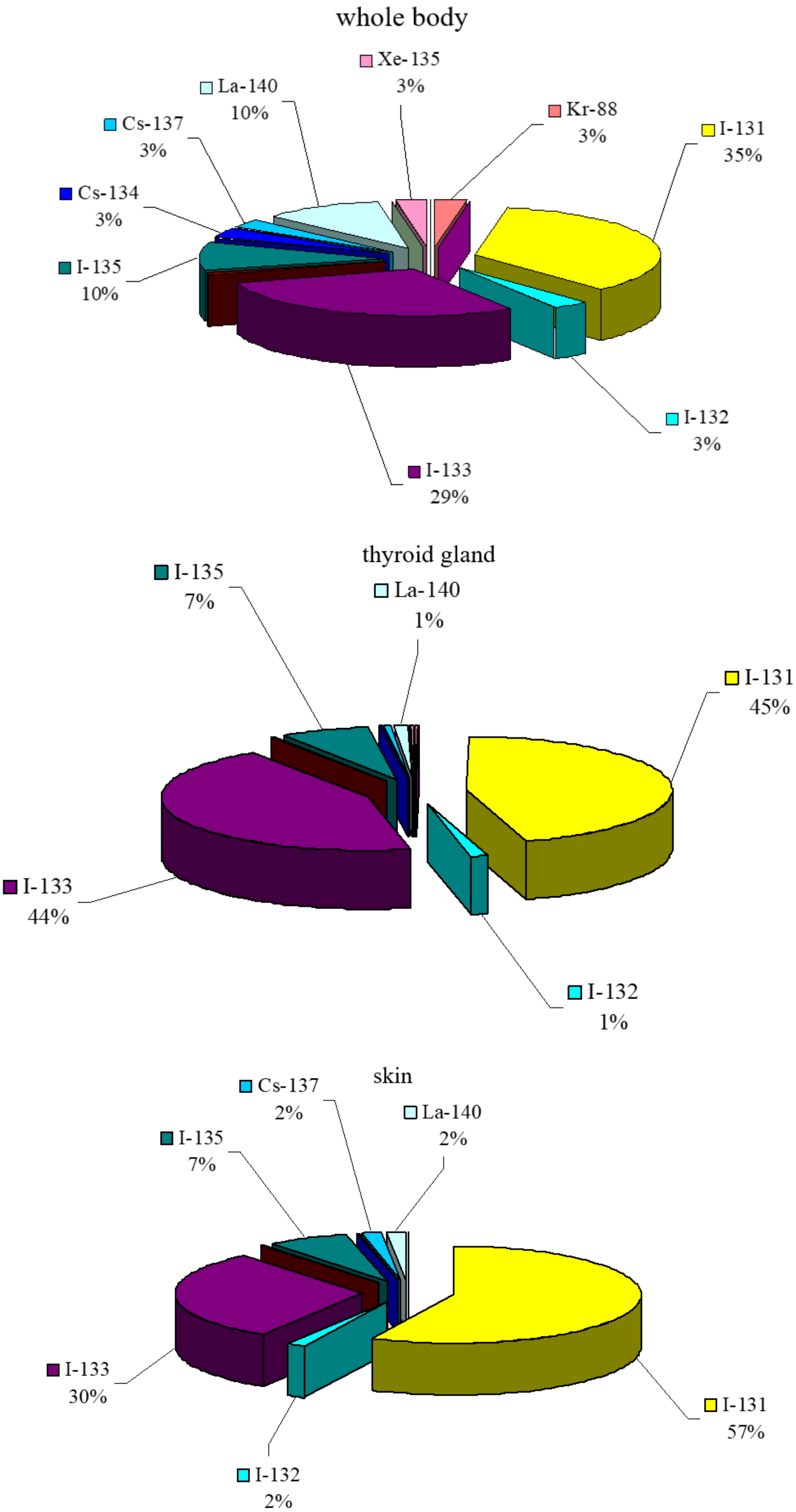


Figure 5.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

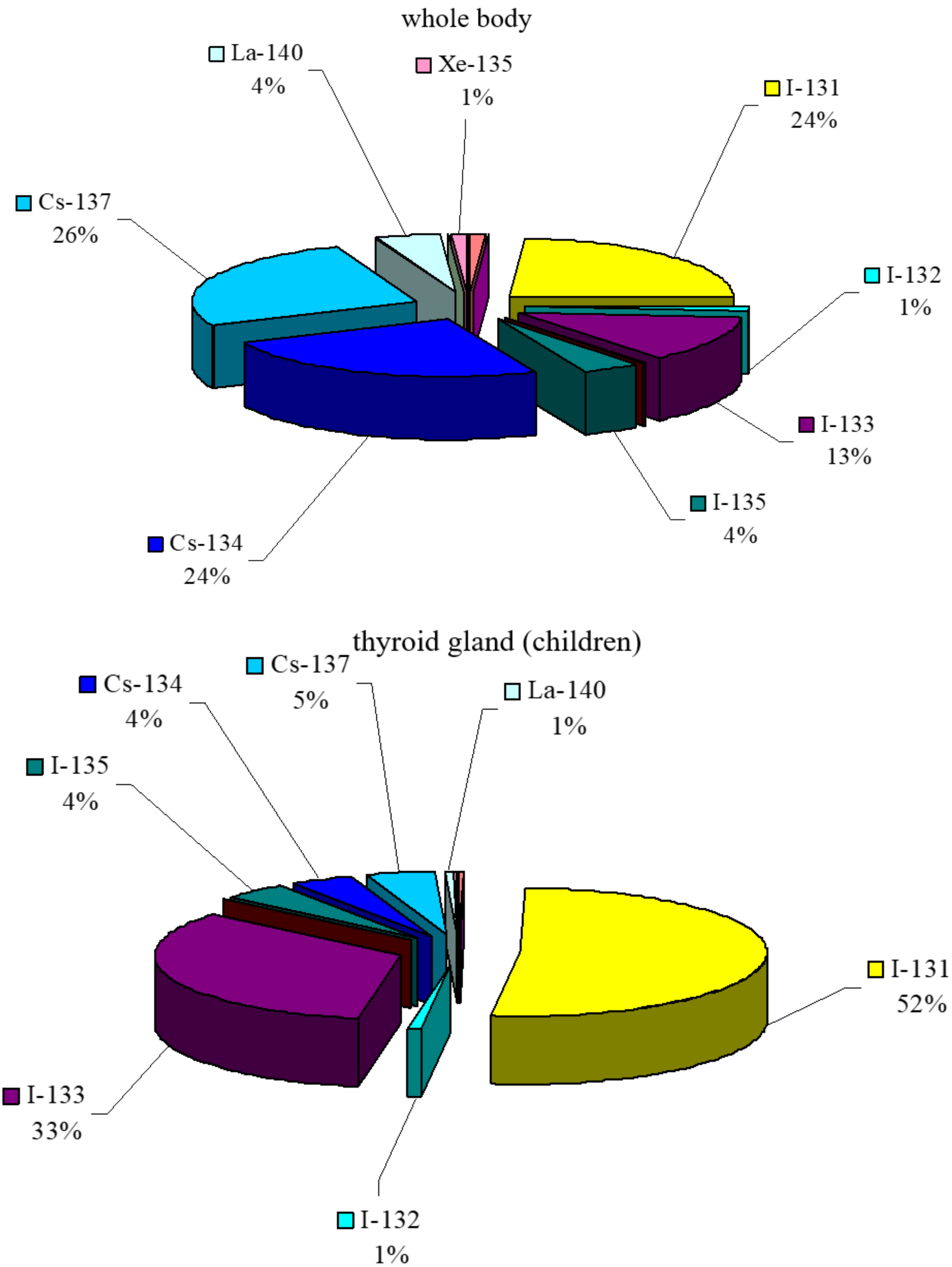


Figure 5.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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

<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 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**

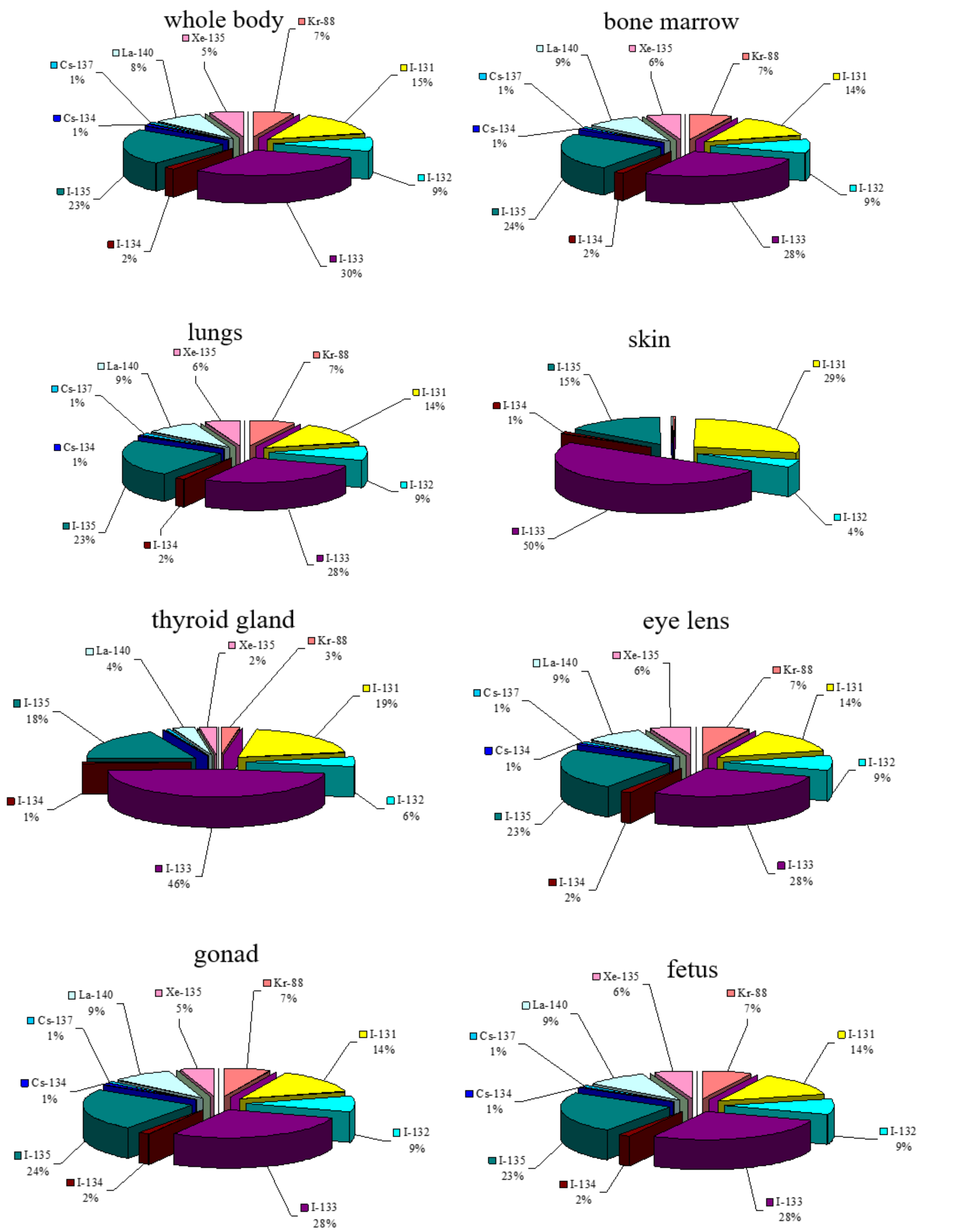


Figure 5.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

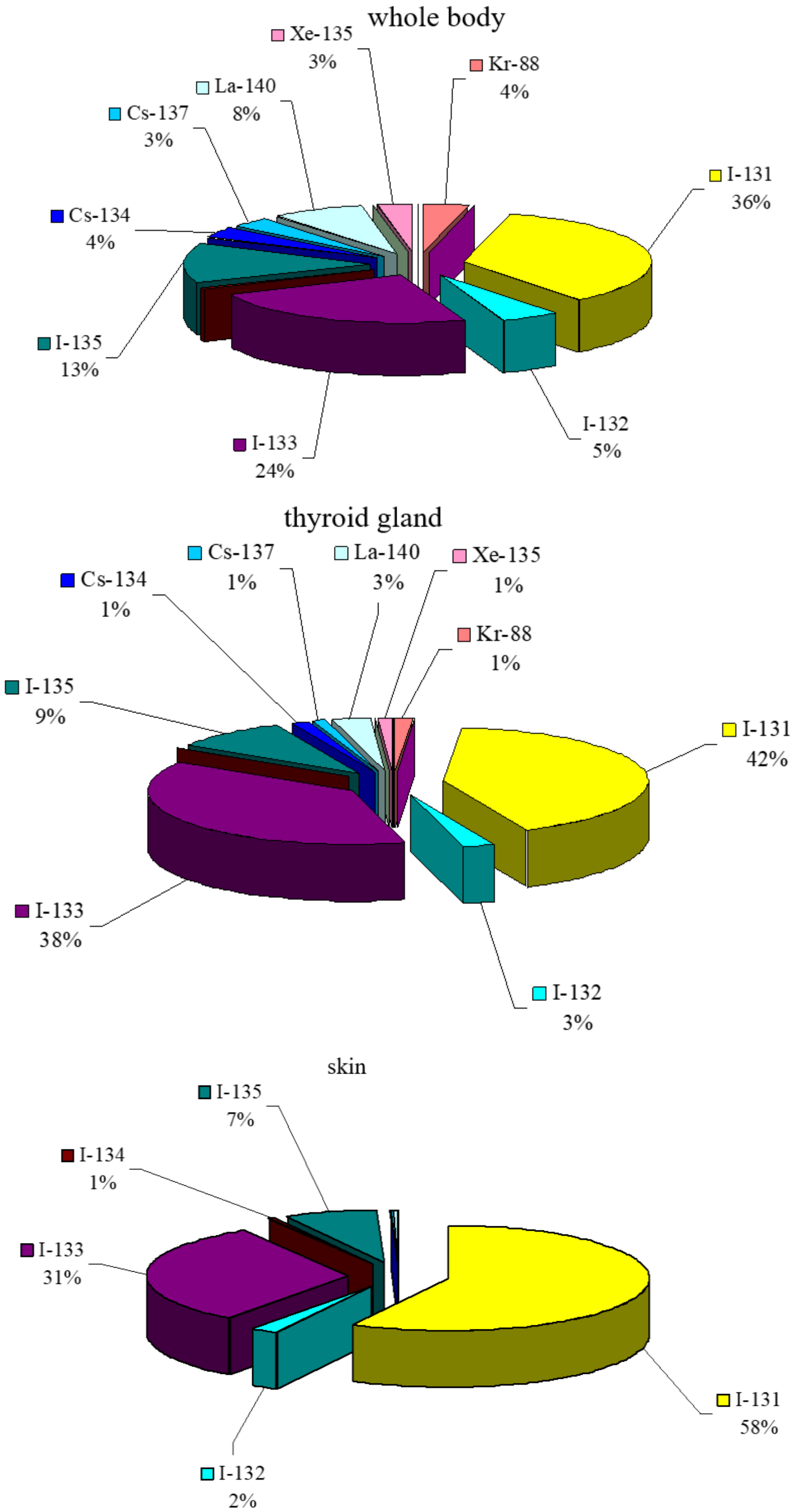
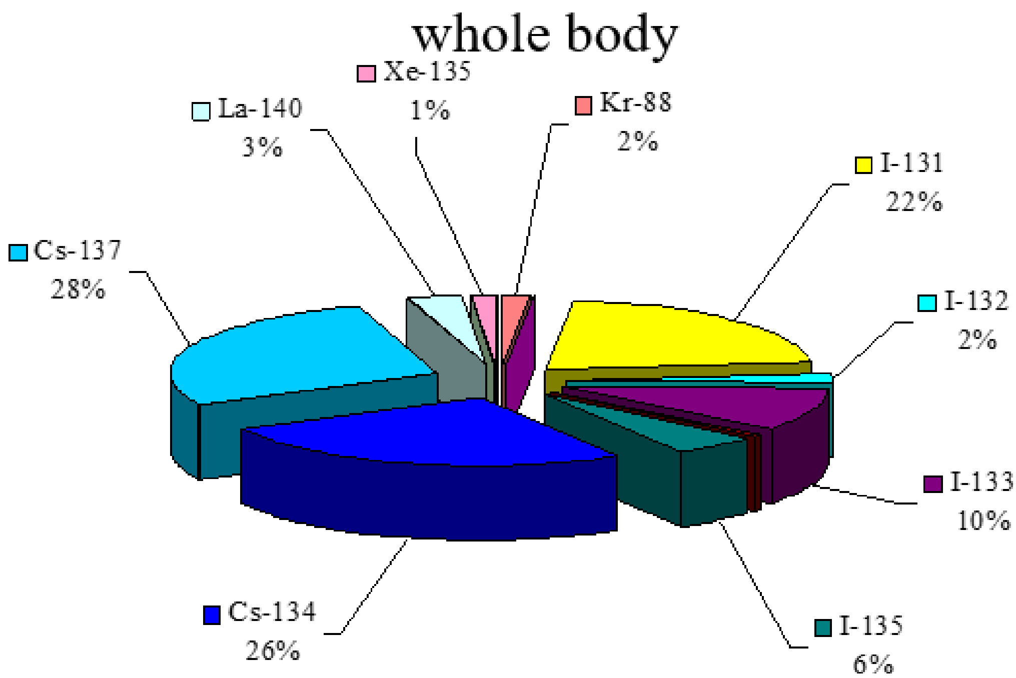


Figure 5.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



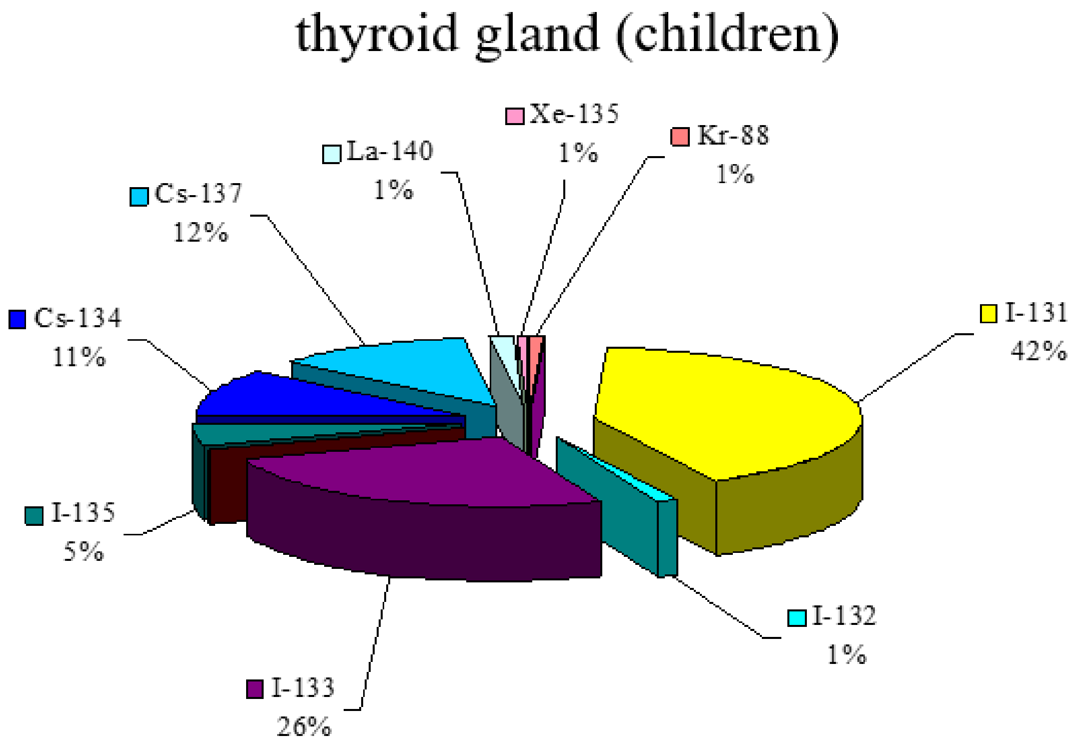


Figure 5.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

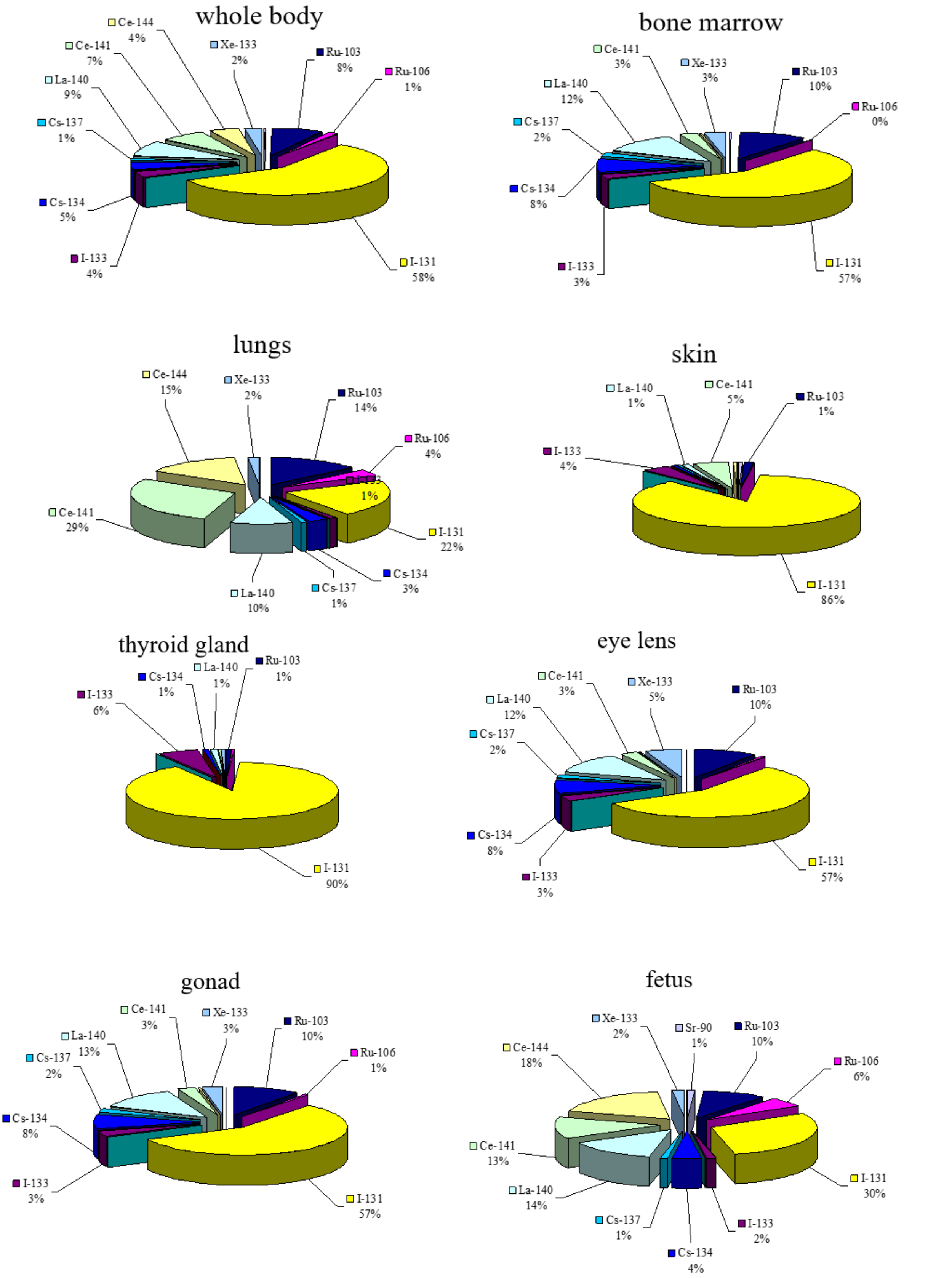


Figure 6.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

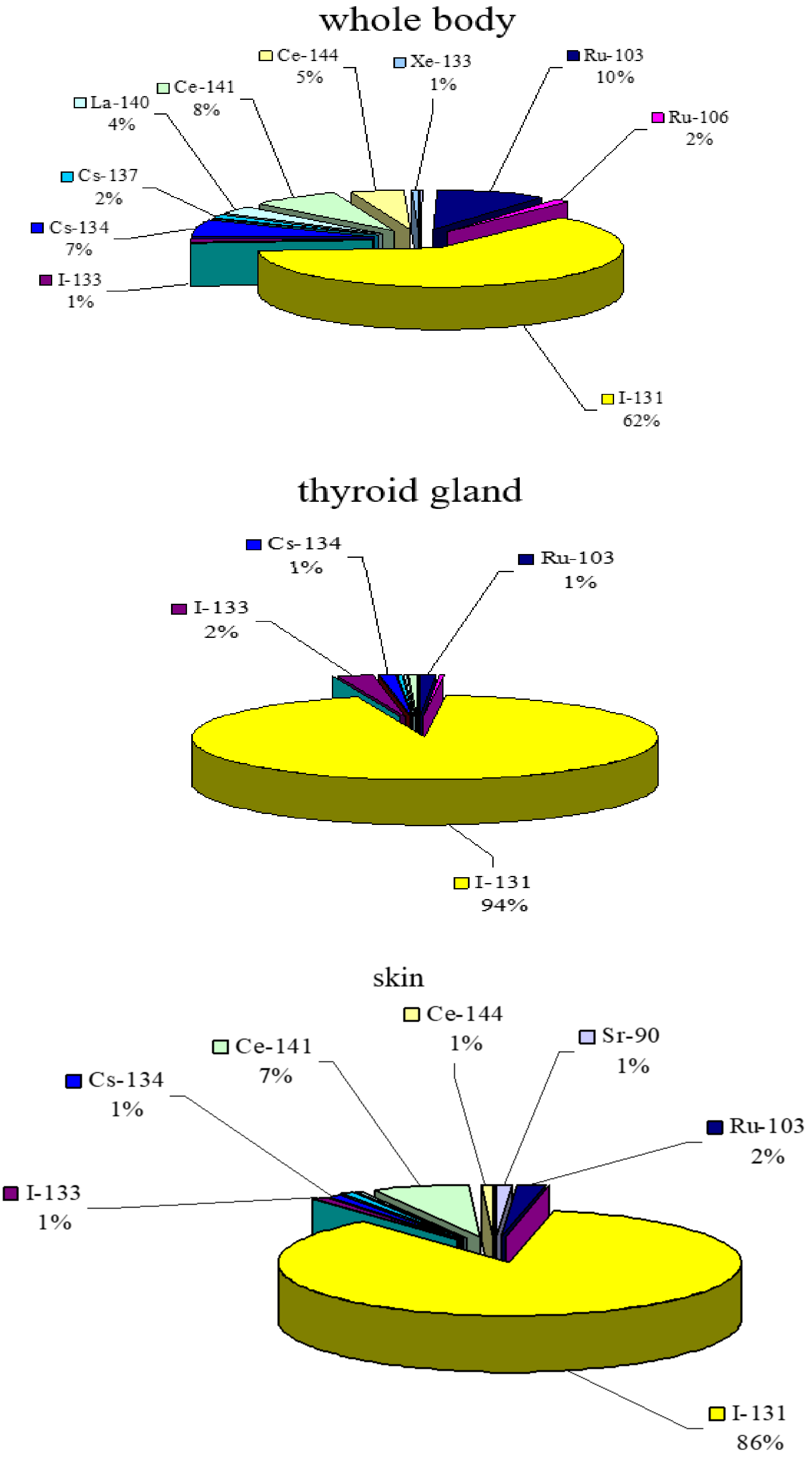
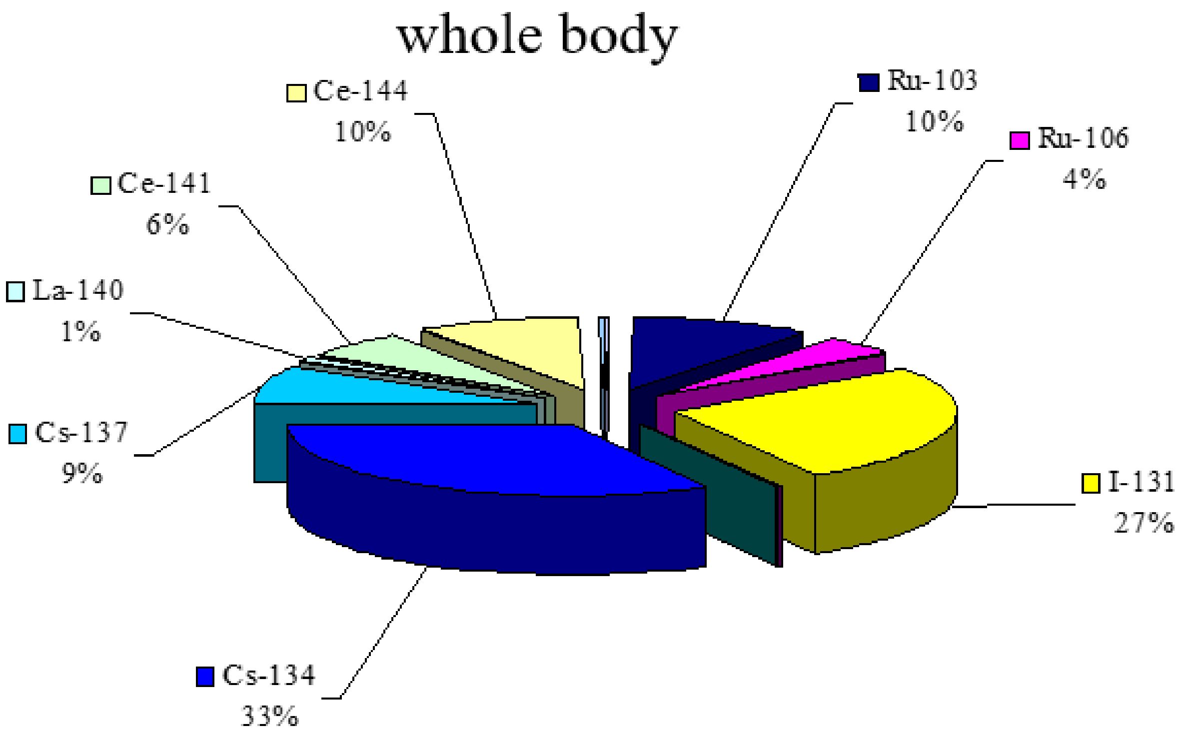


Figure 6.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



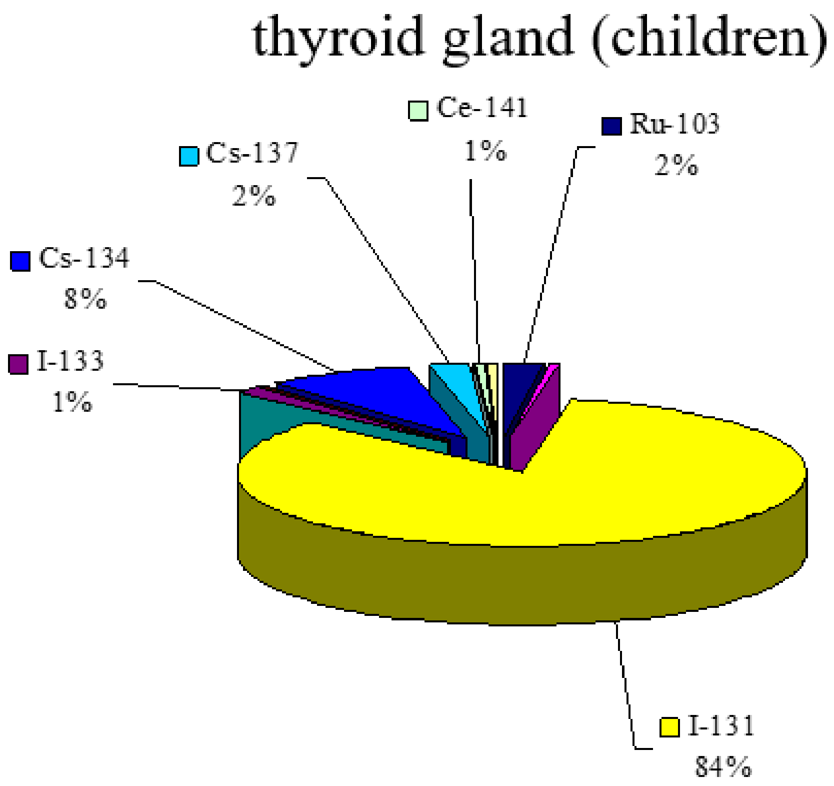


Figure 6.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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.

6.2.2 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 0.0010 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**

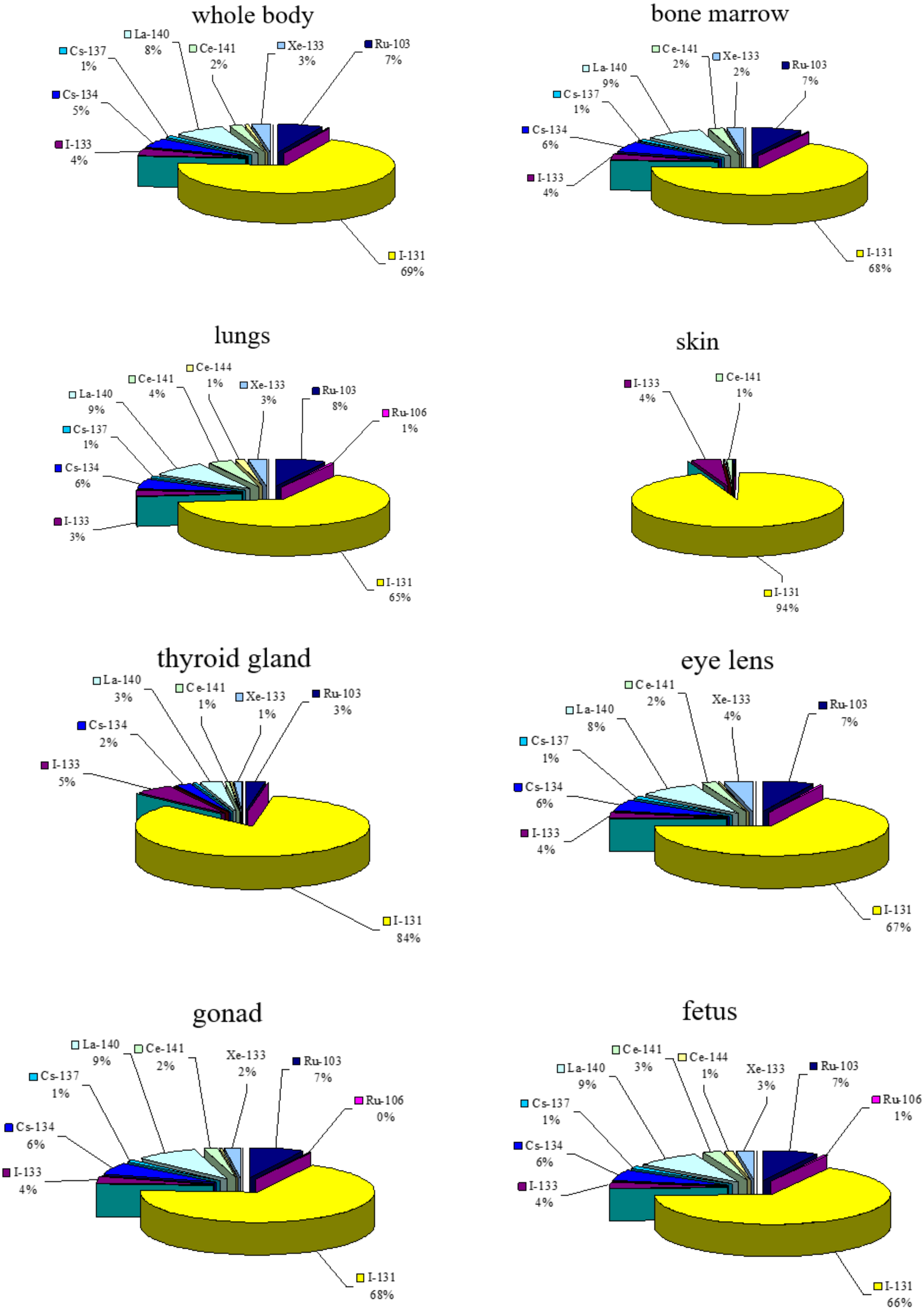


Figure 6.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

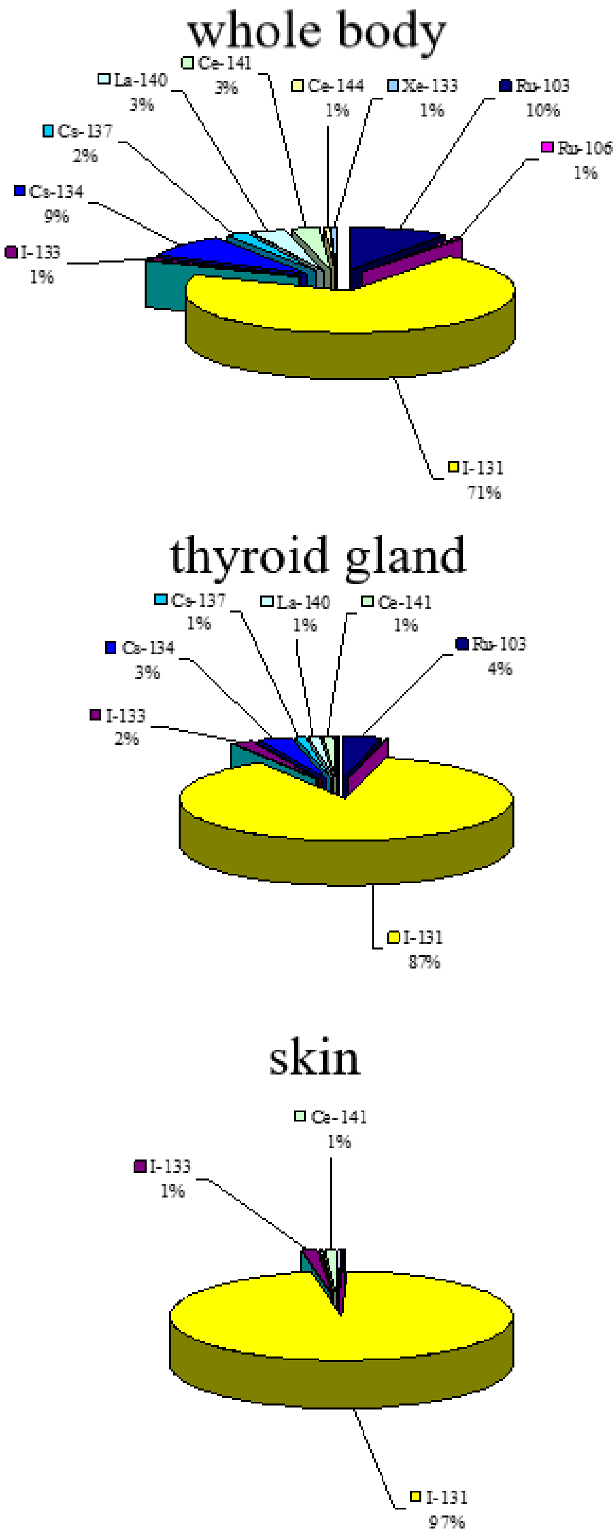
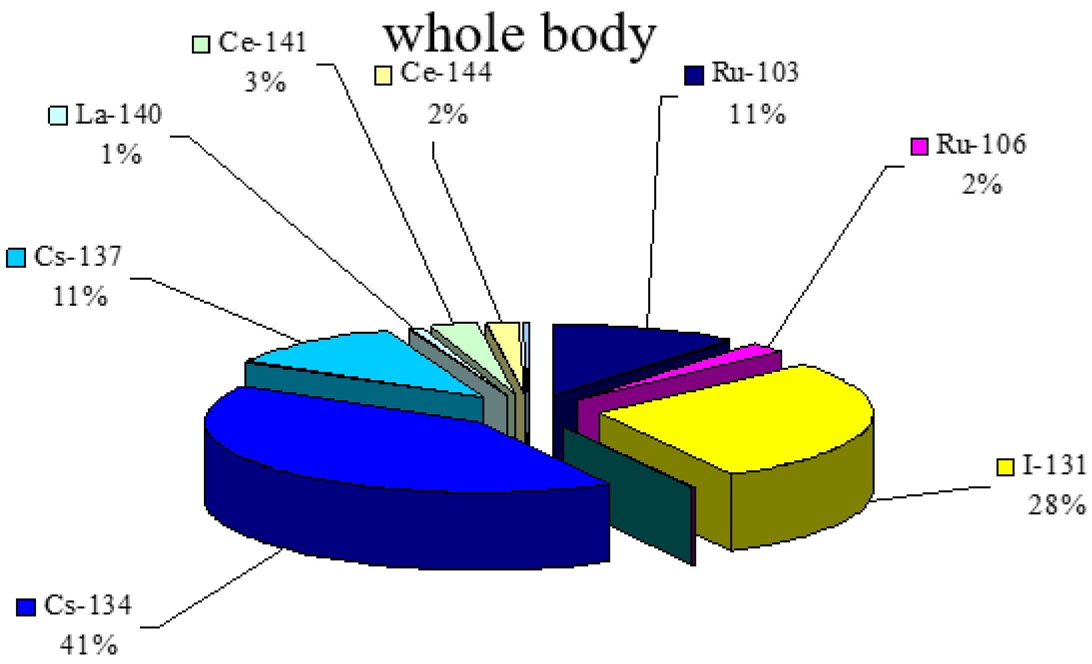


Figure 6.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



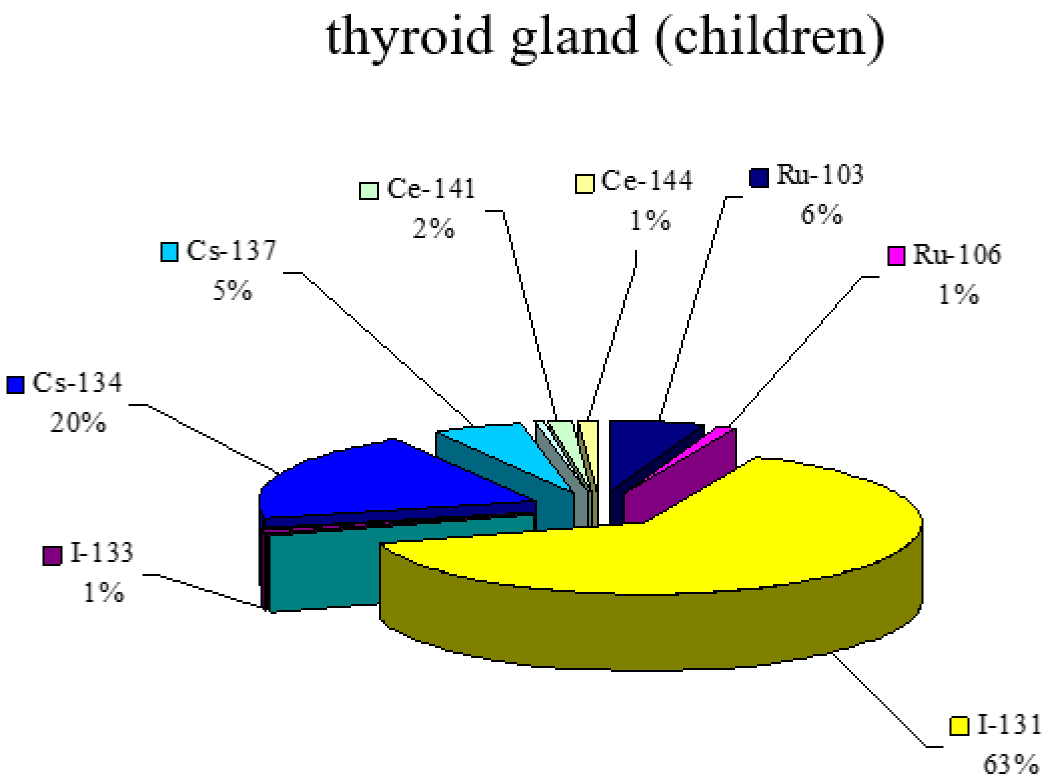


Figure 6.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

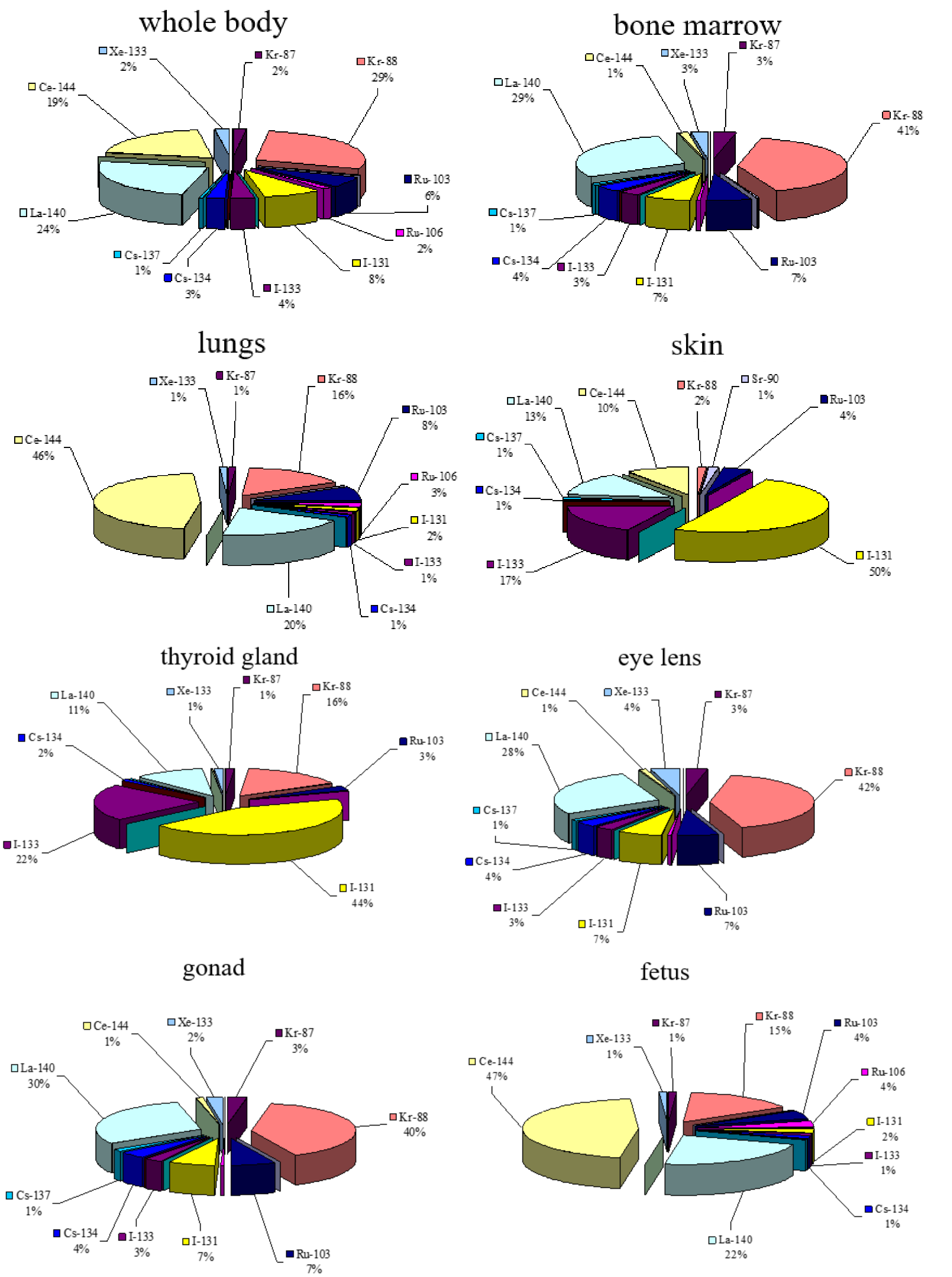


Figure 7.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

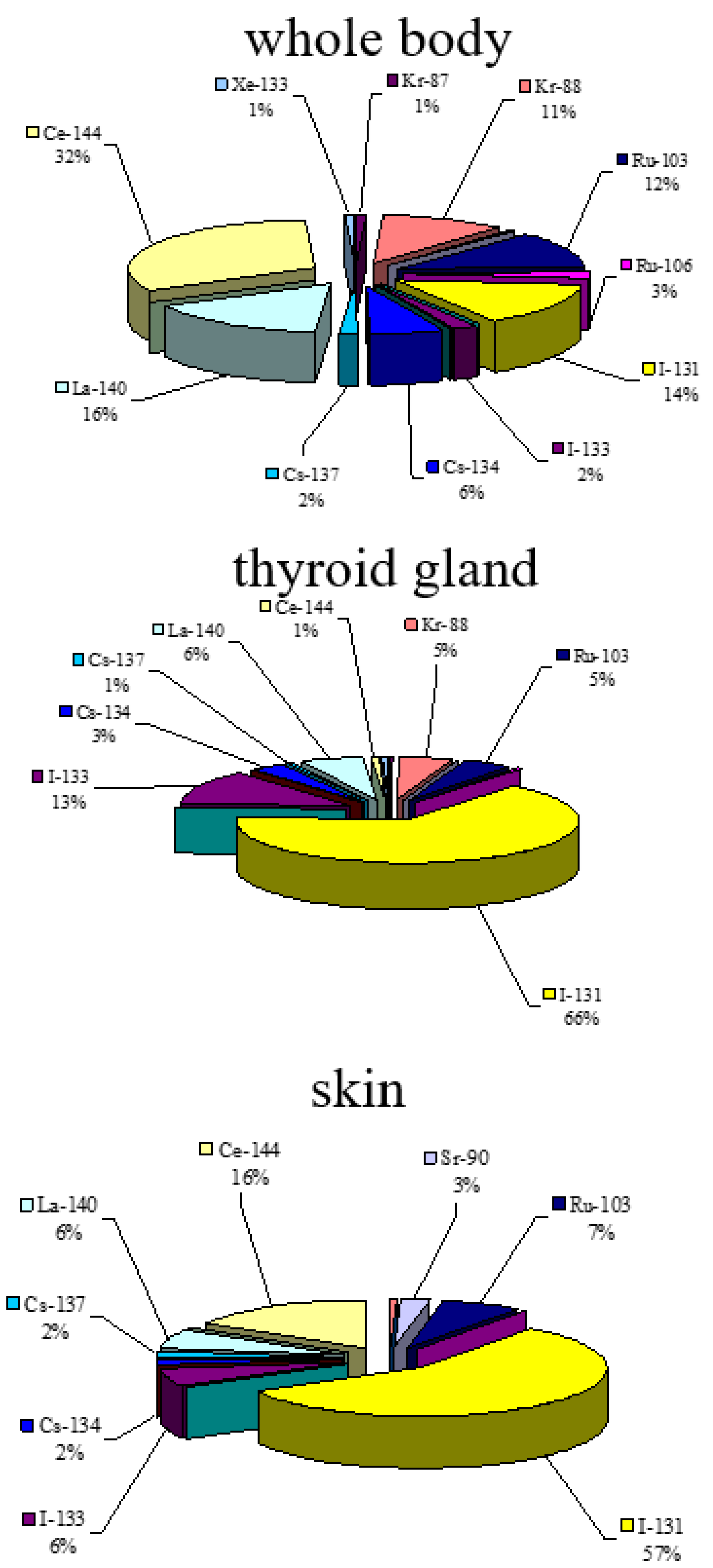
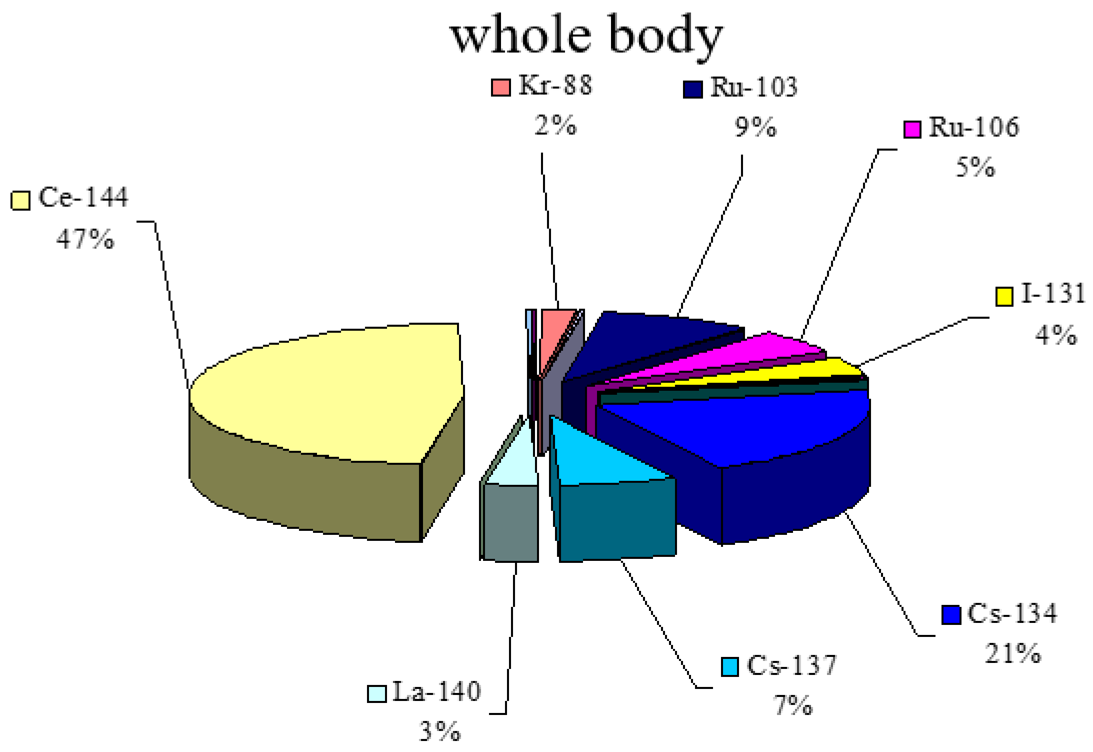


Figure 7.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



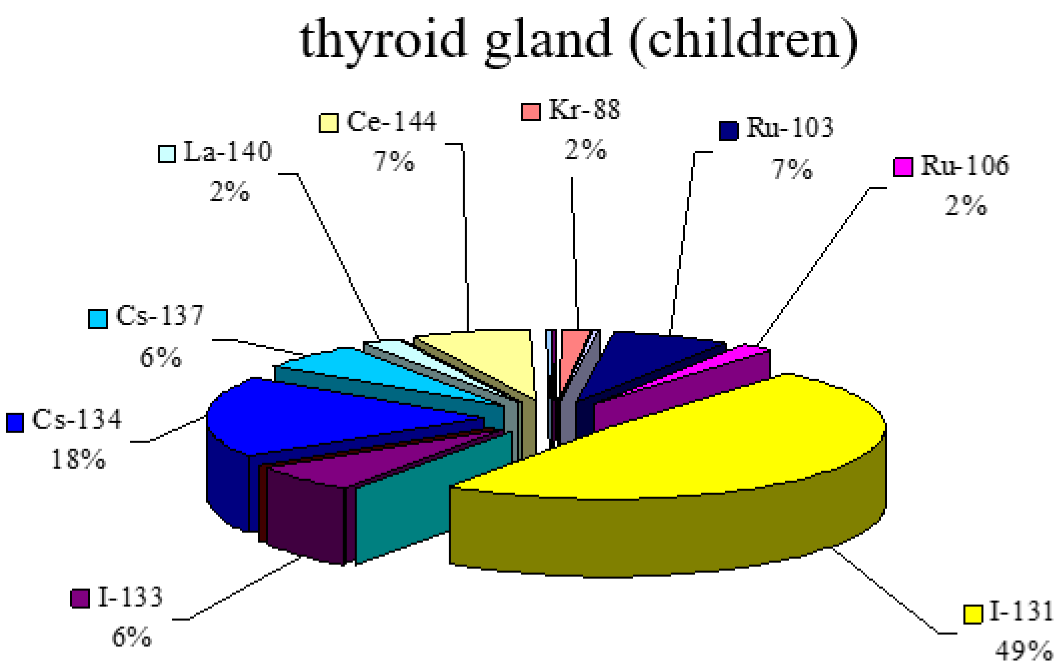


Figure 7.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

7.2.1 Radiation 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**

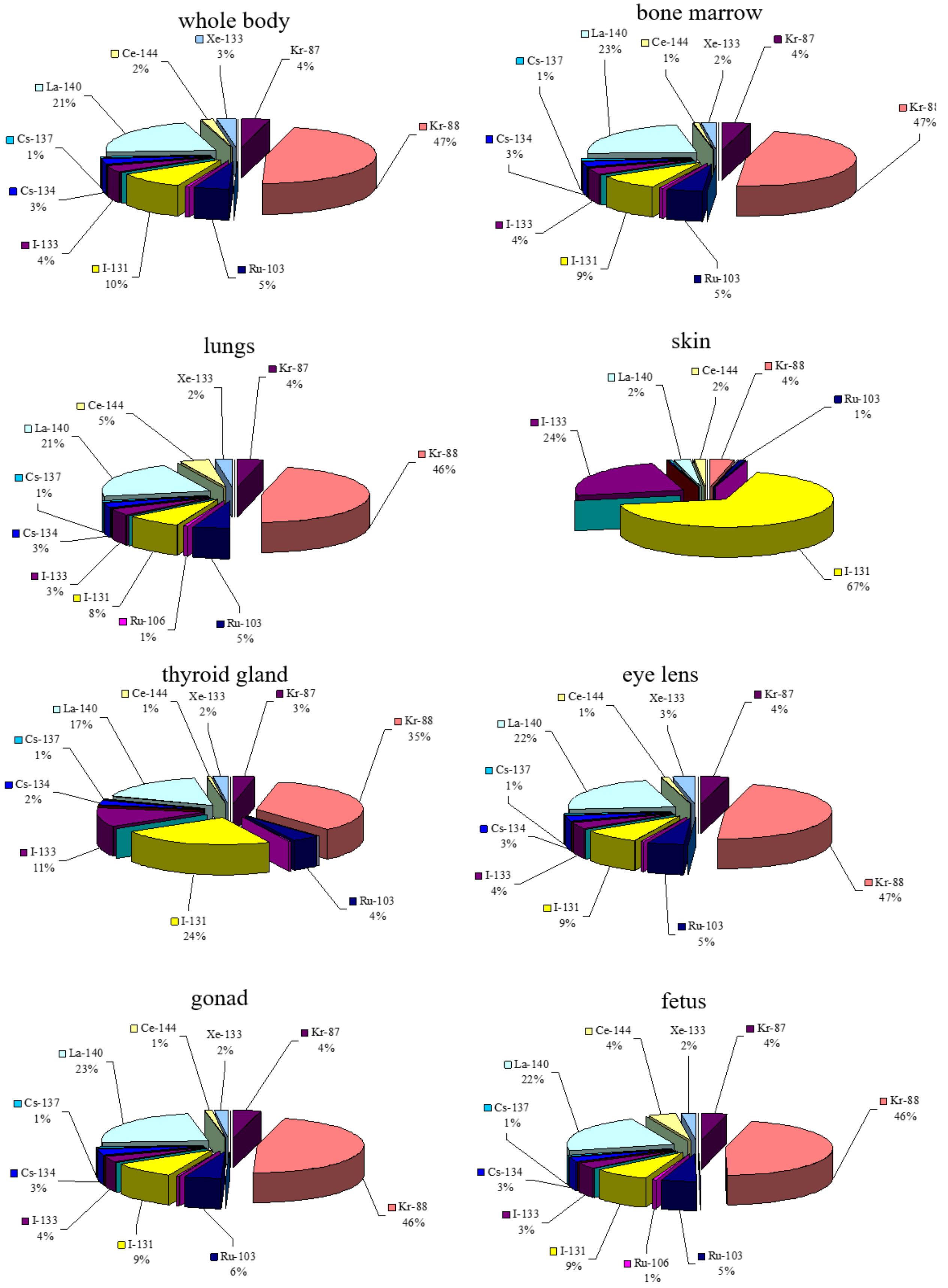
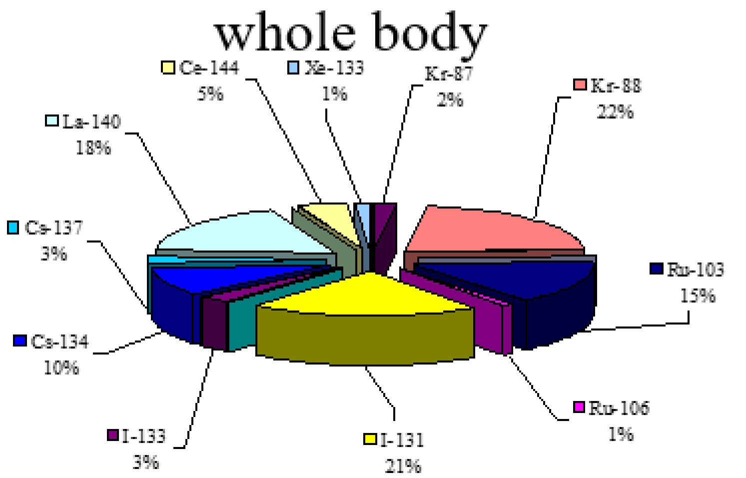
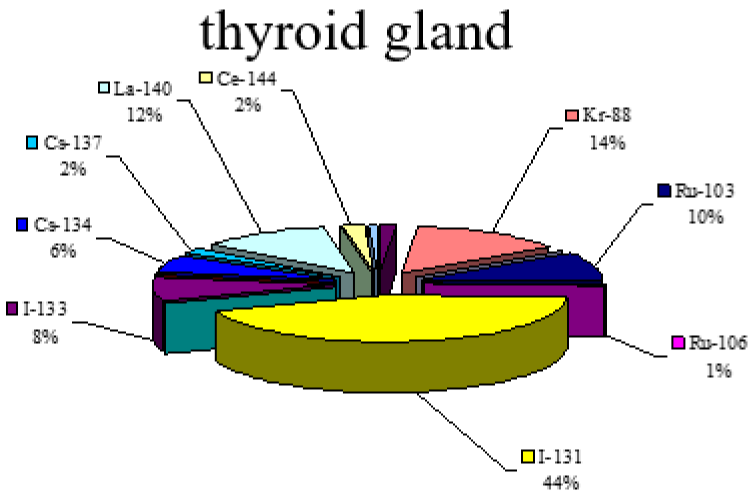


Figure 7.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period





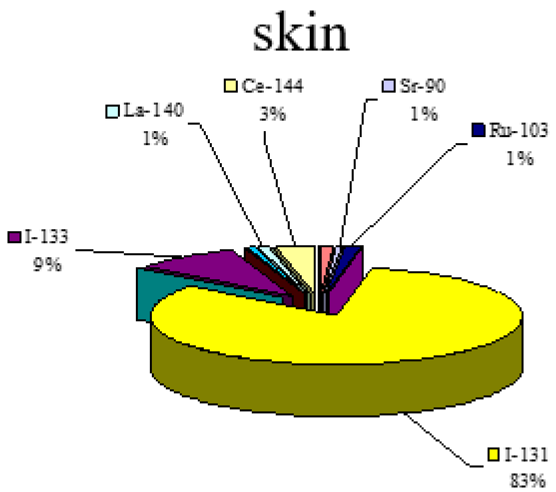
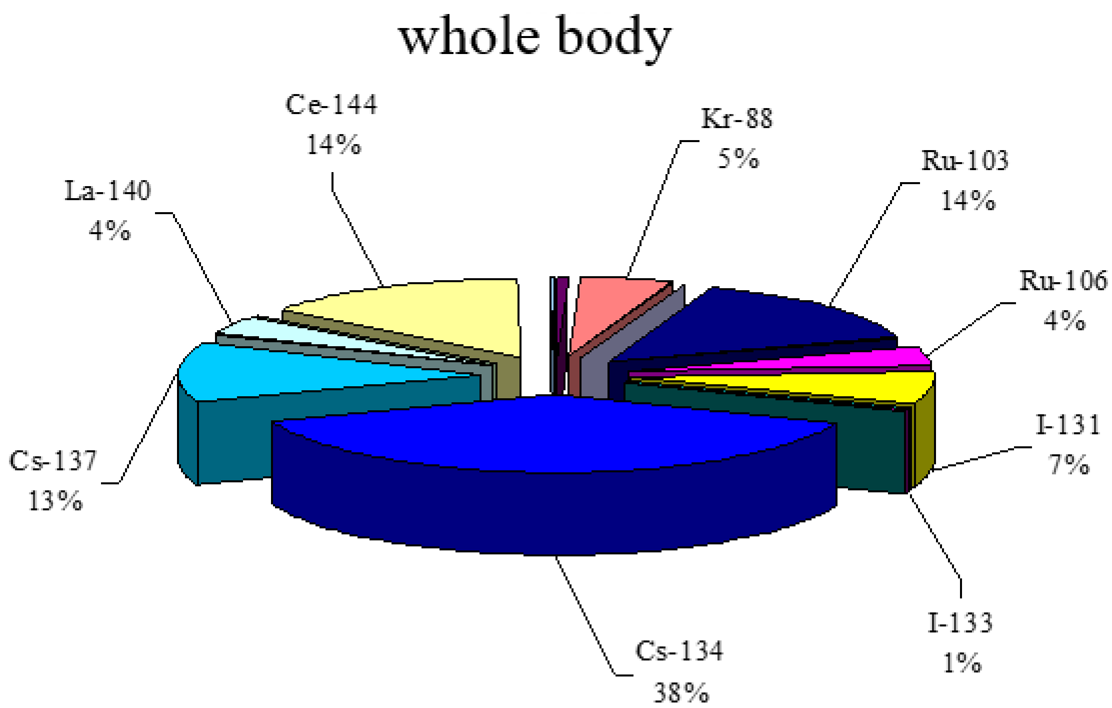


Figure 7.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



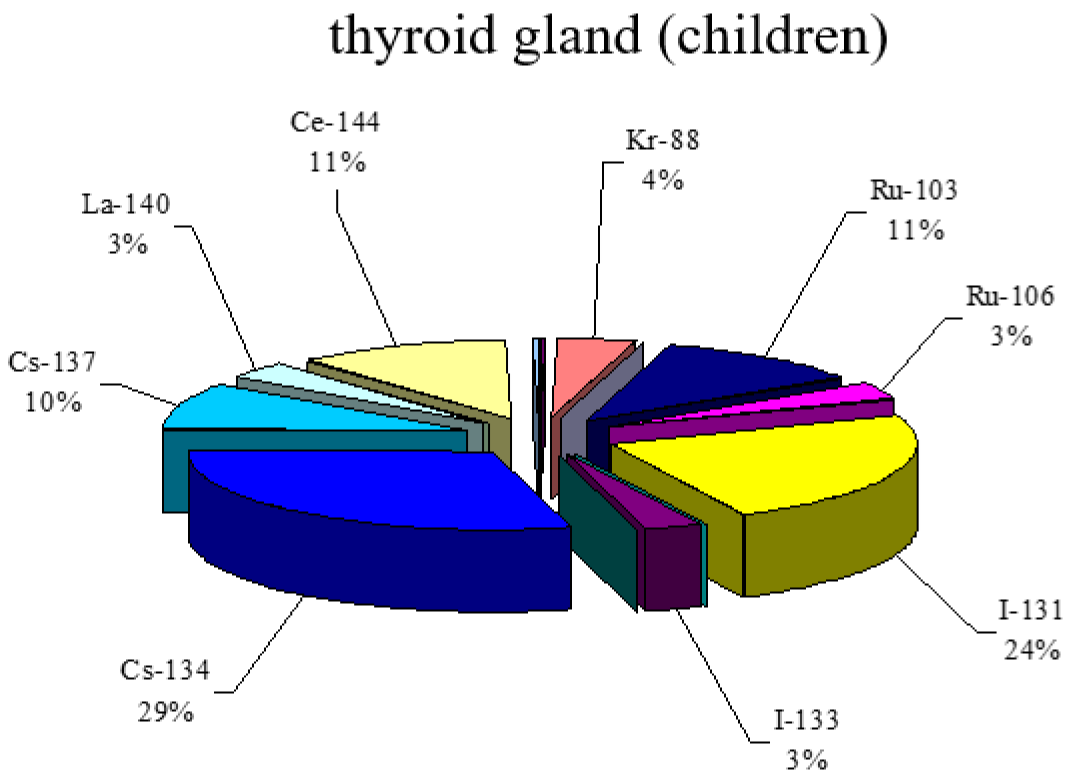


Figure 7.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

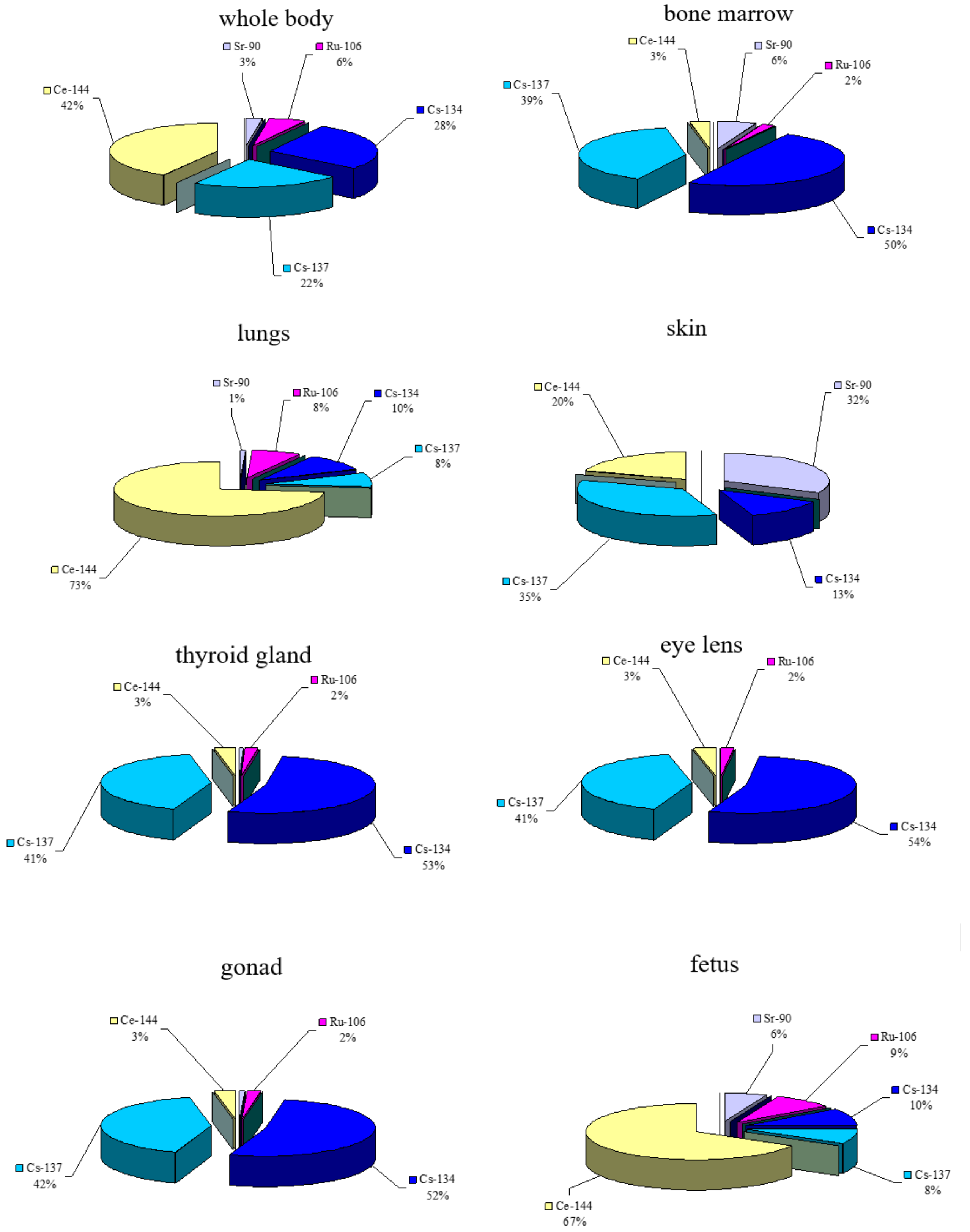


Figure 8.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

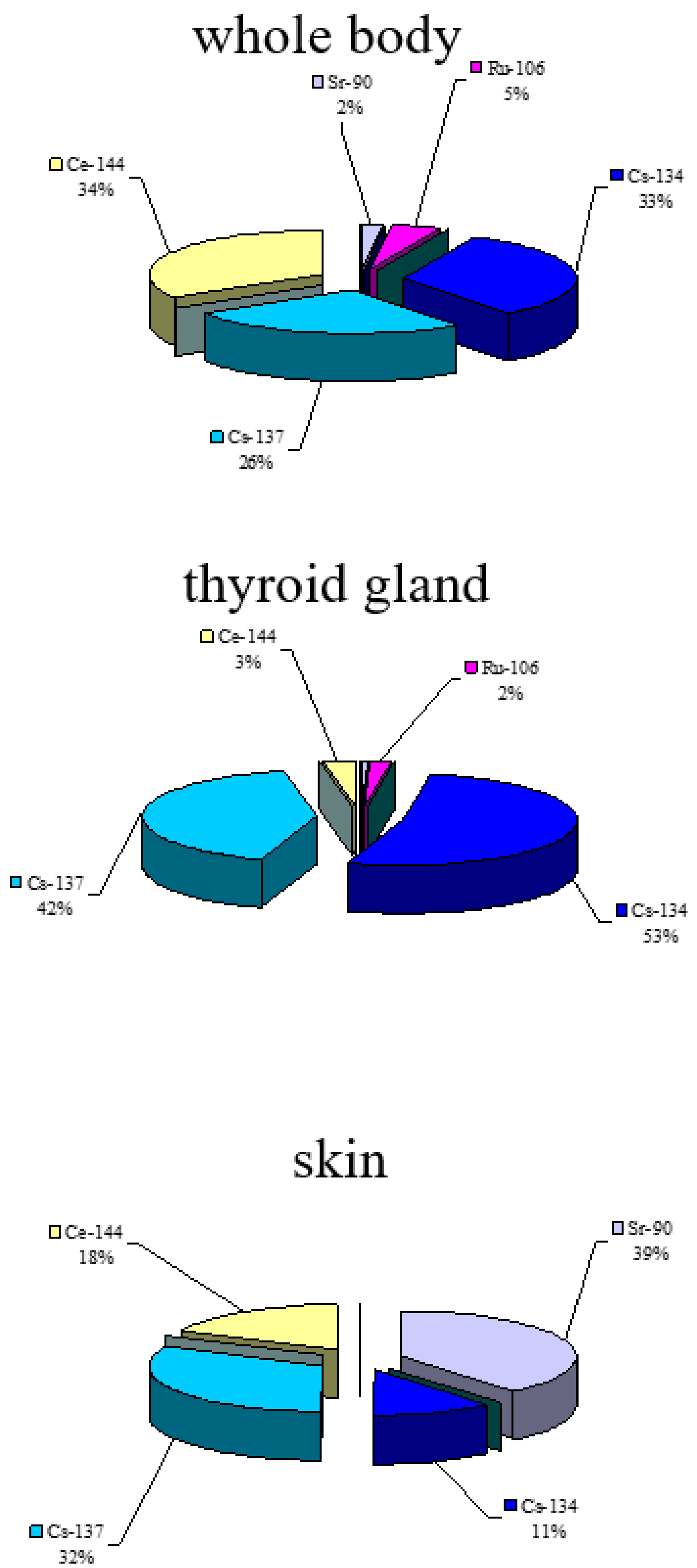


Figure 8.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period

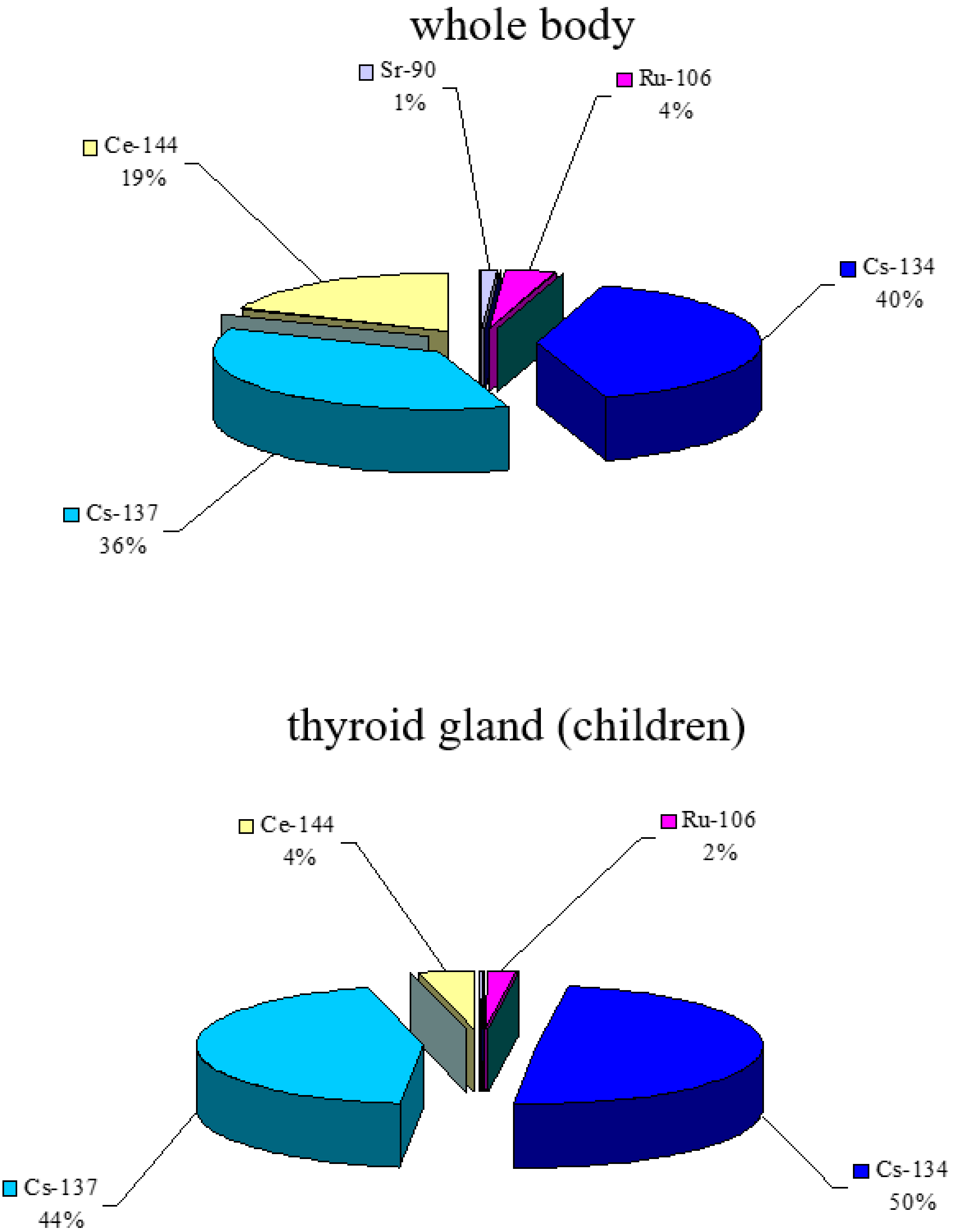


Figure 8.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

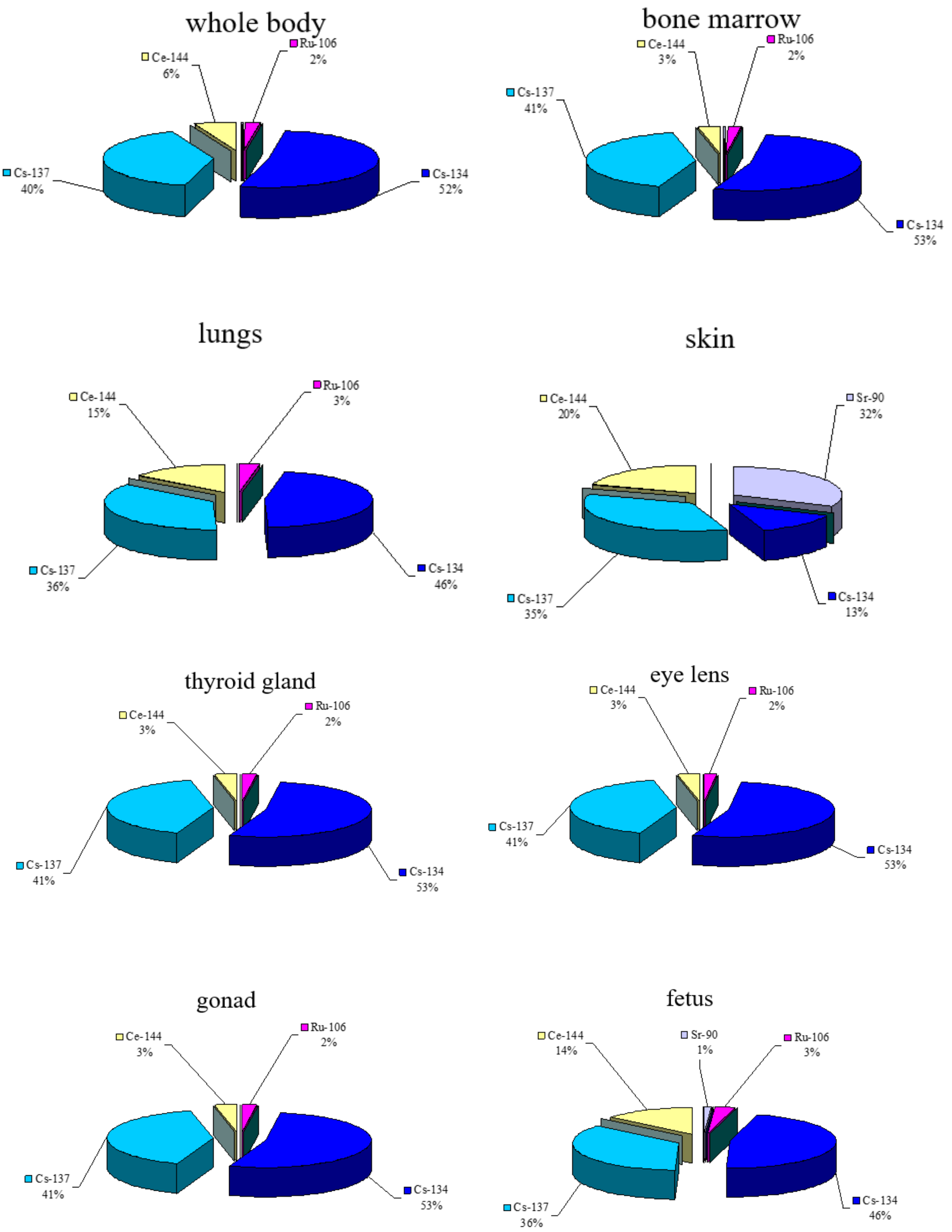


Figure 8.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

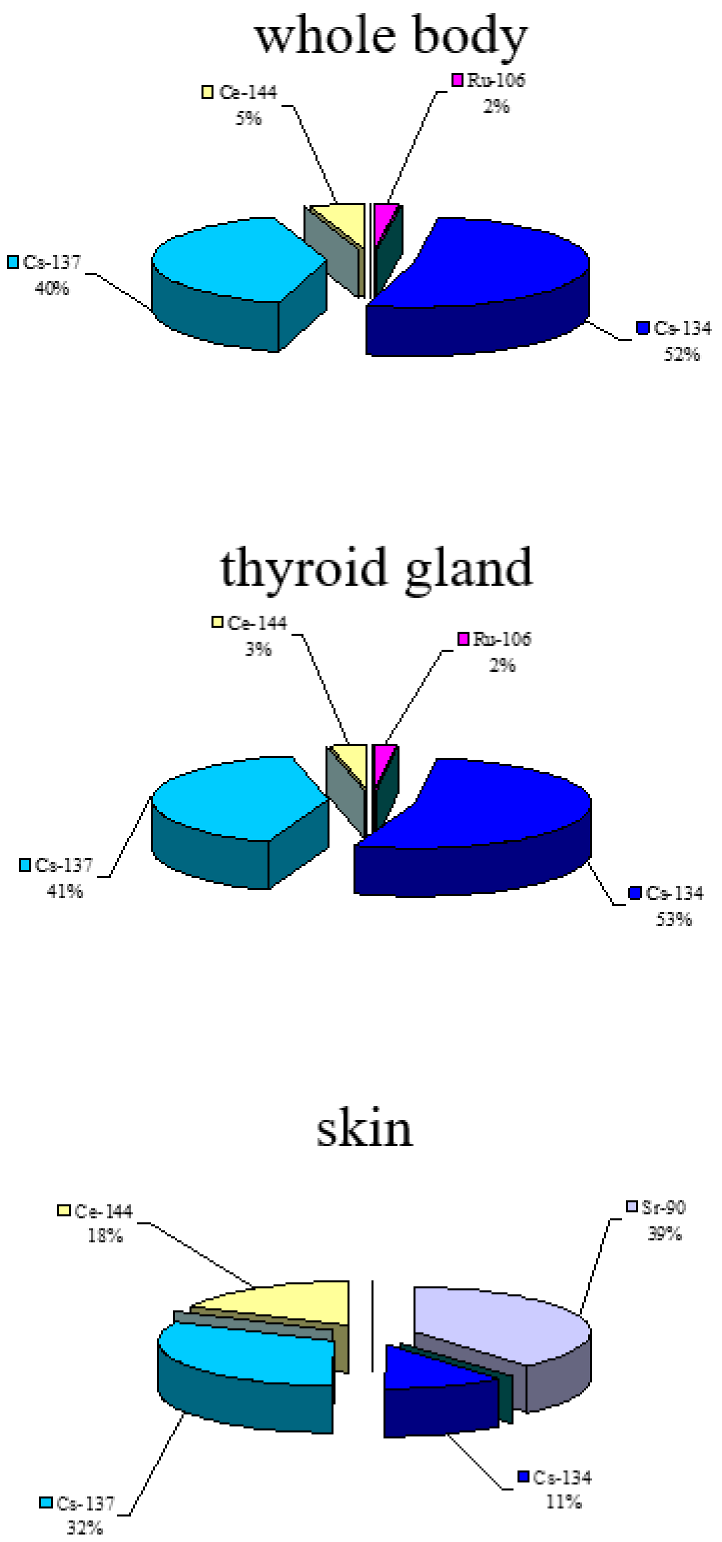
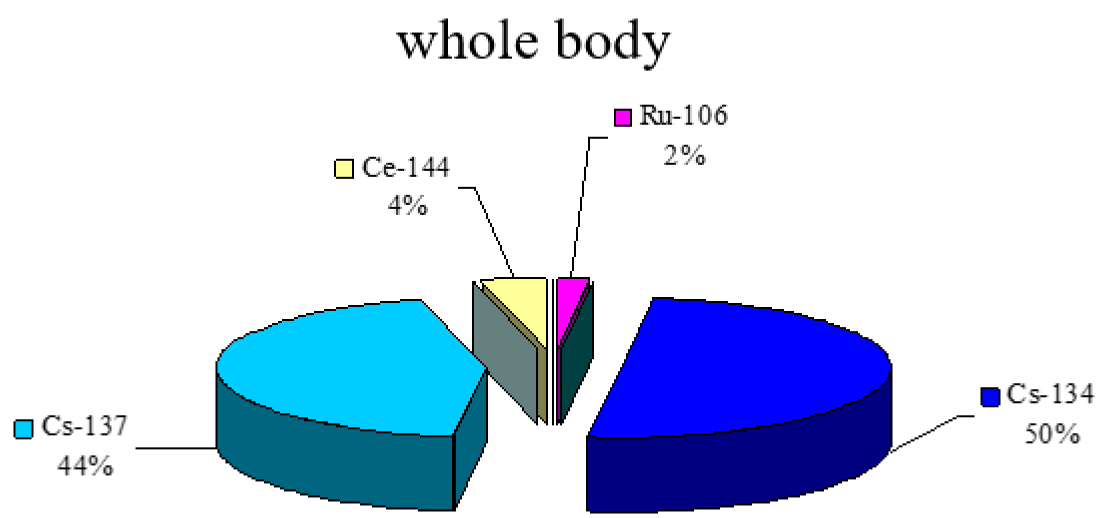


Figure 8.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



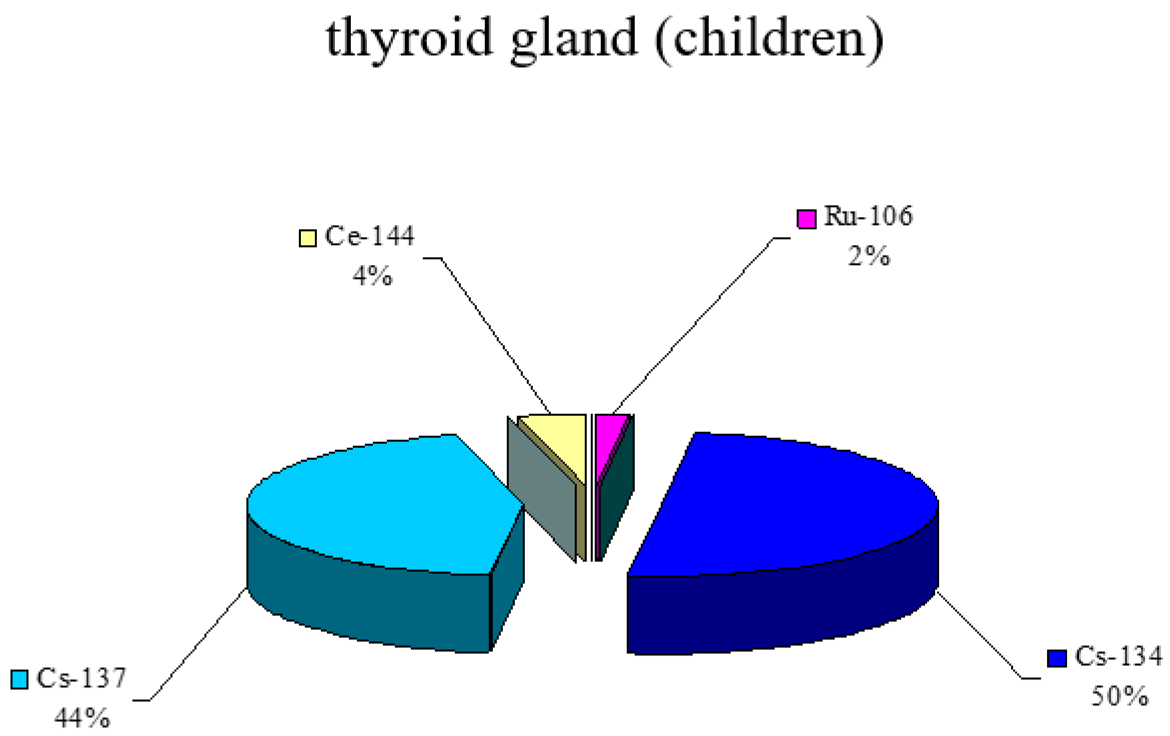


Figure 8.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

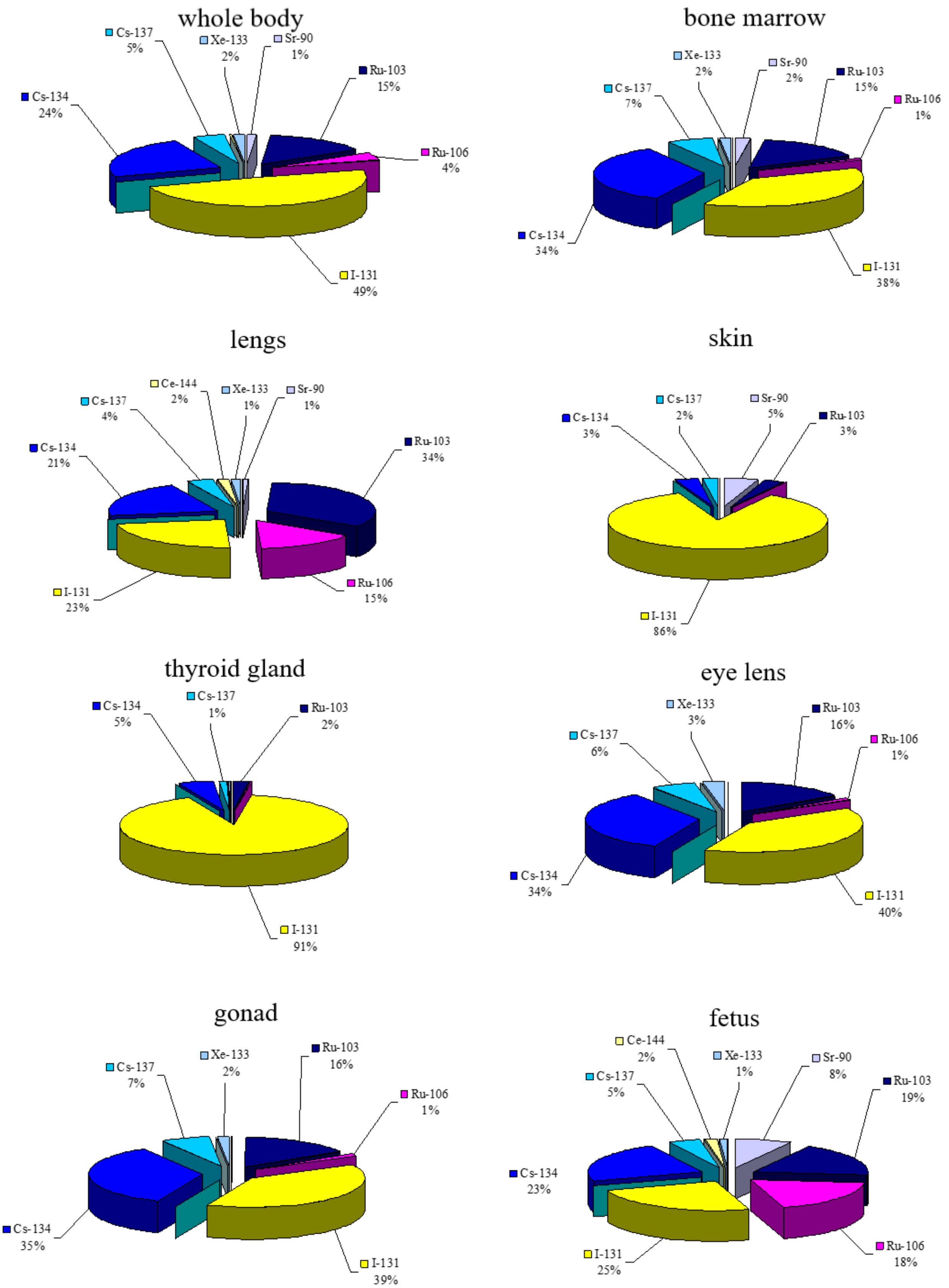


Figure 9.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

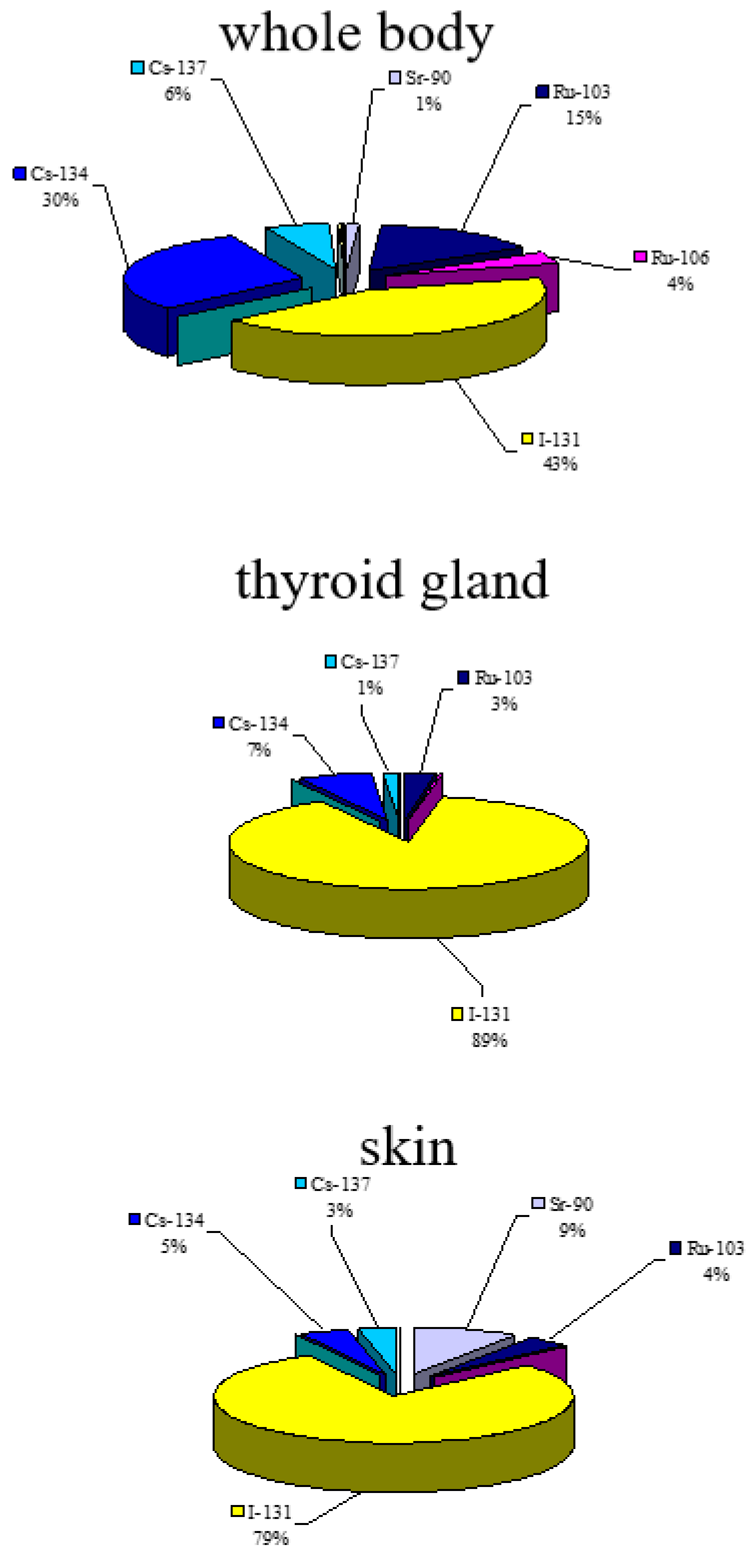
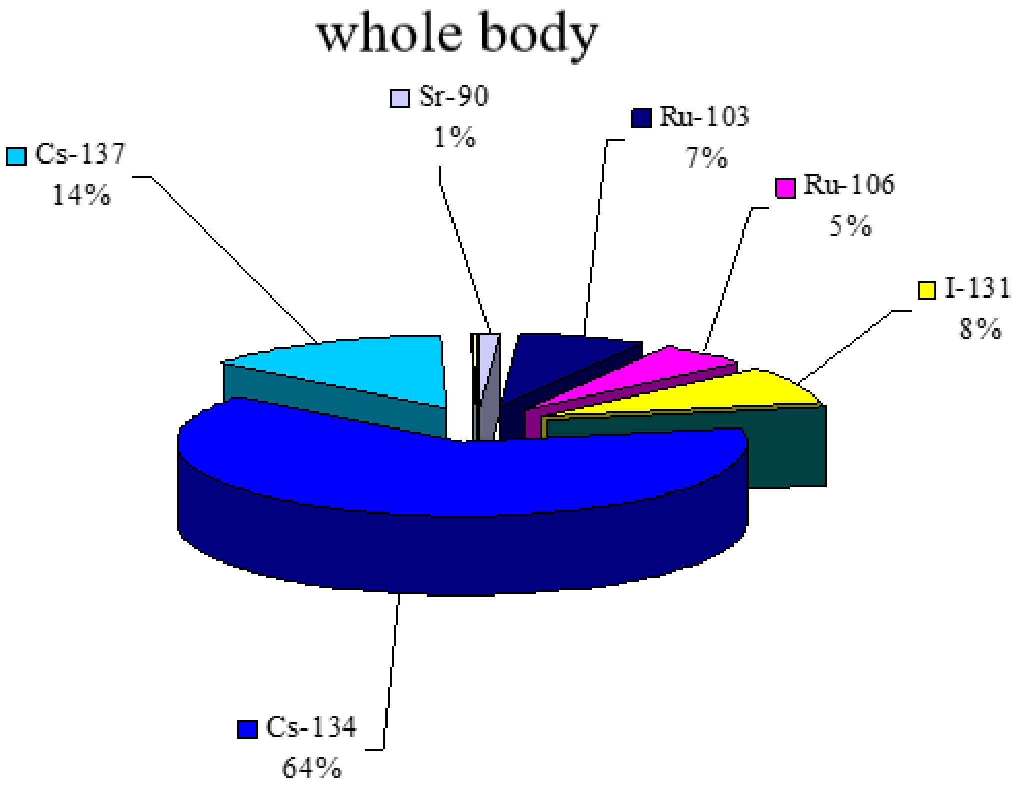


Figure 9.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



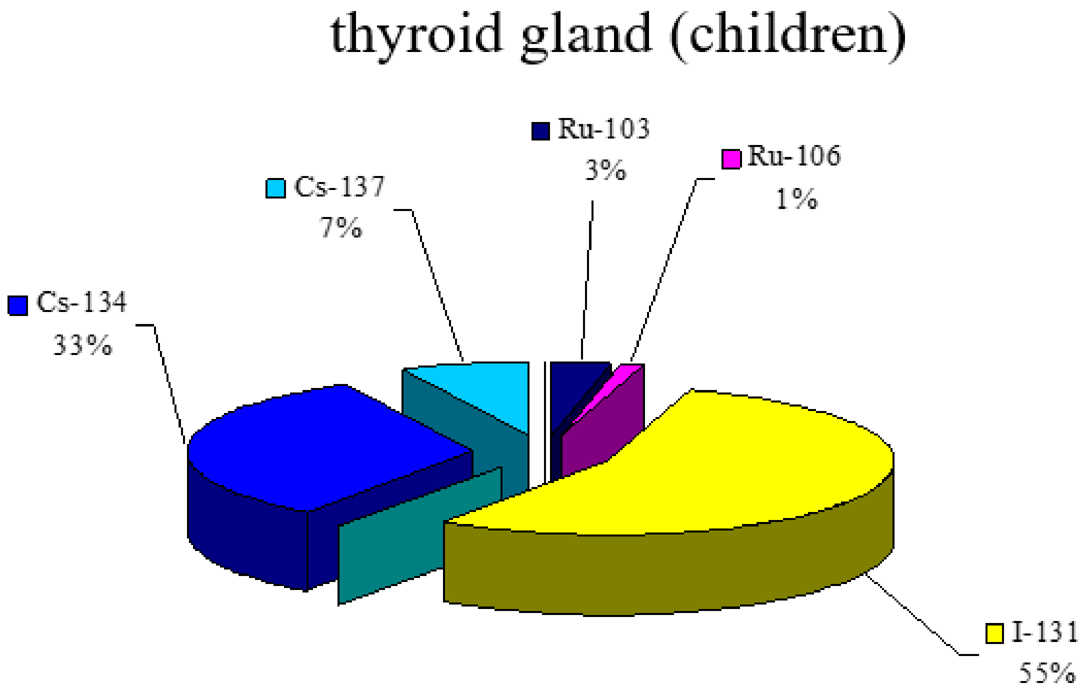


Figure 9.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

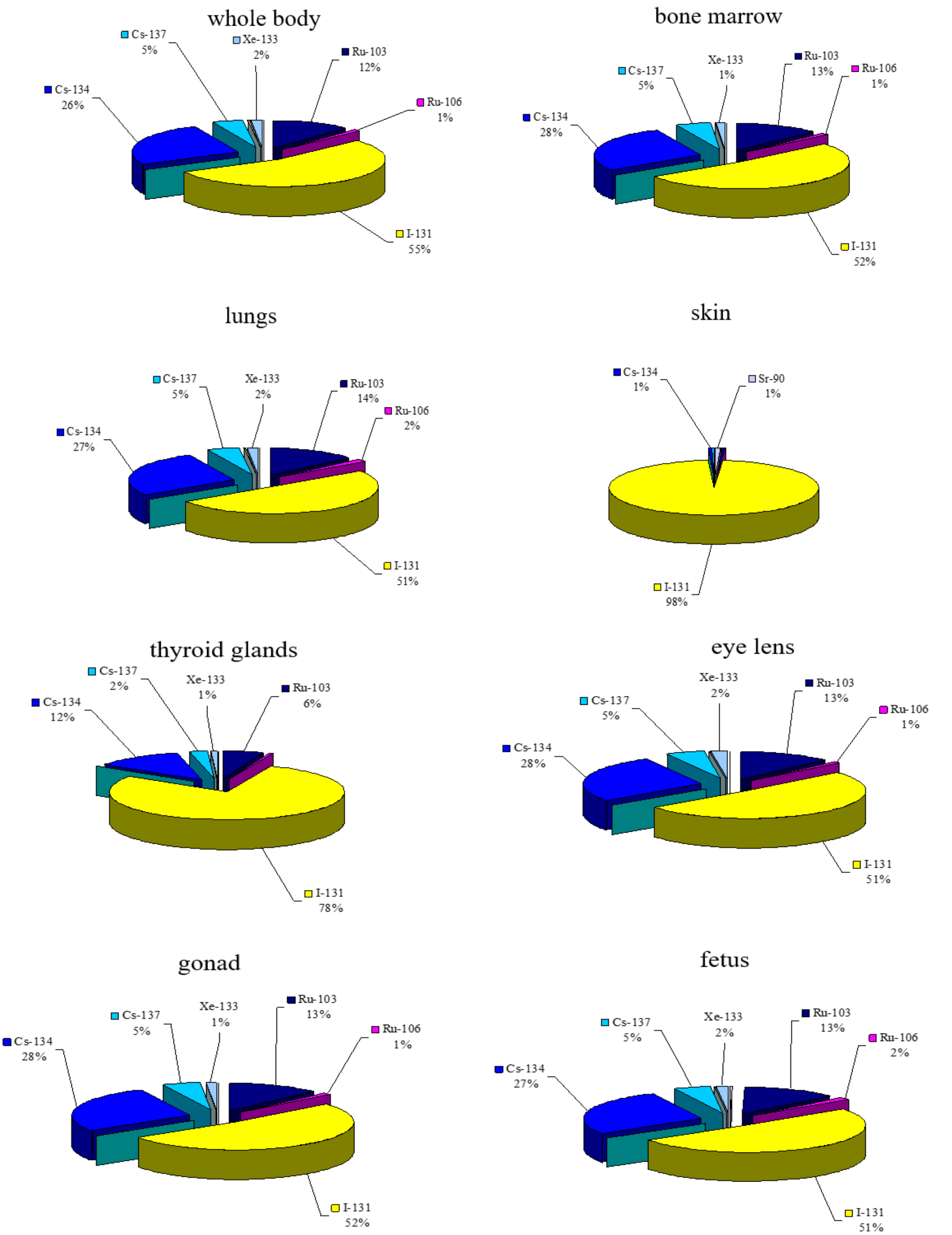


Figure 9.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

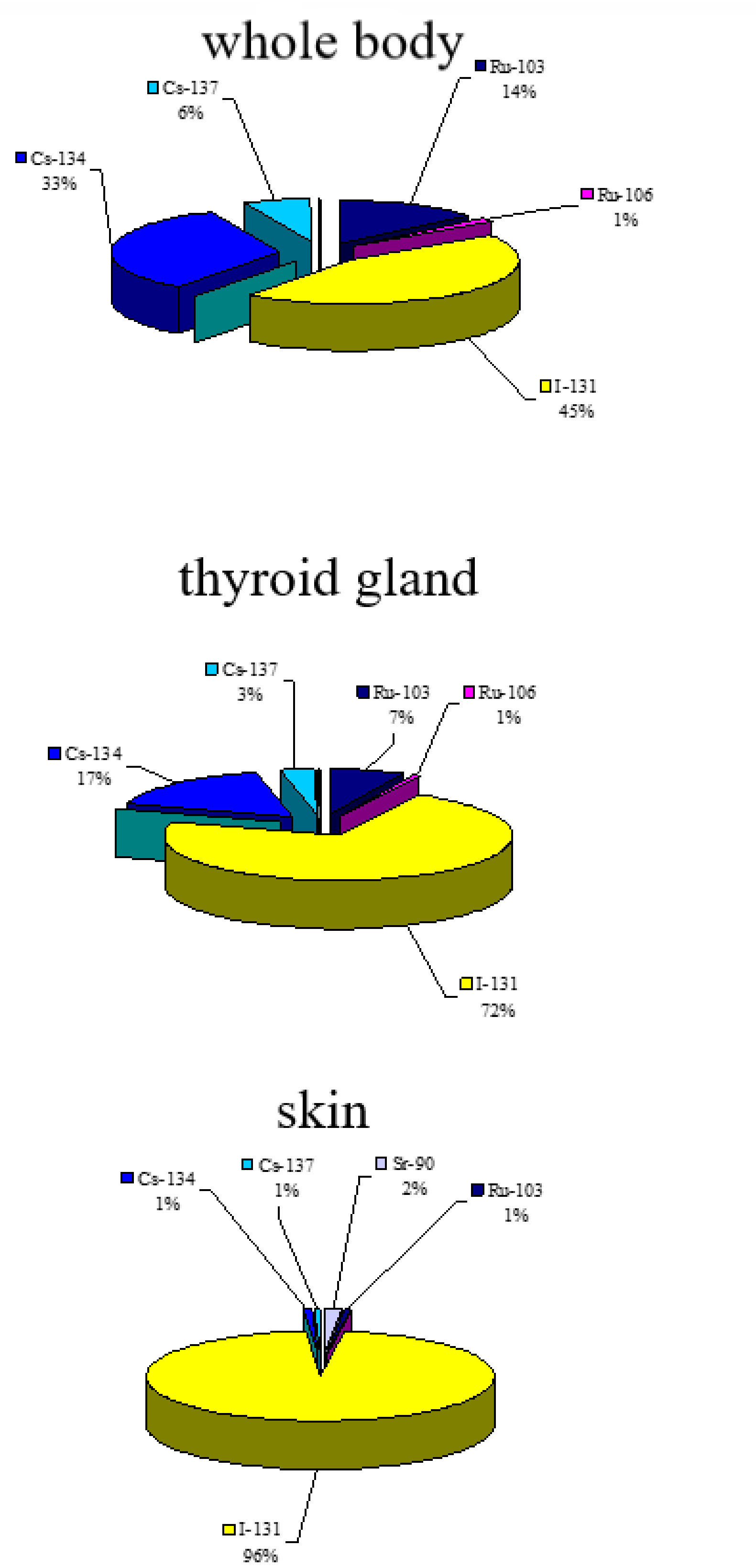
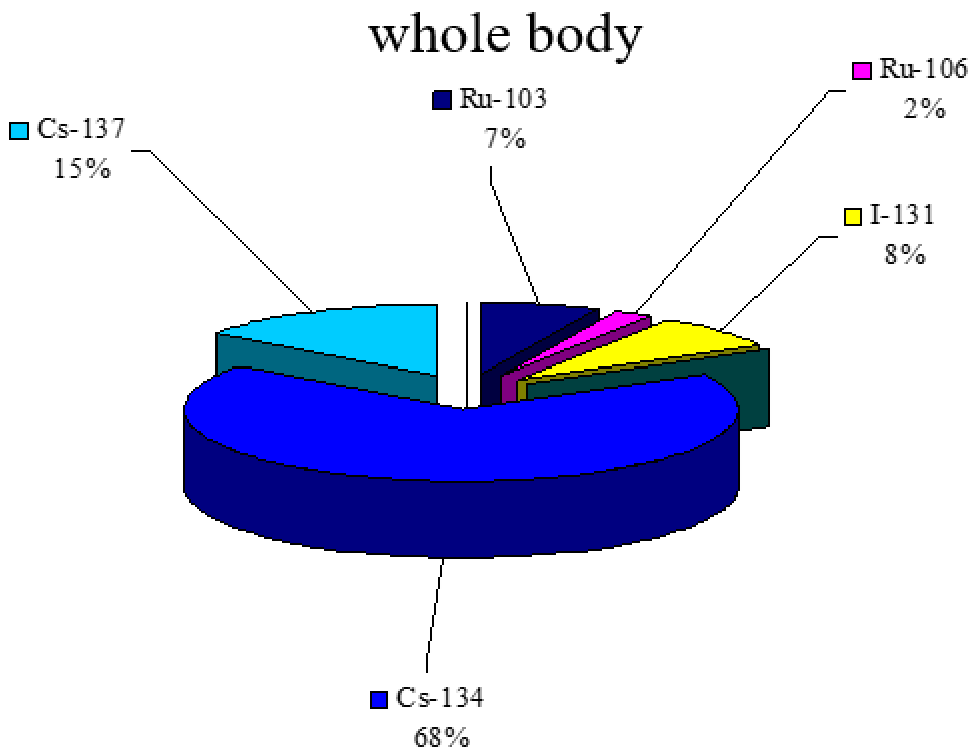


Figure 9.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



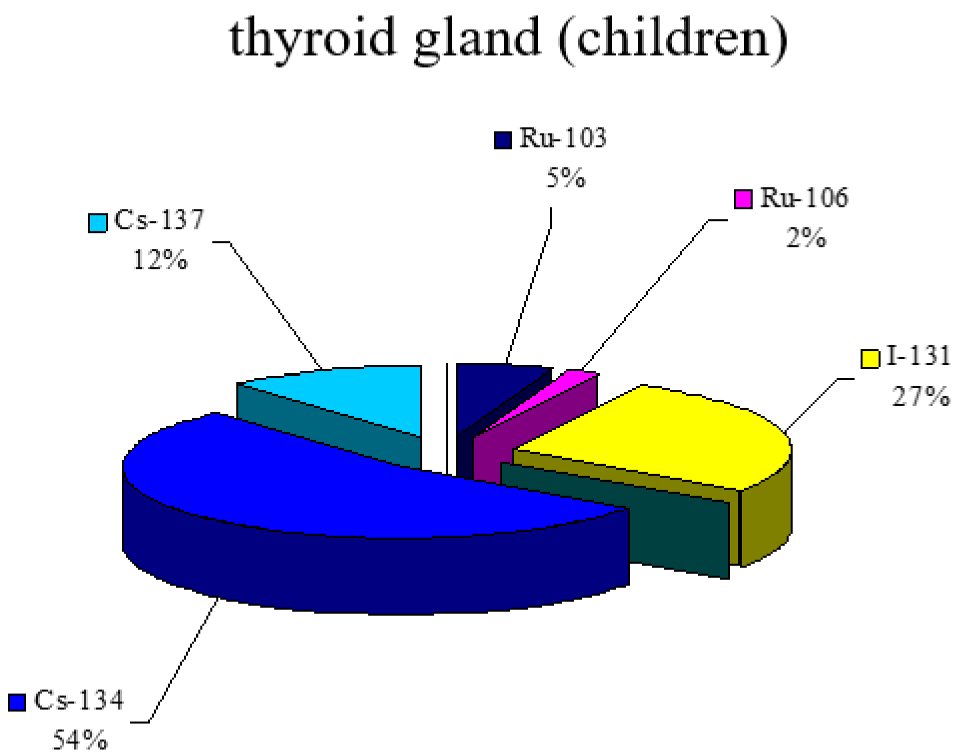


Figure 9.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

9.3.1Radiation 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.

9.3.2Radiation 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**

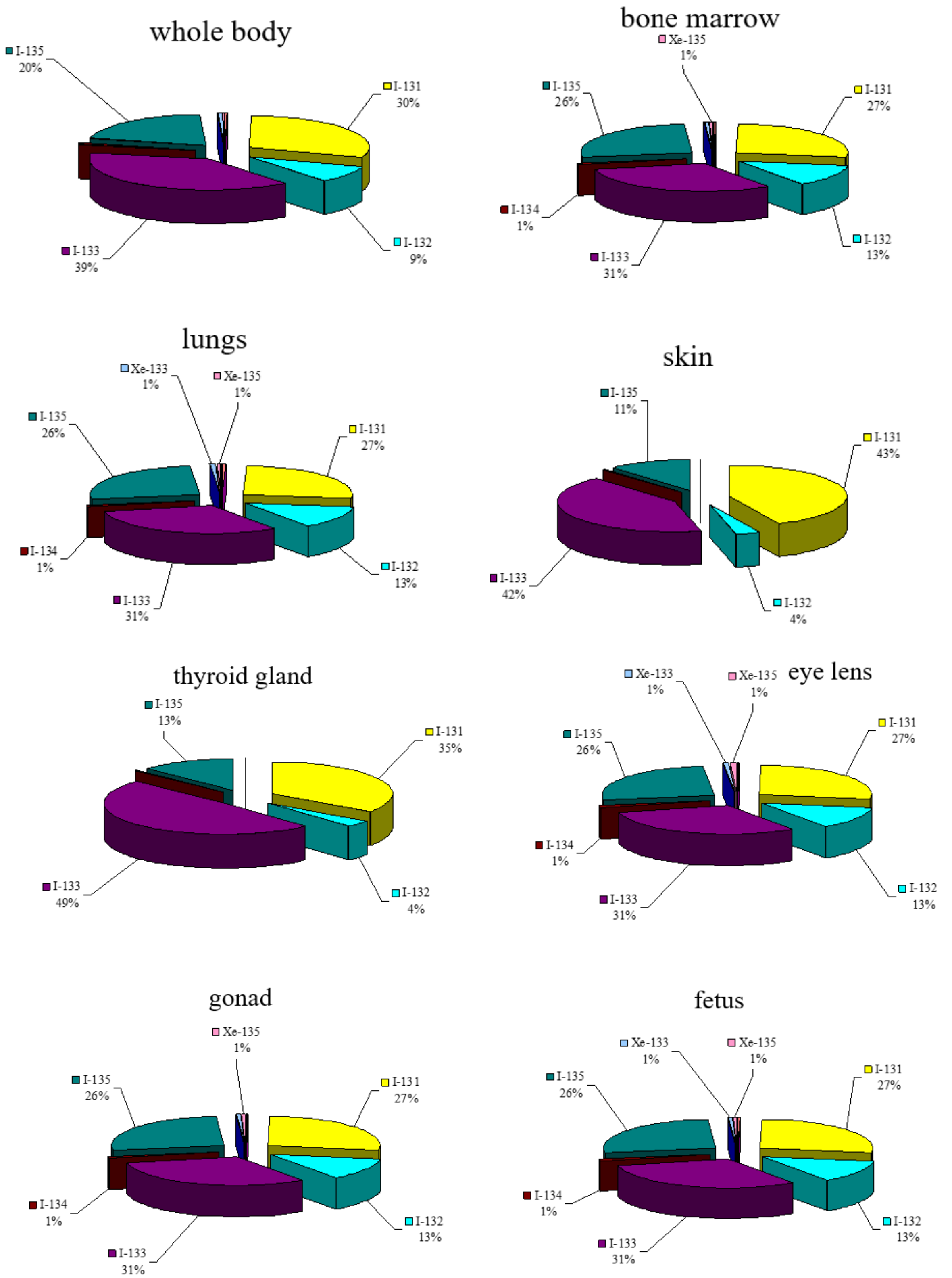


Figure 10.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

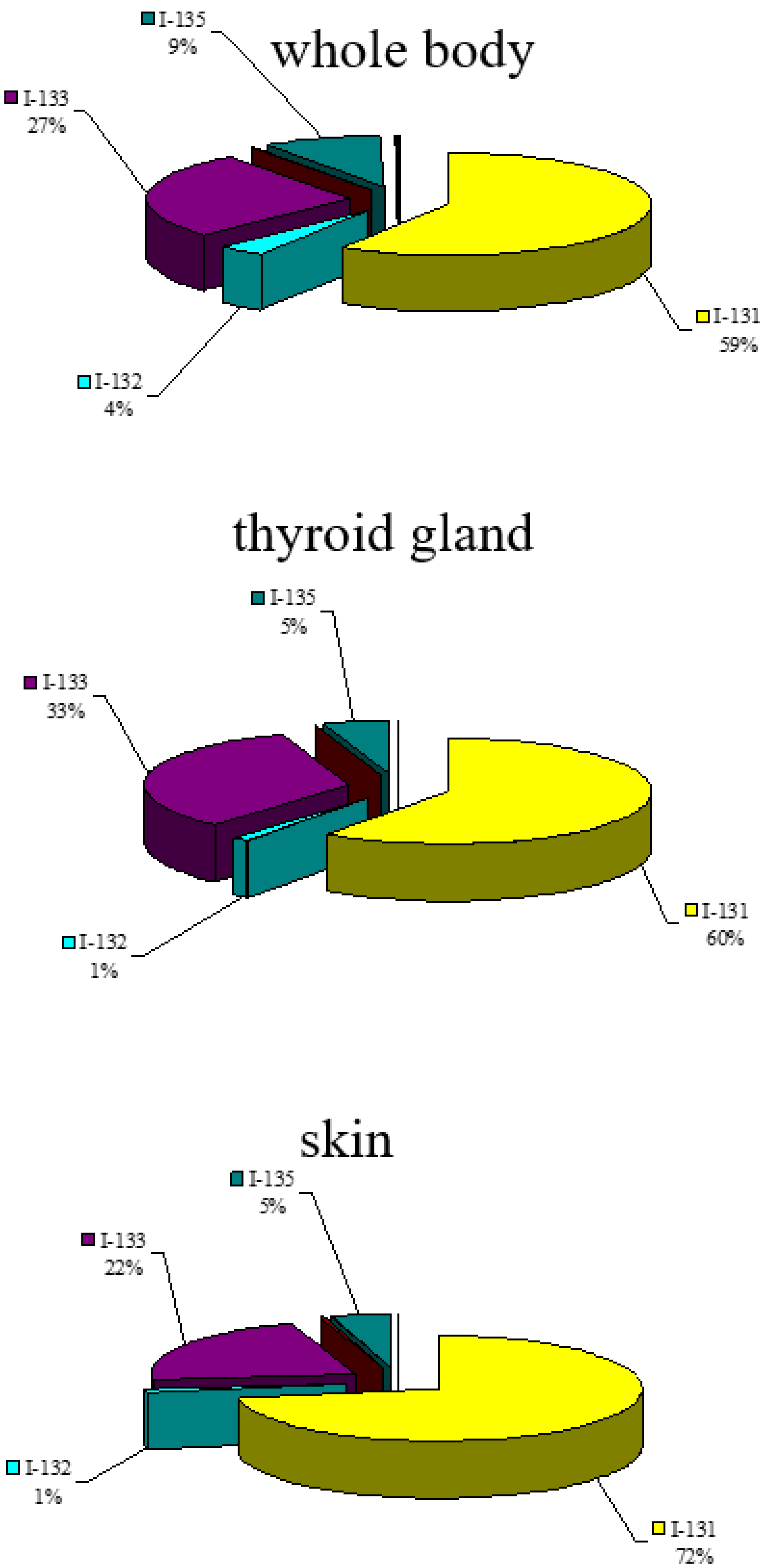
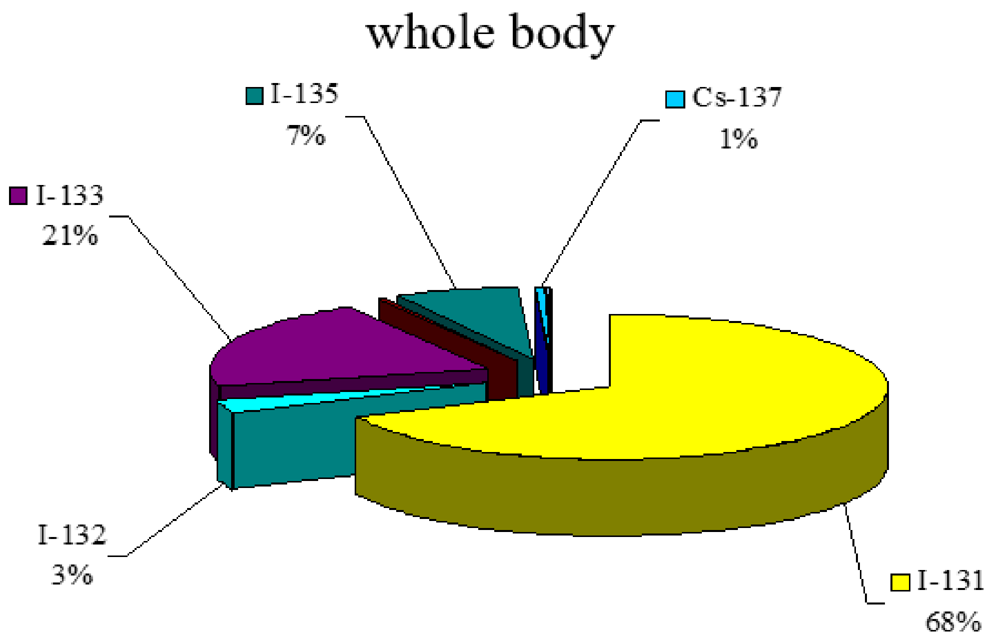


Figure 10.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



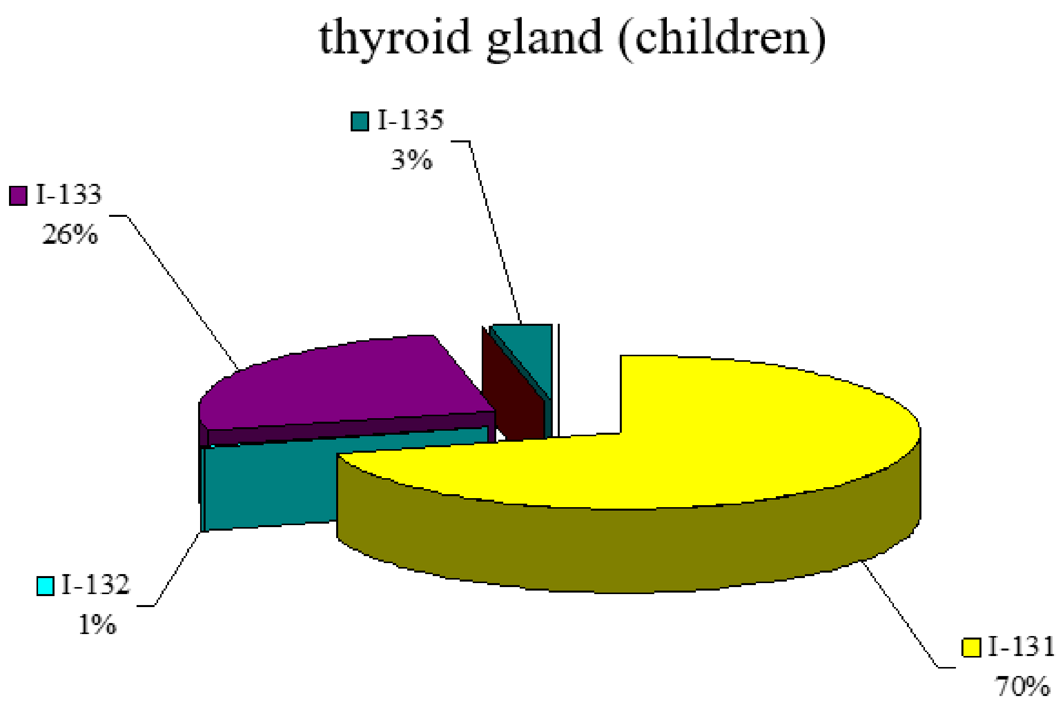


Figure 10.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

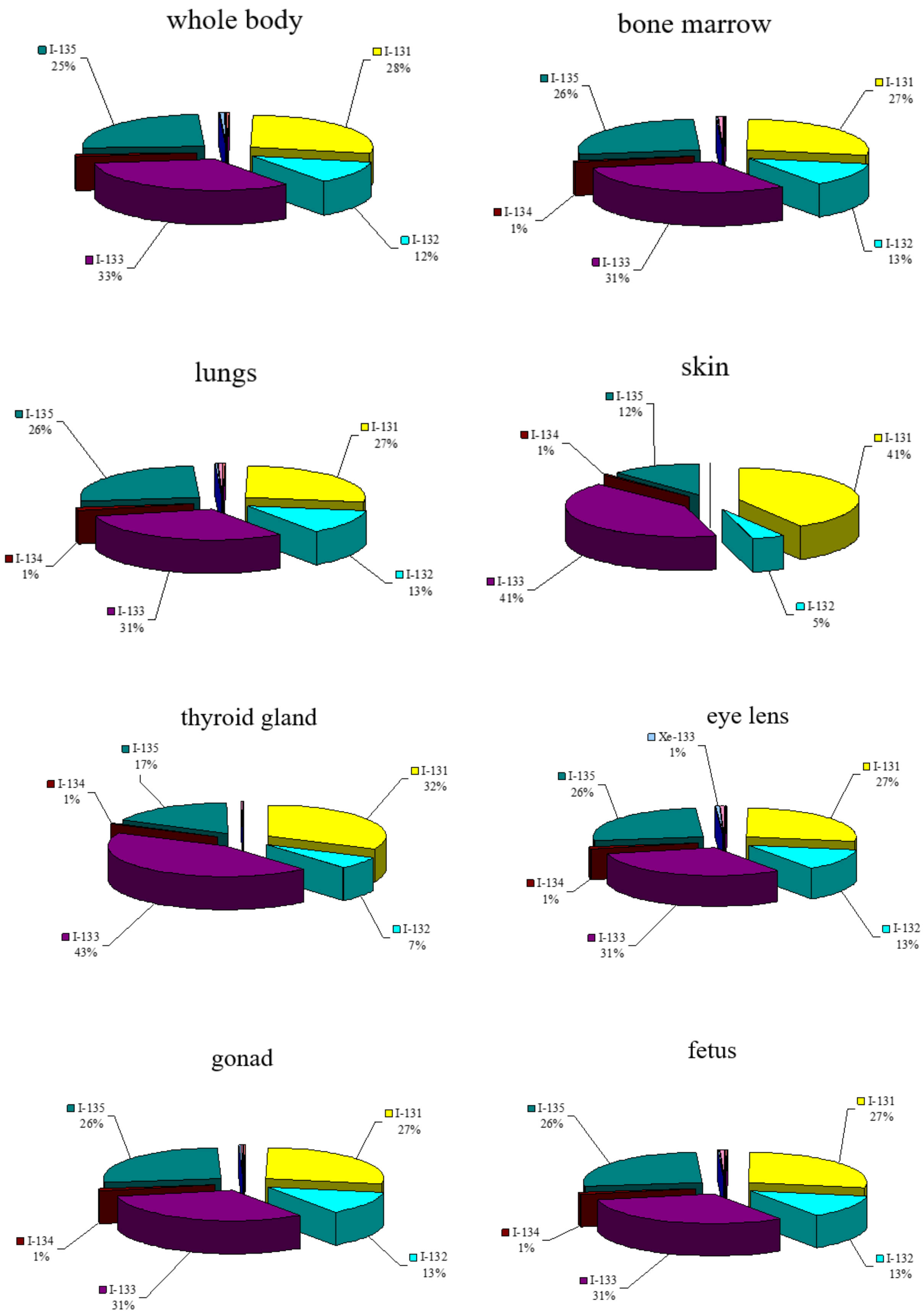


Figure 10.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

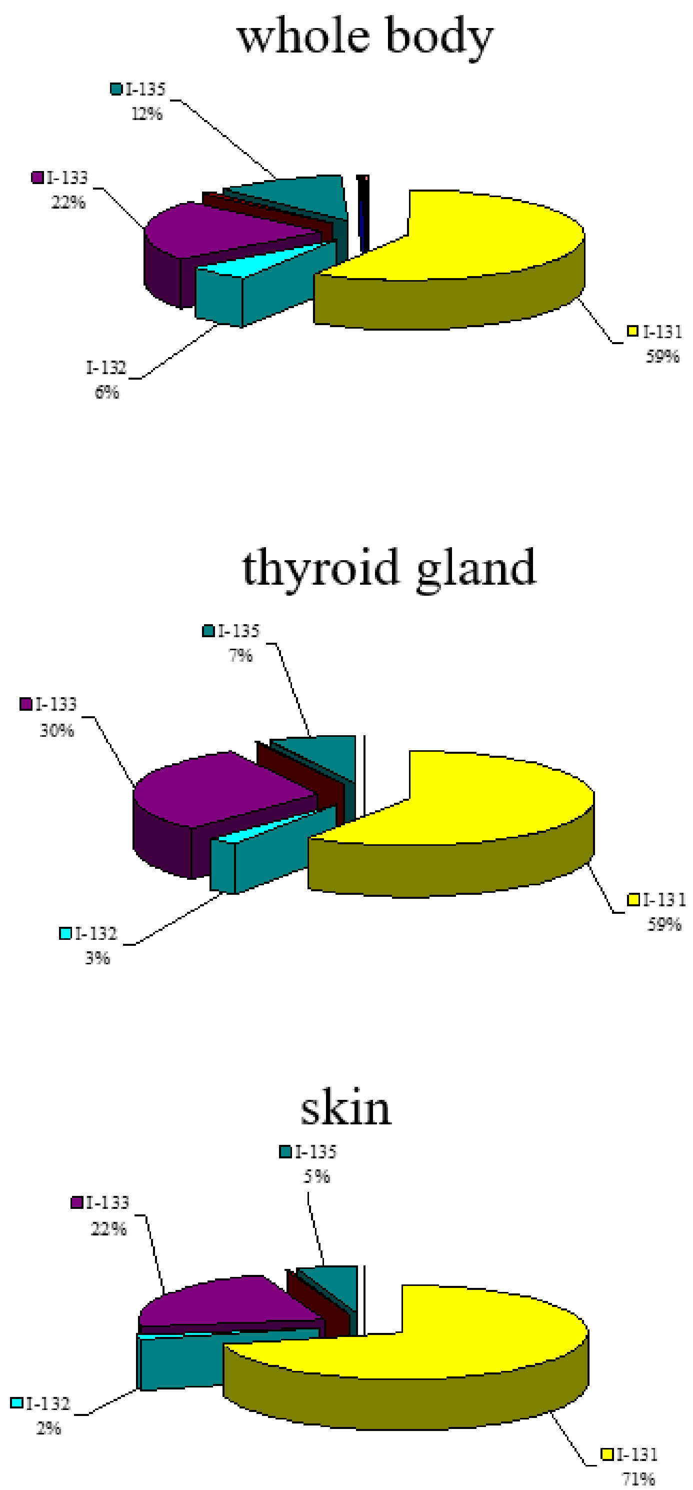
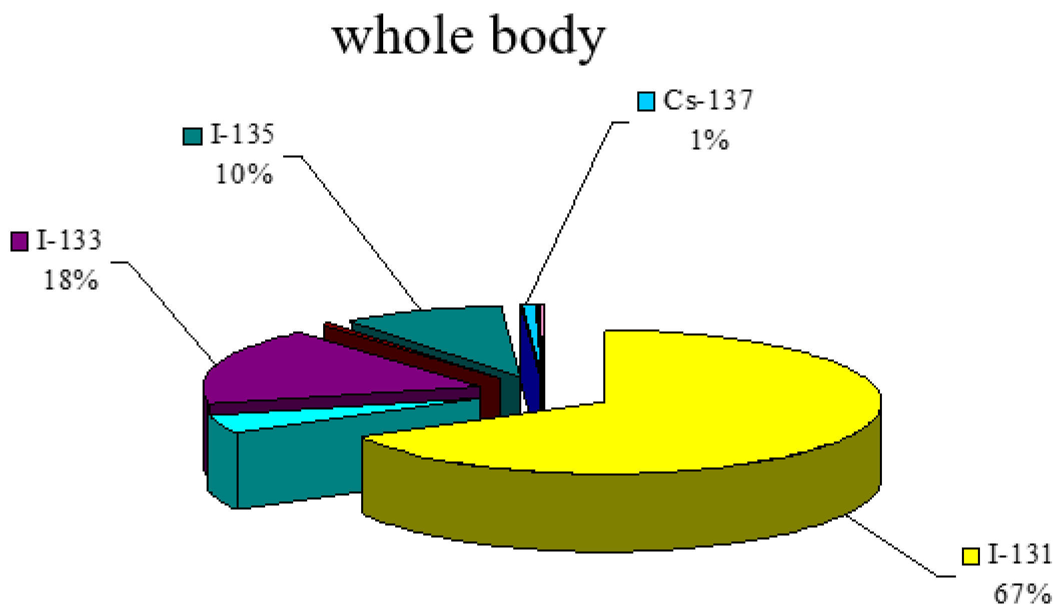


Figure 10.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



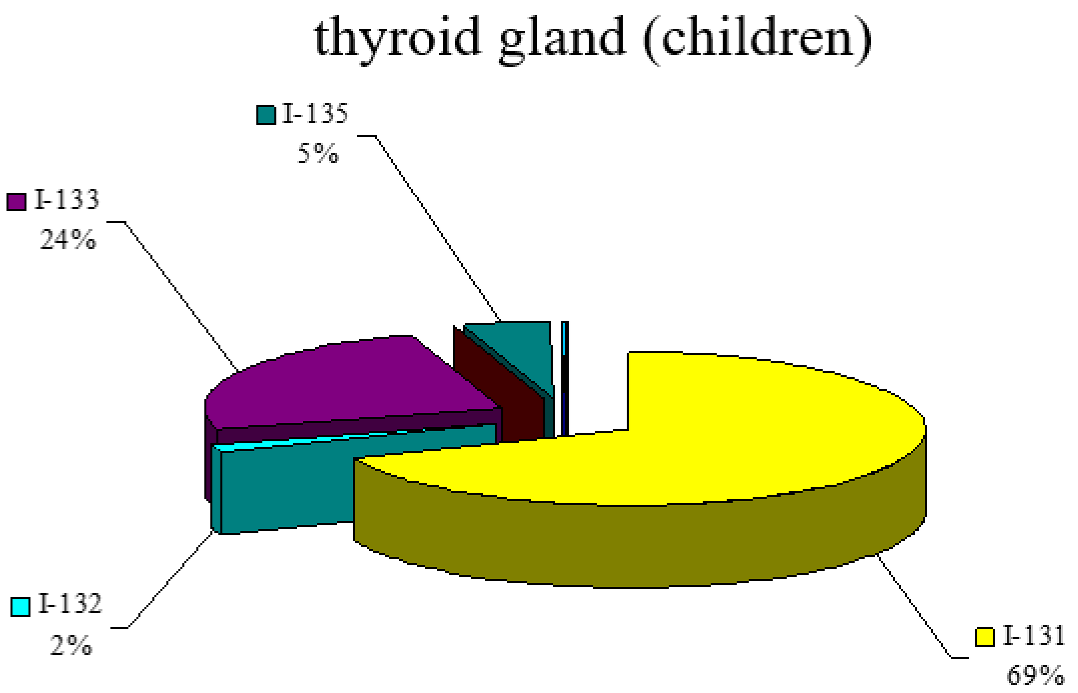


Figure 10.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

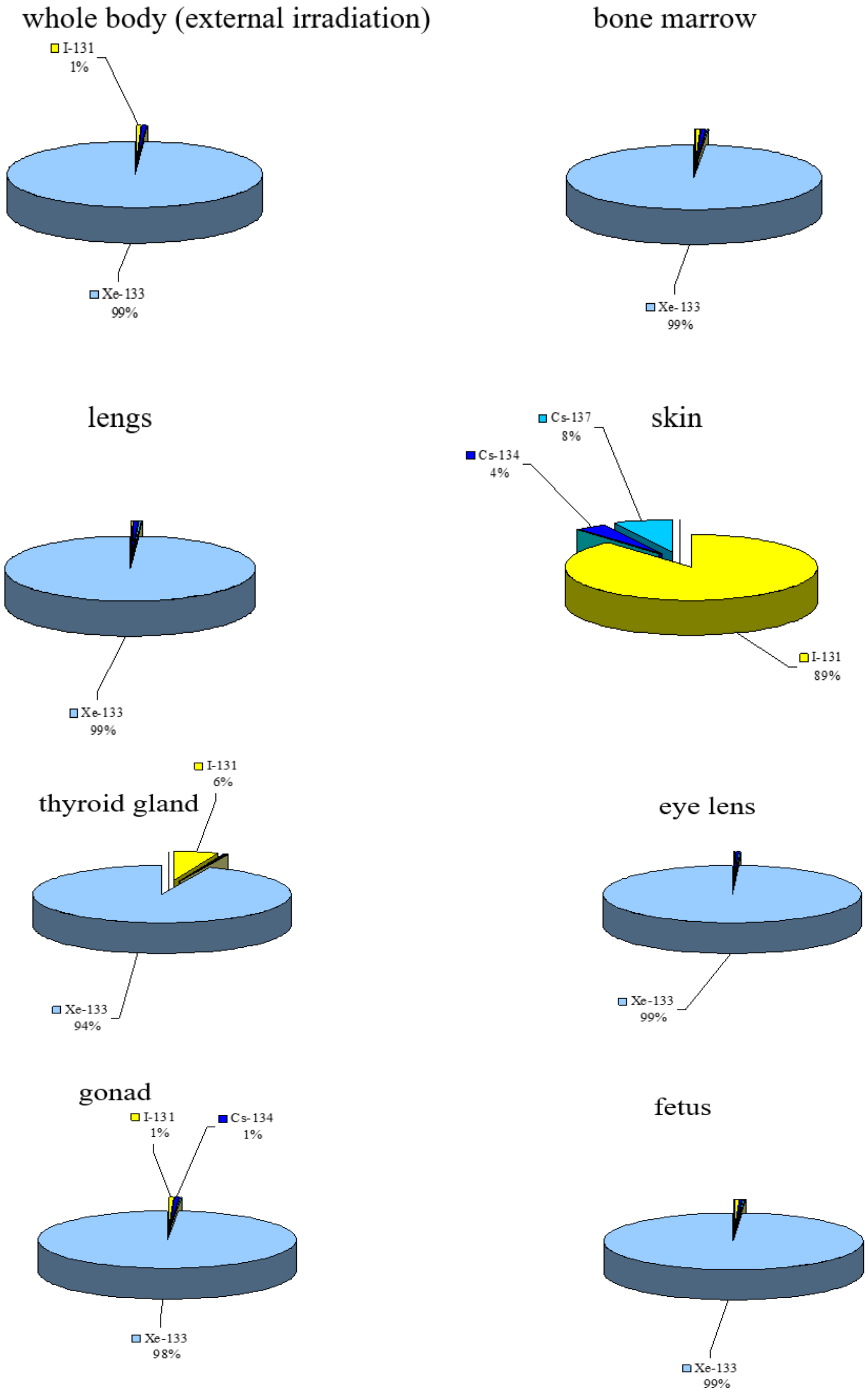


Figure 11.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

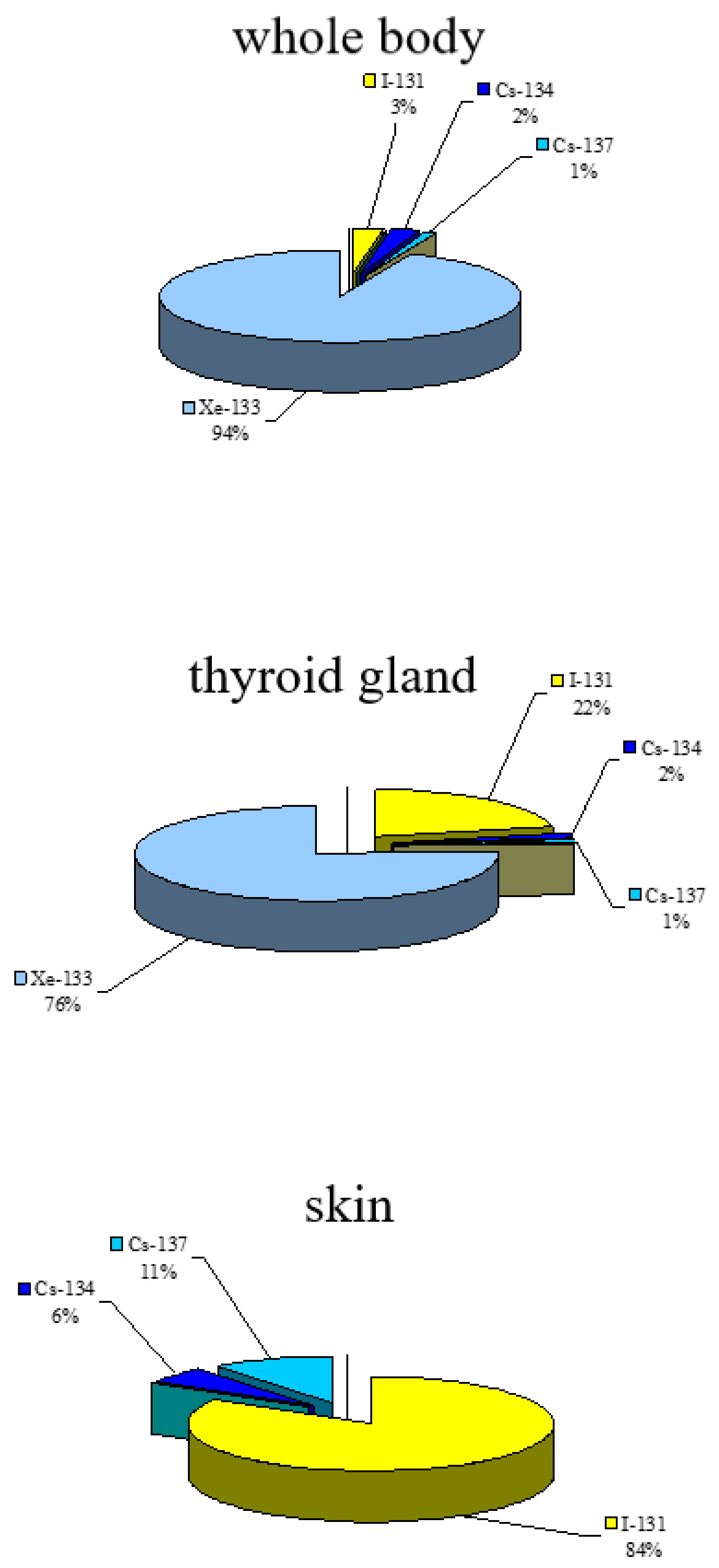
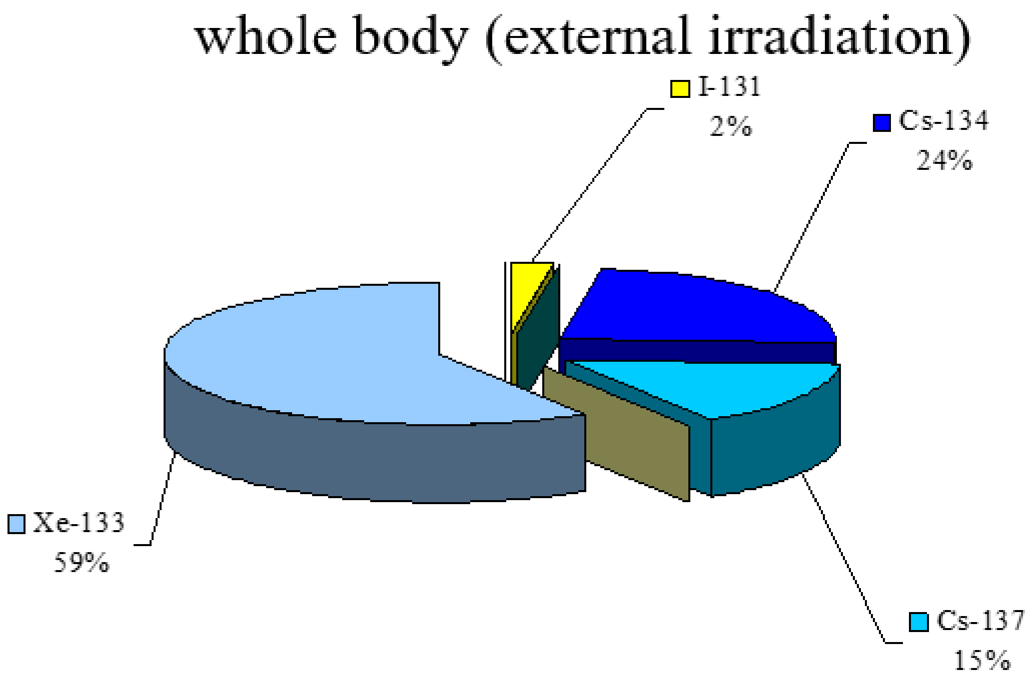


Figure 11.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



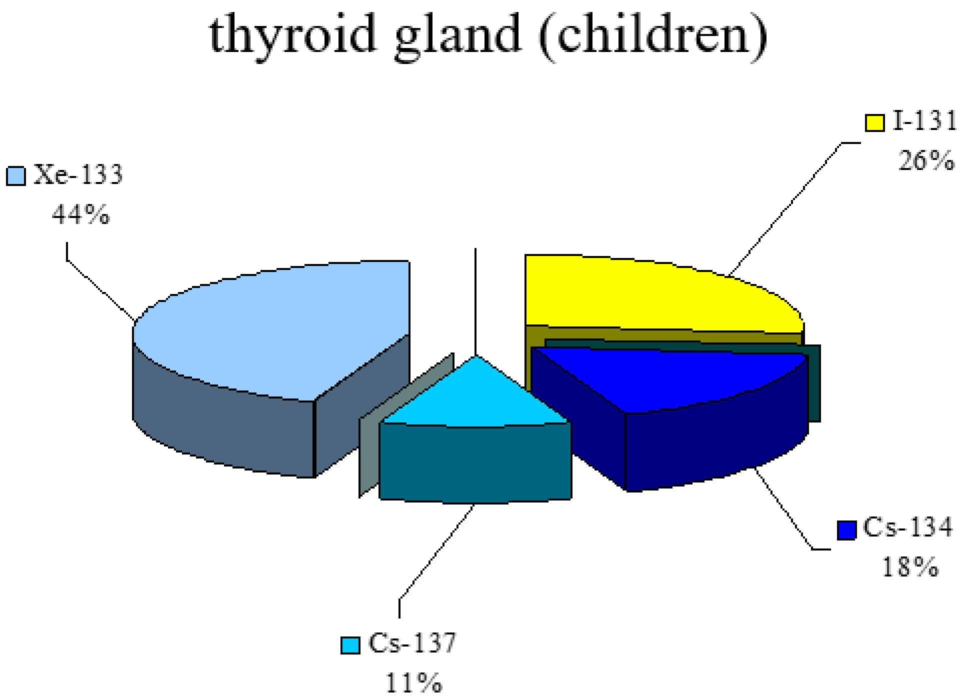


Figure 11.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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

<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 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**

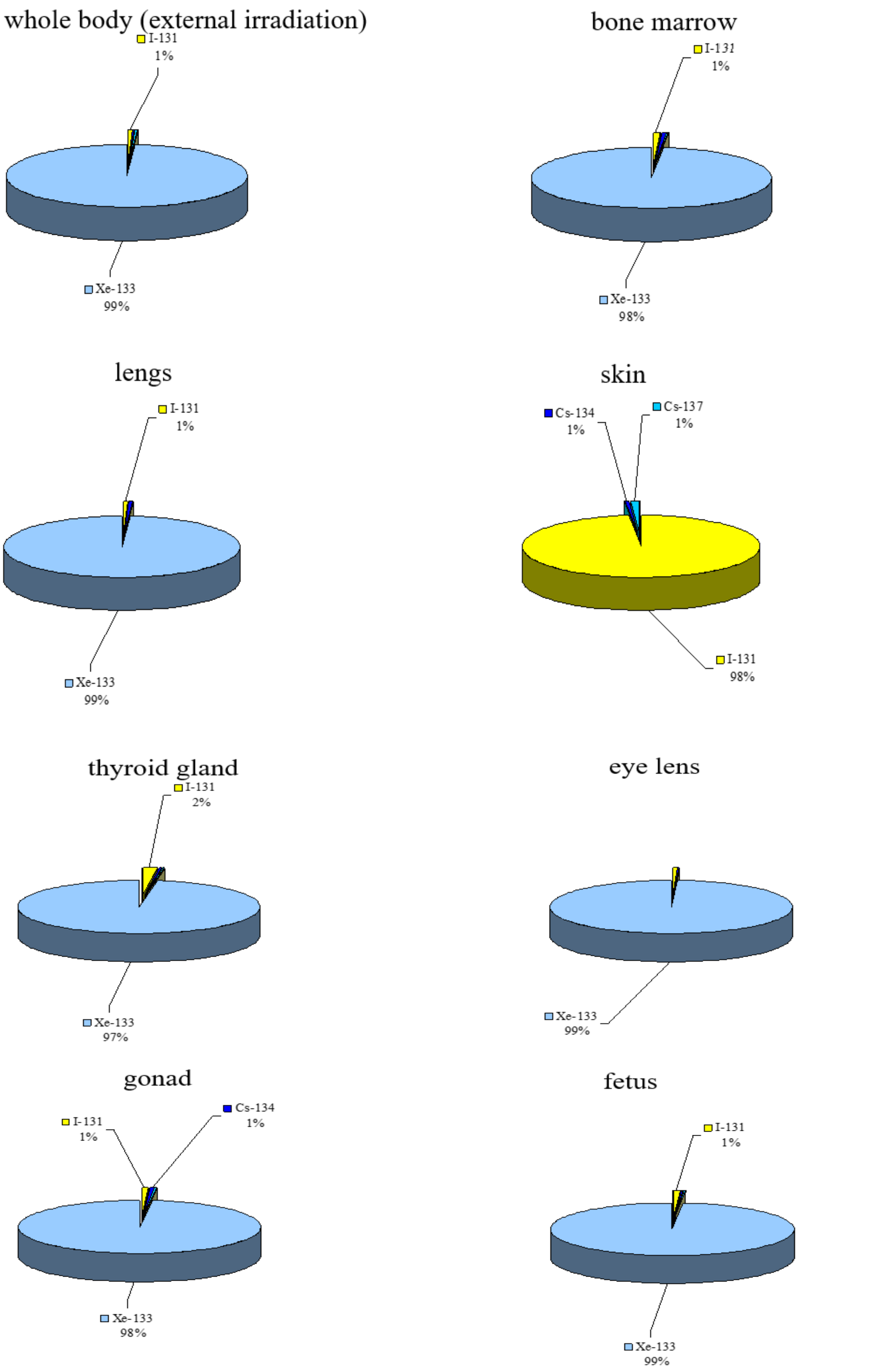


Figure 11.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

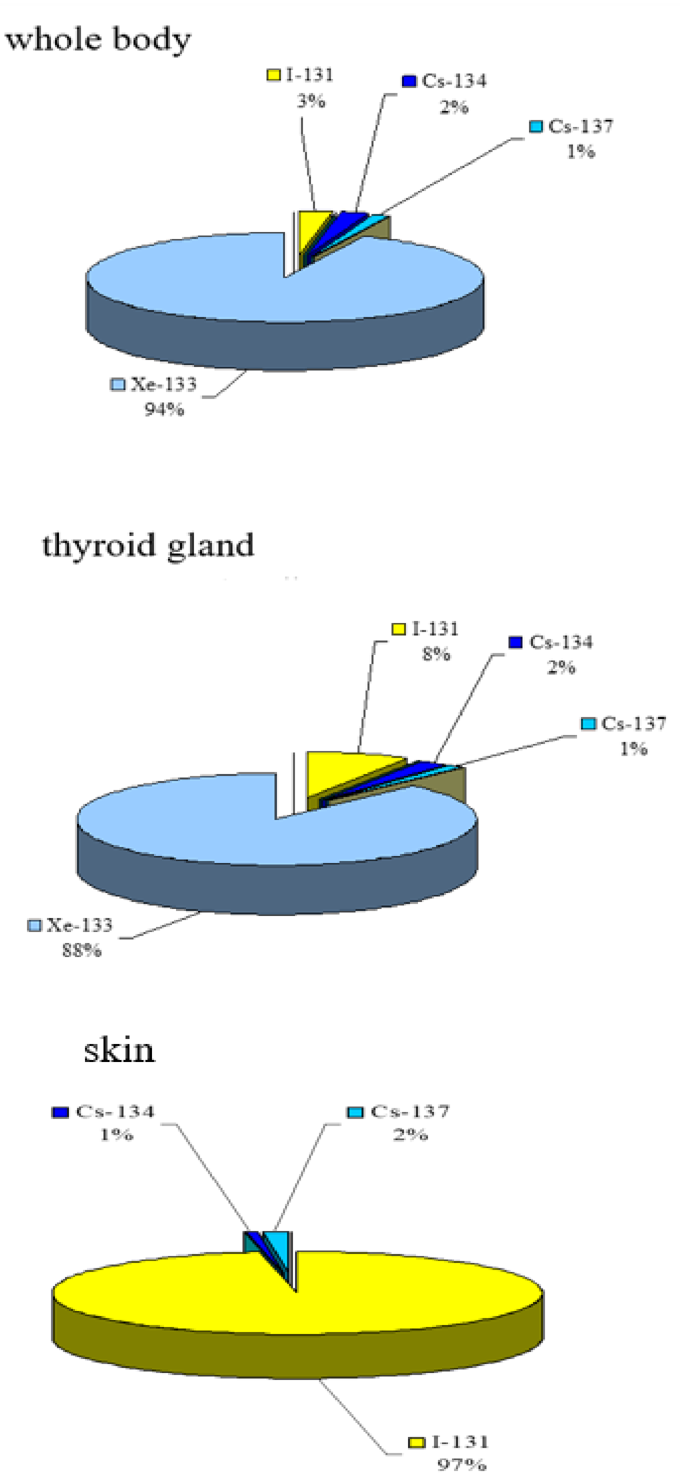
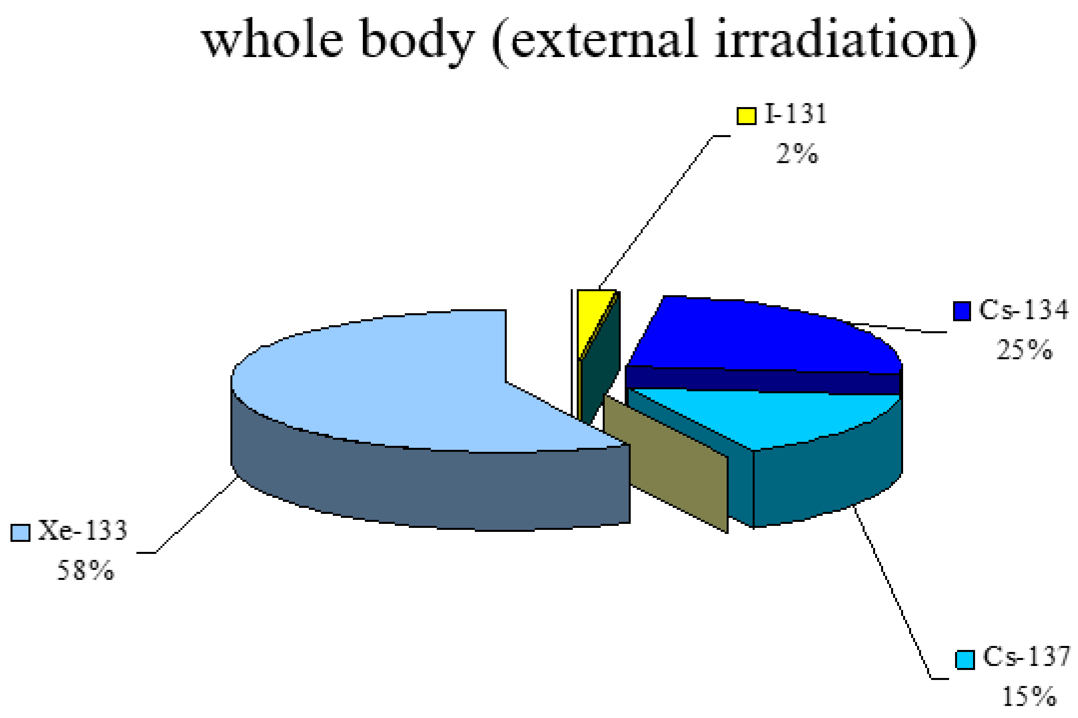


Figure 11.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



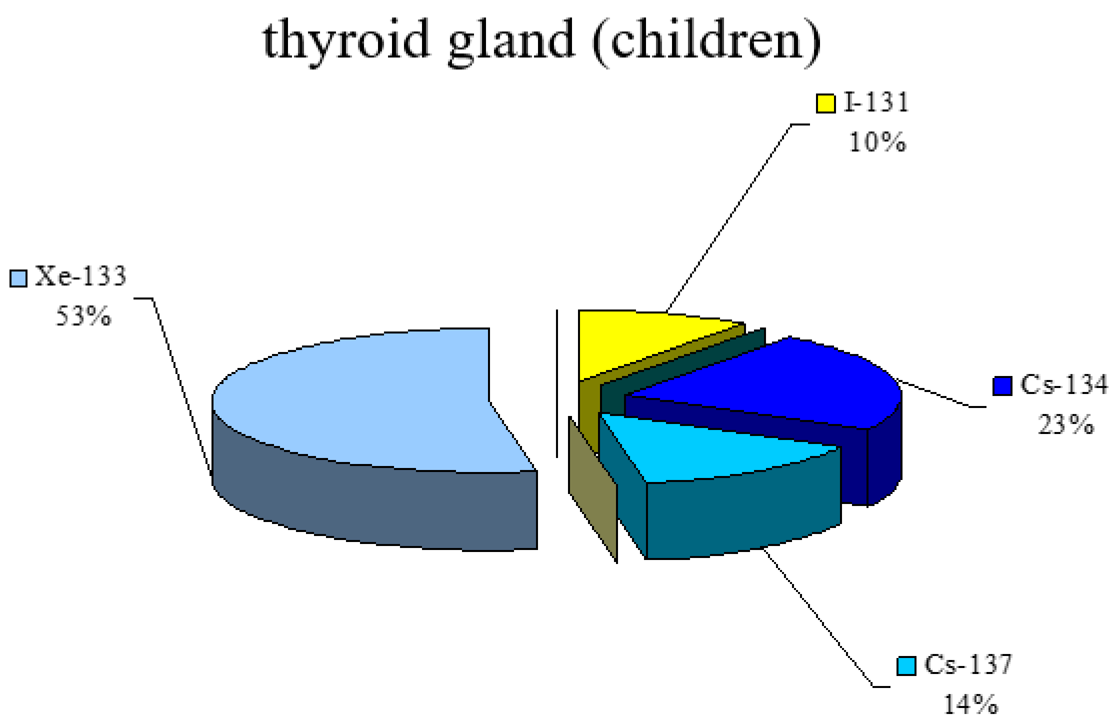


Figure 11.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

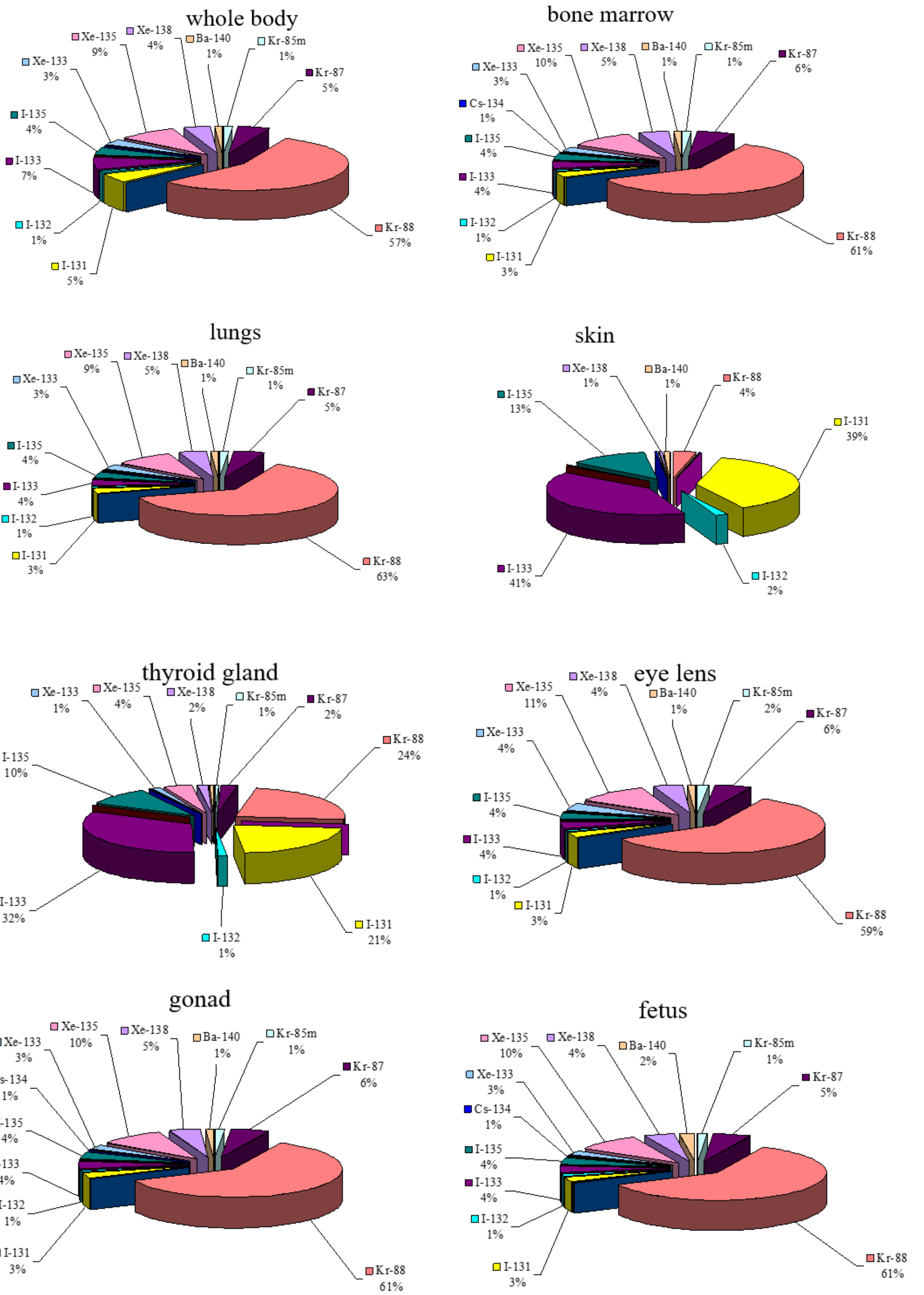


Figure 12.1 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

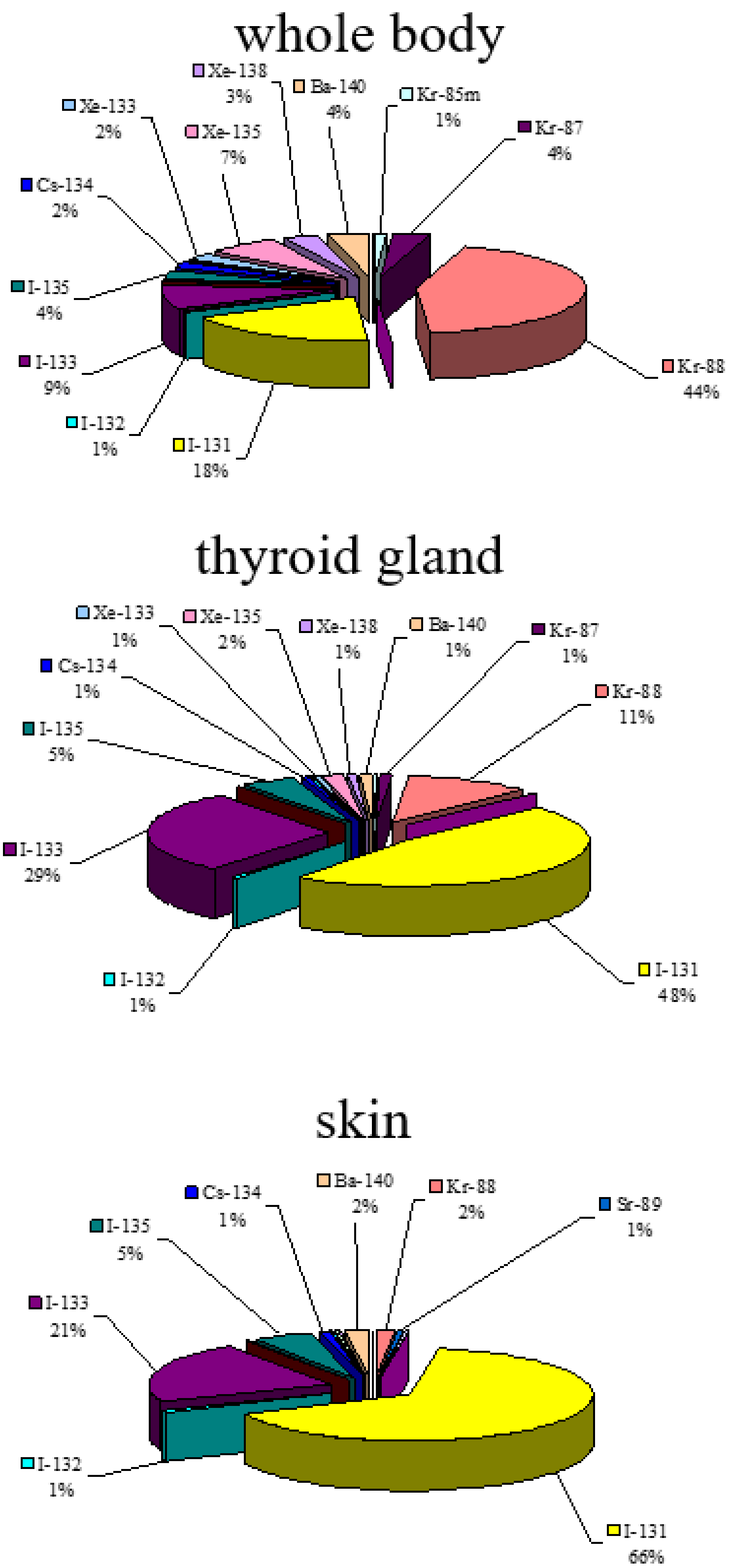
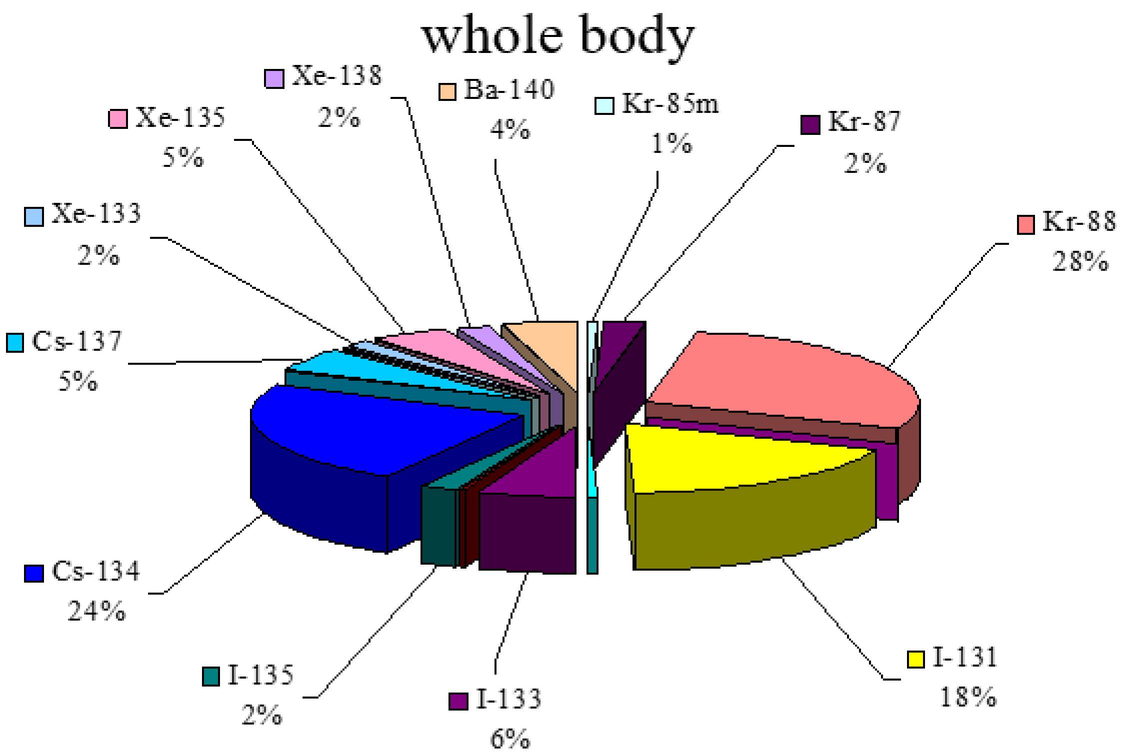


Figure 12.2 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



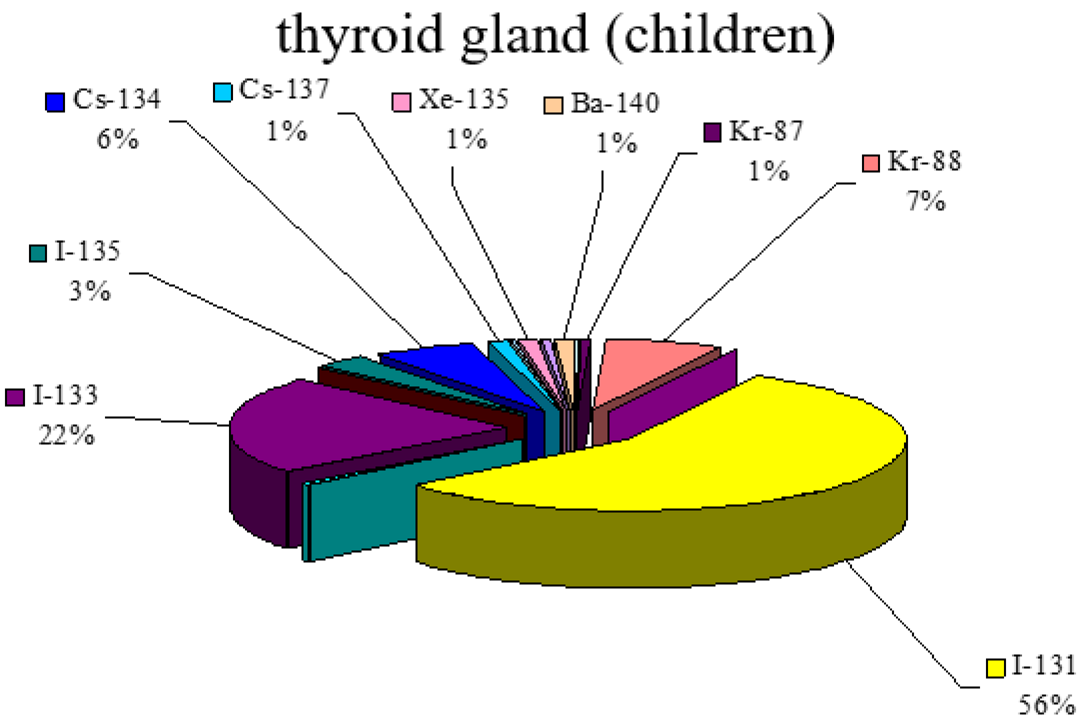


Figure 12.3 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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**

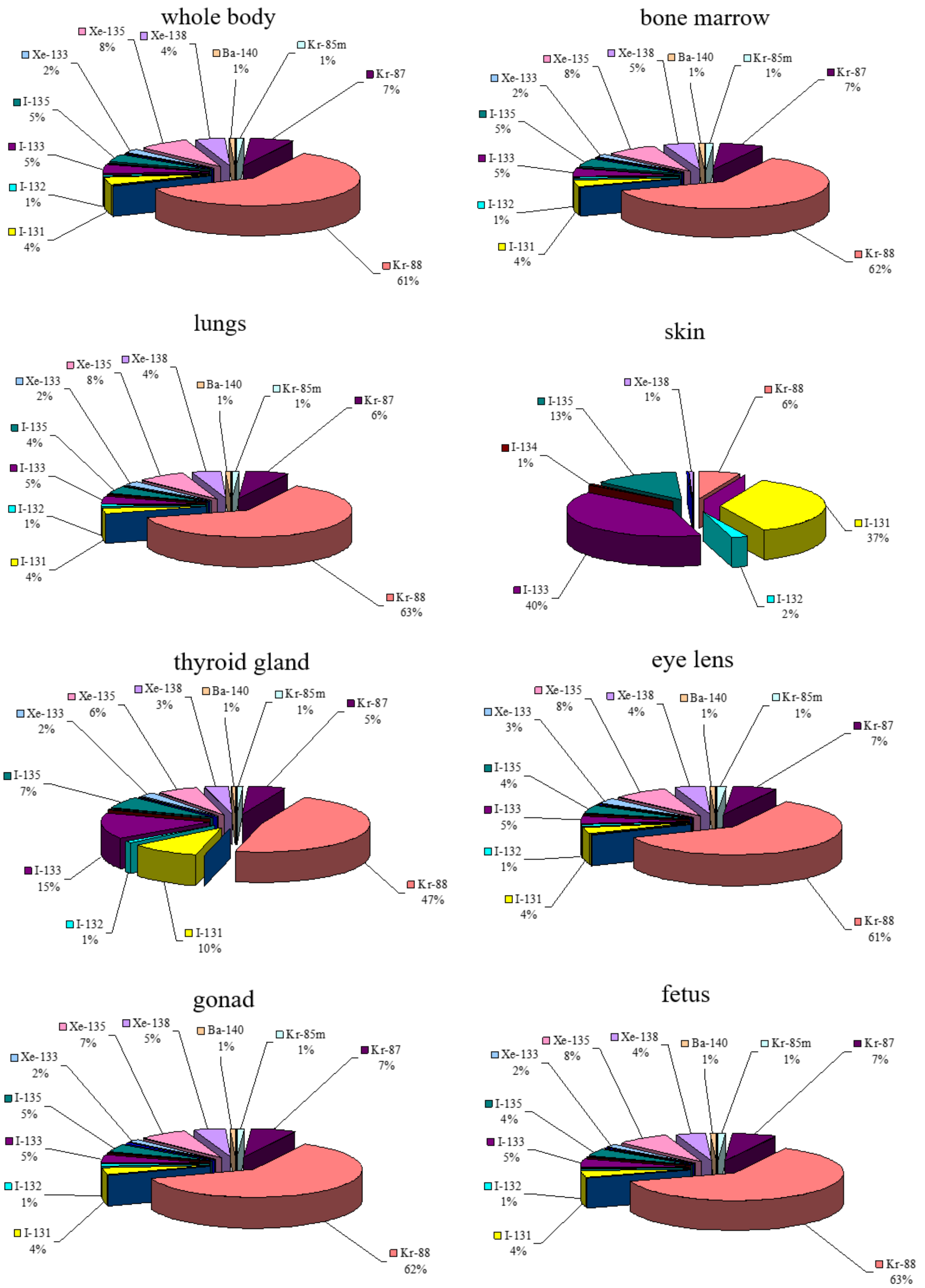


Figure 12.4 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-day period

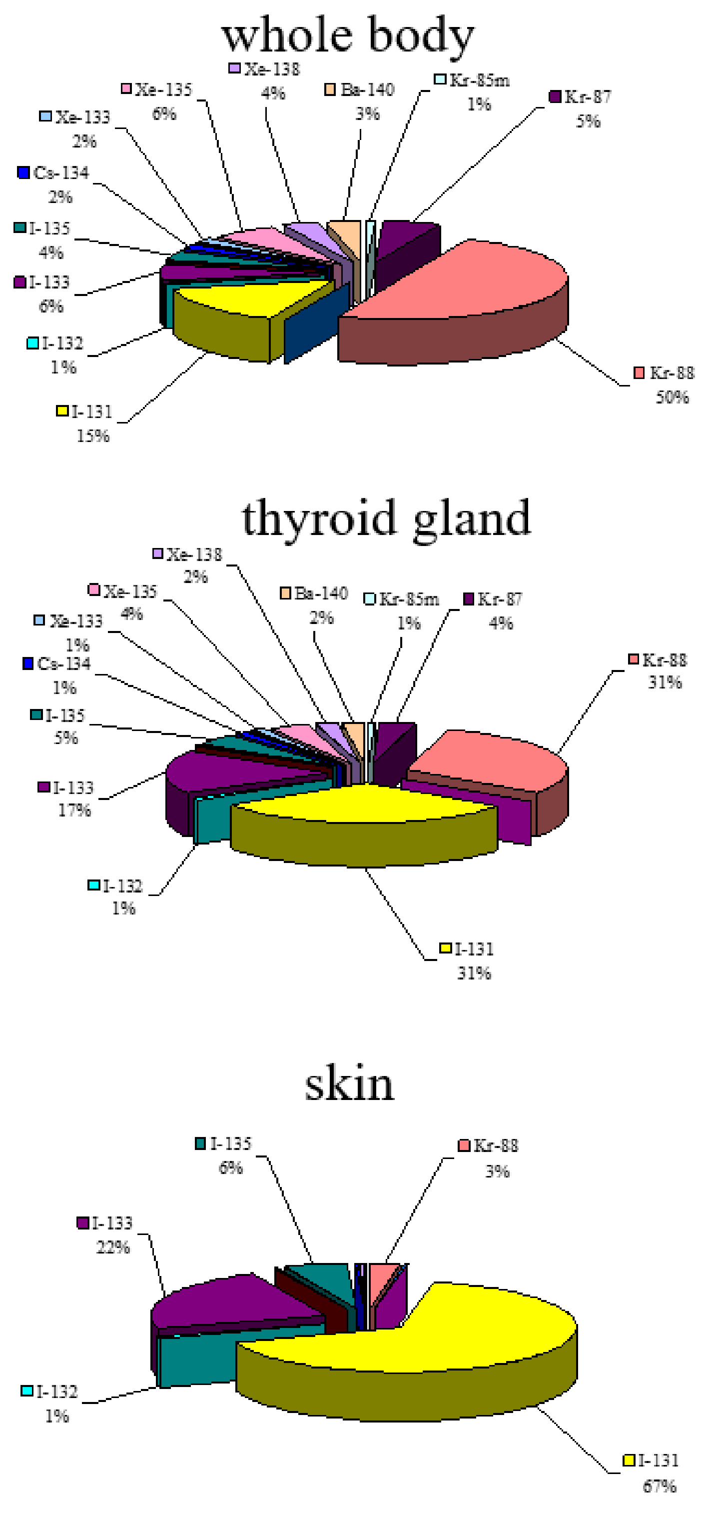
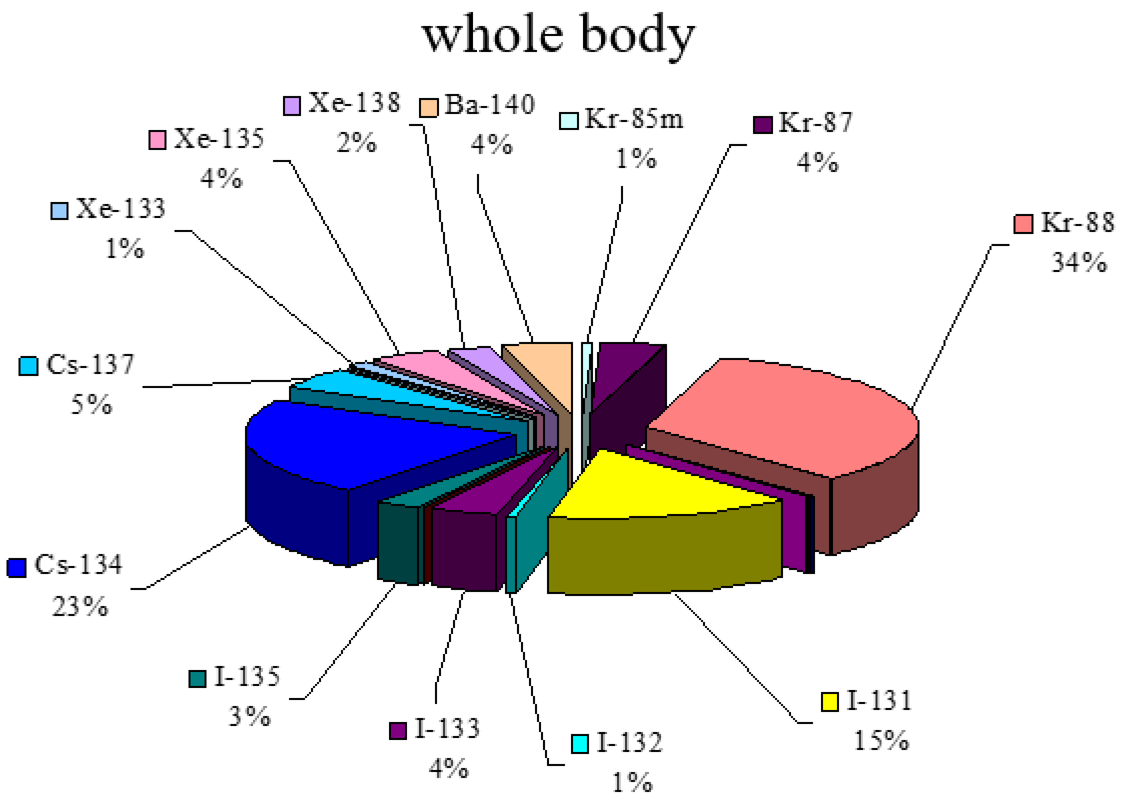


Figure 12.5 - Relative shares of radionuclides in organ and tissue radiation doses over a 2-week period



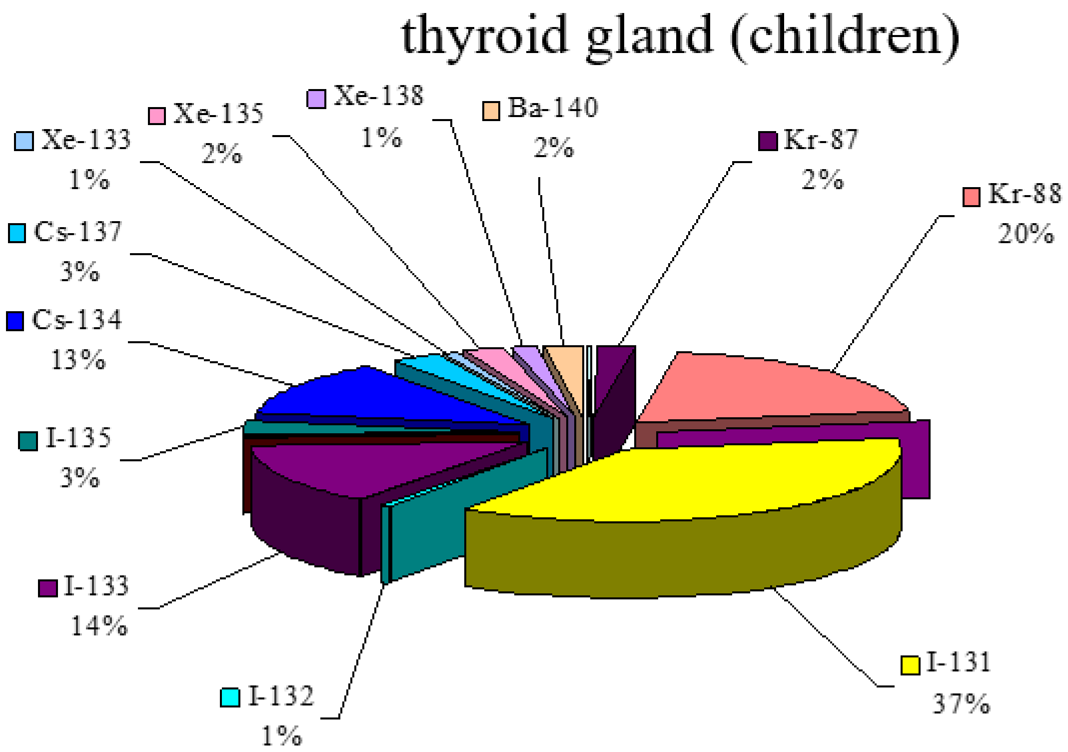


Figure 12.6 - Relative shares of radionuclides in organ and tissue radiation doses over one year period

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.XY.МТ.07-14.

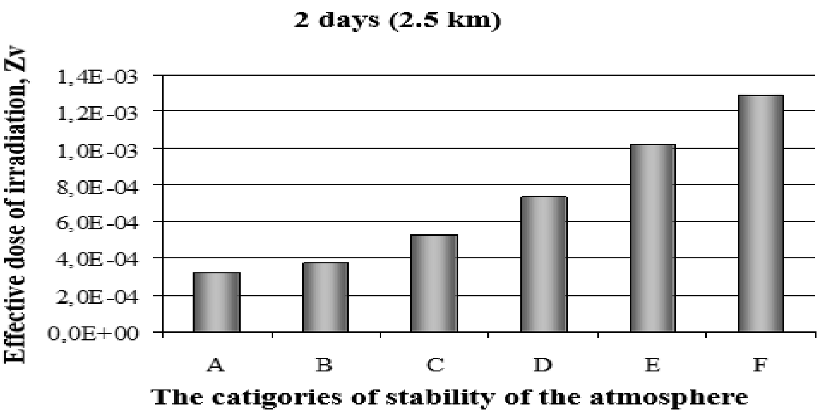
APPENDIX A.
STUDY OF ACCIDENT IMPACT UNDER VARIOUS WEATHER CONDITIONS

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).



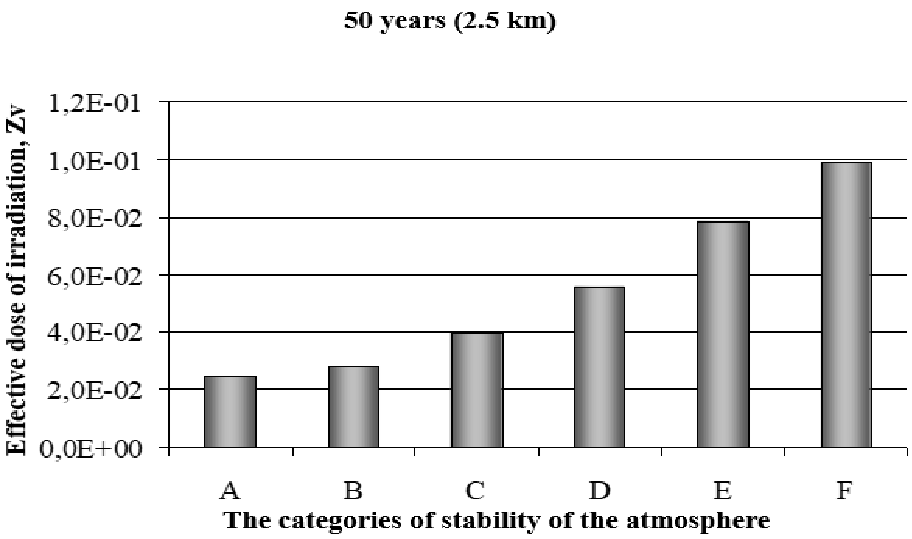


Fig. A.1. Maximum population radiation doses for various stability classes over a 2-day and 50-year periods within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor

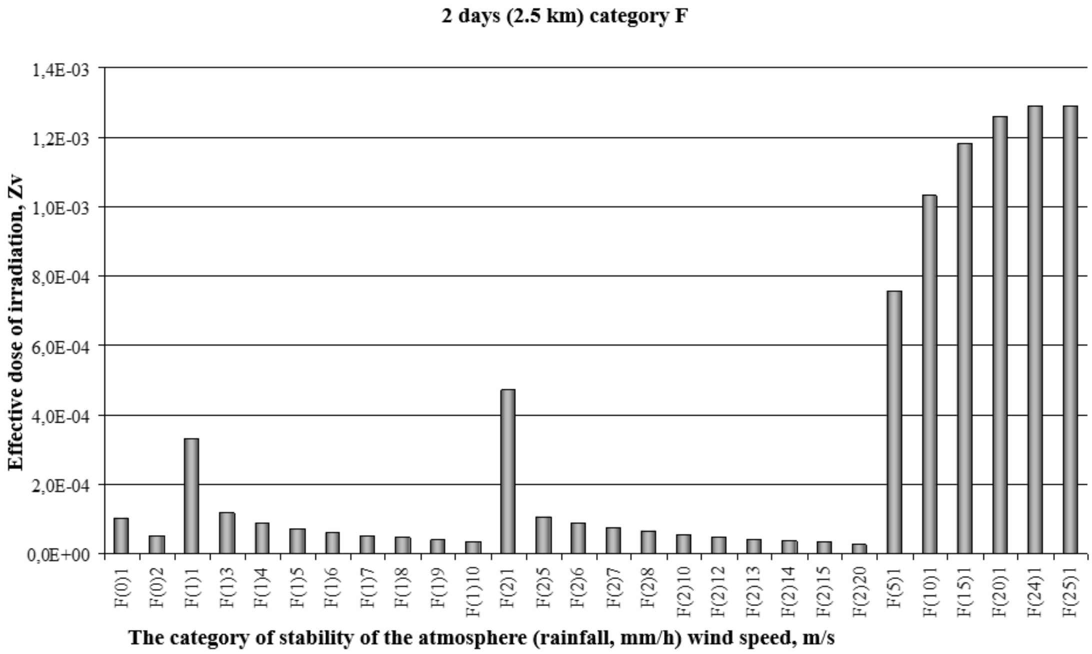


Fig. A.2. Maximum population radiation doses over a 2-day period within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

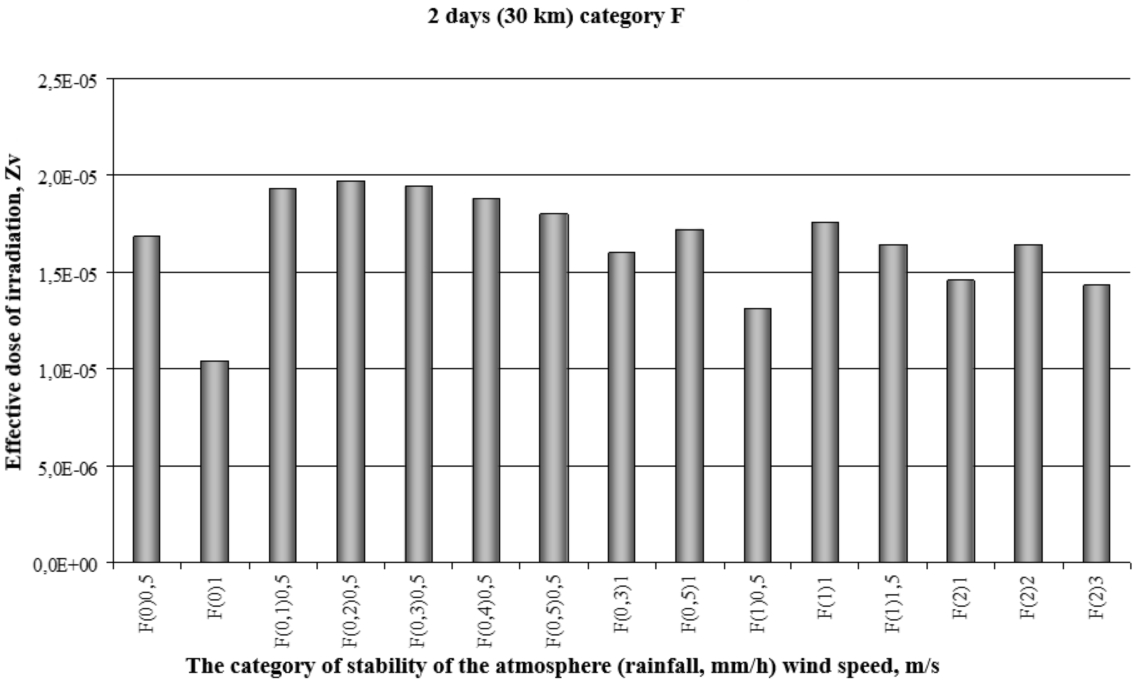


Fig. A.3. Maximum population radiation doses over a 2-day period within 30 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

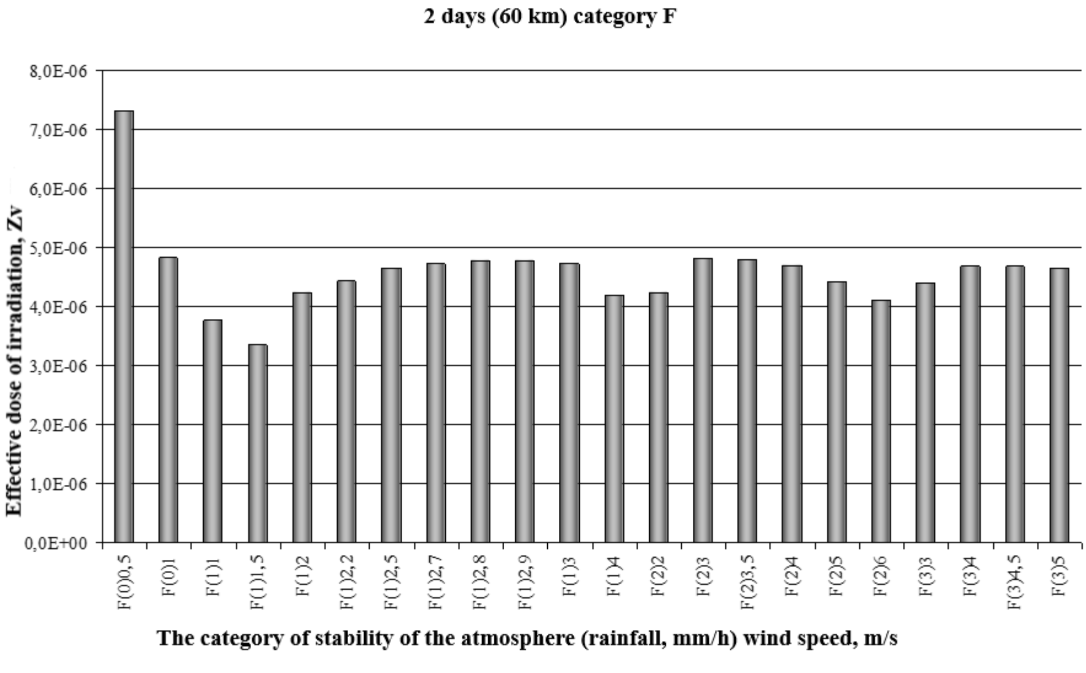


Fig. A.4. Maximum population radiation doses over a 2-day period within 60 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

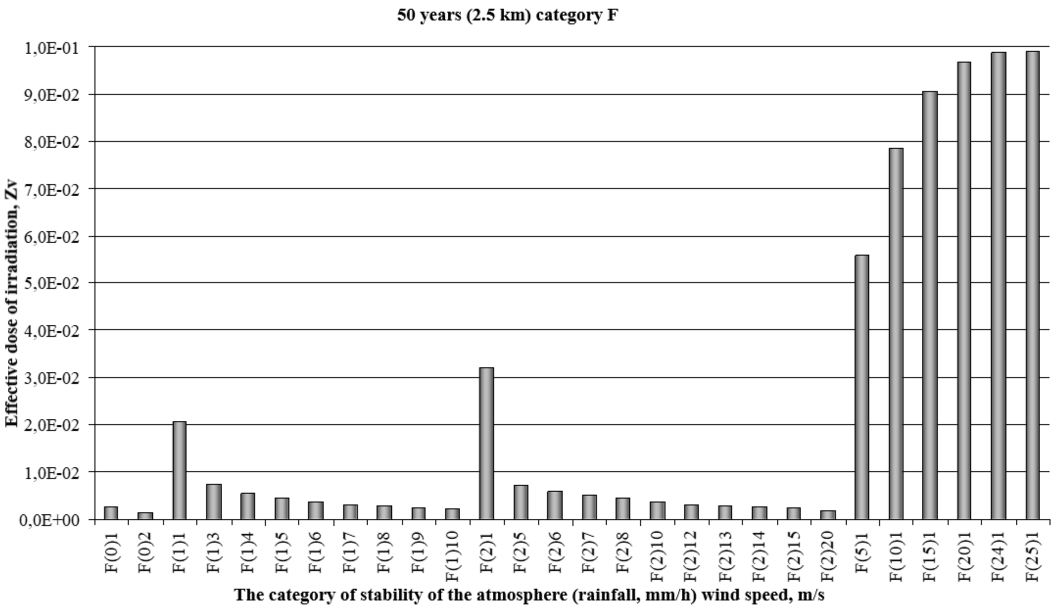


Fig. A.5. Maximum population radiation doses over a 50-year period within 2.5 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

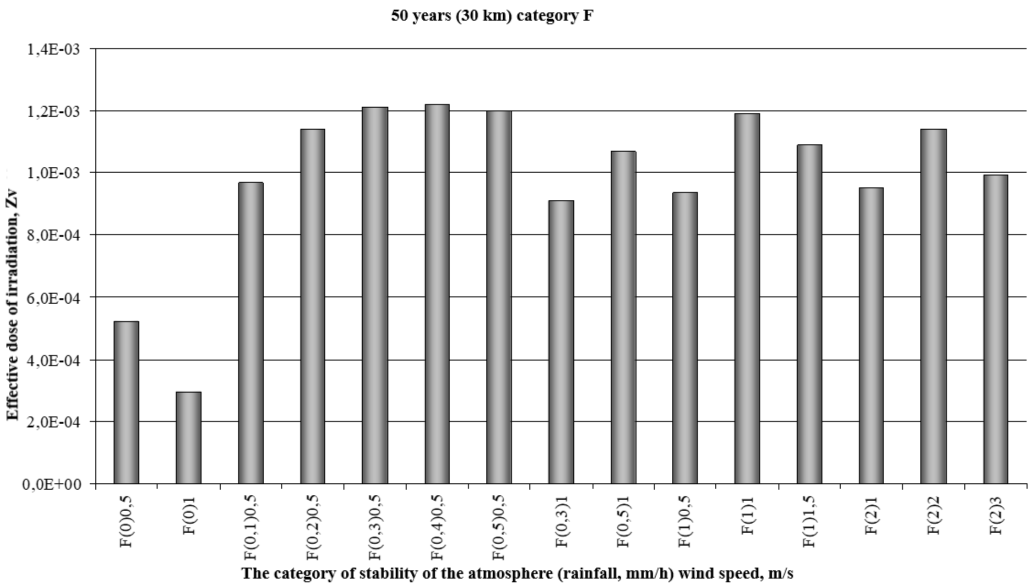


Fig. A.6. Maximum population radiation doses over a 50-year period within 30 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

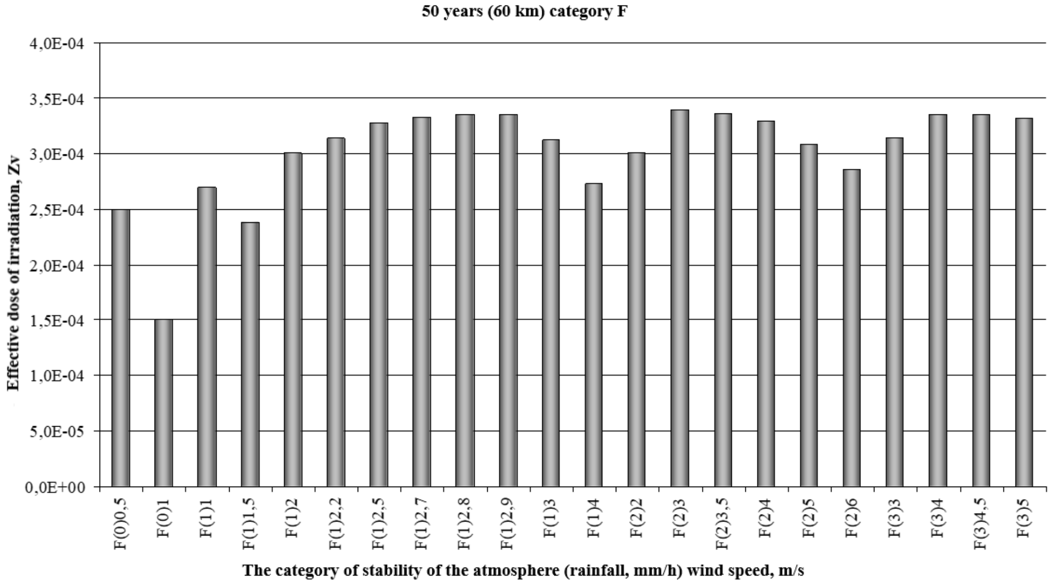


Fig. A.7. Maximum population radiation doses over a 50-year period within 60 km in case of the MDBA at the NPP with a VVER-1000 reactor, based on stability class F

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.