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Director of NT Engineering

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"__" December 2018

REPORT
ON
SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Book 7

Transboundary Environment Impact of The Production Activity

Version 2

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2018

УДК 621.039:504.064.3

МІНІСТЕРСТВО ЕКОЛОГІЇ ТА ПРИРОДНИХ РЕСУРСІВ УКРАЇНИ

УКРАЇНСКИЙ НАУКОВО-ДОСЛІДНИЙ ІНСТИТУТ ЕКОЛОГІЧНИХ ПРОБЛЕМ (УКРНДІЕП)

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ЗВІТ

За темою **«Проведення оцінки впливу на довкілля майданчику ВП «Рівненська АЕС»**

Етап 3

Транскордонний вплив виробничої діяльності на навколишнє середовище

(остаточна редакція)

за договором № 0709/849/2.4 от 12.04.2018 р.

Науковий керівник,

зав. лаб. 2.4

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Abstract

This report contains calculations and justification of radiation impact of radioactive releases from SS Rivne NPP on the environment and the population during normal operation and in emergency cases in a transboundary context.

All calculations have been performed for conservative conditions of impurity propagation and radiation dose formation (at maximum doses).

It has been shown that maximum permissible values of radiation criteria for equivalent and absorbed doses in body organs and the entire body at borders with other countries, as defined by regulatory documents, are met during normal operation of power units, or in case of design basis or beyond design basis accidents.

It has been justified that planned activities have no major transboundary impact, and there is no affected party in terms of the Convention on Environmental Impact Assessment in a Transboundary Context. In execution of para. 8, Art. 3 of Convention on Access to Public Information, posting the information on environmental impact of the planned activities in a transboundary context at common access Internet resources, e. g. on websites of the government authorities concerned - the Ministry of Ecology and Natural Resources of Ukraine and the Ministry of Energy and Coal Industry of Ukraine - will suffice.

The report contains 68 pages, including 14 figures and 27 tables.

Keywords: NPP, radiation dose, maximum design basis accident, beyond design basis accident, transboundary impact.

Contents

Abbreviations

NPP	Nuclear power plant
ARSMS	Automated Radiation State Monitoring System
VVER	Water-water power reactor
SS	Separate Subdivision
VS	Ventilation system
WP	Waste piping
LLN	Long-lived nuclides
SE NNEGC Energoatom	State Enterprise “National Nuclear Energy Generating Company Energoatom”
RNPP	Rivne Nuclear Power Plant
BDBA	Beyond design basis accident
OZ	Observation zone
IRG	Inert radioactive gases
RWMT	RW level monitoring tanks
EDR	Equivalent dose rate
ICRP	International Commission on Radiological Protection
MDBA	Maximum design basis accident
VA	Volumetric activity
ISS	Industrial/storm sewerage
CS	Control station
RW	Radioactive waste
RC	Radiation control
RR	Reactor room
LRW	Liquid radioactive waste
RU	Reactor unit
RAWT	Radioactive water treatment
SPB	Special purpose building
RCS	Radiation Control System

LRWR	Liquid radioactive waste repository
SRWR	Solid radioactive waste repository
FE	Fuel element
TPP	Thermal power plant
TLD	Thermoluminescent dosimeter
SRW	Solid radioactive waste

Introduction

In accordance with the requirements of the International Convention on Environmental Impact Assessment in a Transboundary Context, as ratified by the Law of Ukraine No. 534-XIV dated 19 March 1999, the radiation environmental impact of Rivne NPP in a transboundary context, i. e. its impact on the territories of the neighbouring states, has been assessed. The impact of RNPP has been assessed both during normal operation and during accidents.

1 Environmental impact facility description and purpose of operations

The impact facility, SS Rivne NPP, is a separate subdivision (unit) of the State Enterprise “National Nuclear Energy Generating Company Energoatom” (SE NNEGC Energoatom). SE NNEGC Energoatom carries out activities in accordance with its Articles of Association and is subordinate of the Ministry of Fuel and Energy of Ukraine.

SE NNEGC Energoatom is assigned the functions of an operating organization responsible for the safety of all nuclear power plants in the country.

Rivne NPP is located on the Styr River in the north-west part of the Rivne Region, 120 km from the City of Rivne, in the Volodymyretskyi District.

The location of SS Rivne NPP and the boundaries of its observation zone (OZ) are shown in Fig. 1.1 [1].

The gross installed capacity is 2 mln 835 thous. kW. The design CUF capacity utilization factor is 74.2 %.

The construction started in 1983.

The plant was commissioned in 1980.

Type of activity - electricity generation.

RNPP produces approx. 19 bln kW·h of electricity annually, which accounts for 21.6 % of gross electricity generation by nuclear power stations (NPP), or 12.0 % of Ukraine's gross electricity generation.

RNPP operates four power units:

Power unit I (VVER-440) with a capacity of 420 MW since 1980.

Power unit II (VVER-440) with a capacity of 415 MW since 1981.

Power unit III (VVER-1000) with a capacity of 1000 MW since 1986.

Power unit IV (VVER-1000) with a capacity of 1000 MW since 2004.

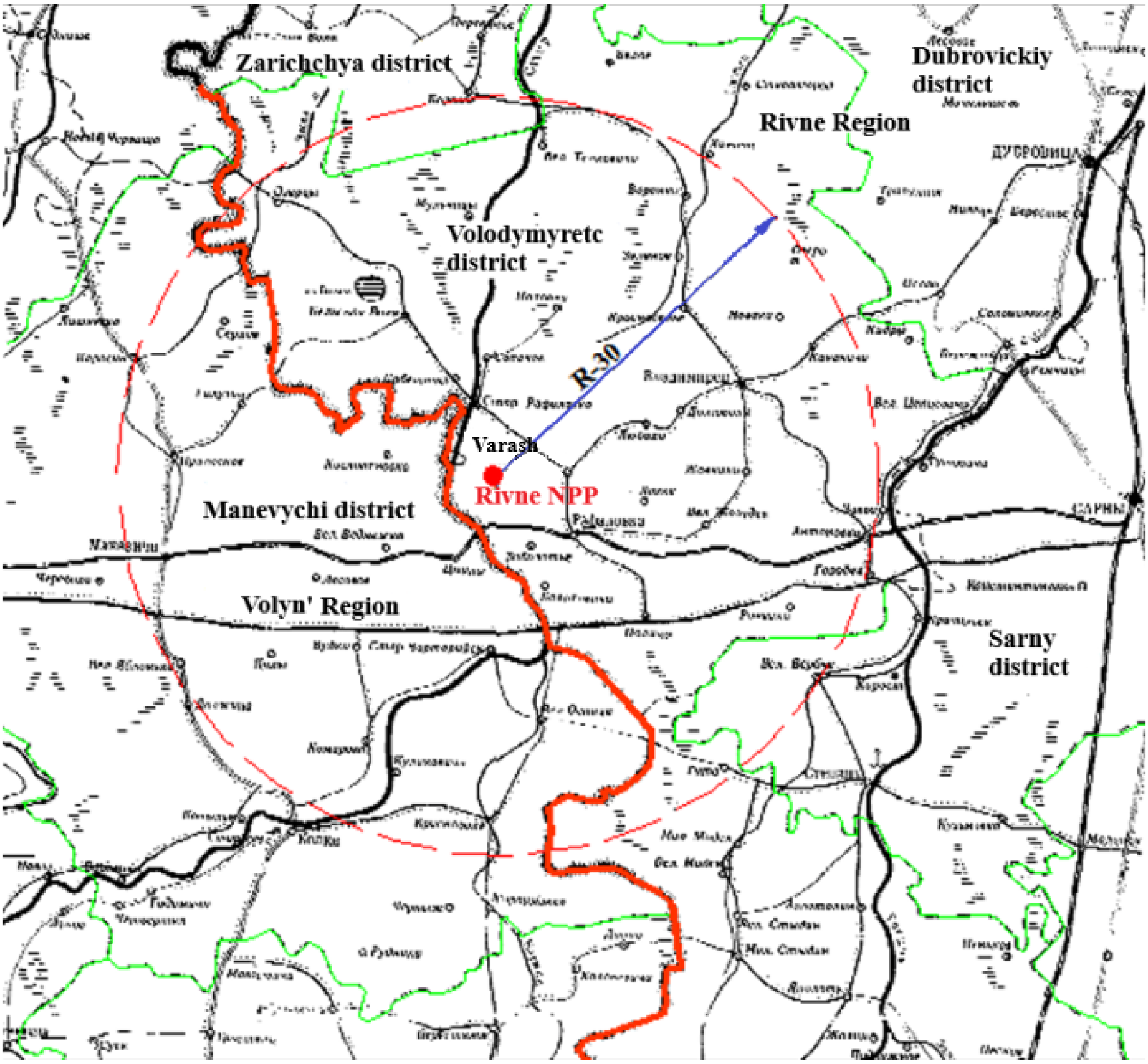

Figure 1.1 Rivne NPP location

1.1 Brief description of power units and production processes

The general site layout plan of Rivne NPP is shown in Fig. 1.2 [2].

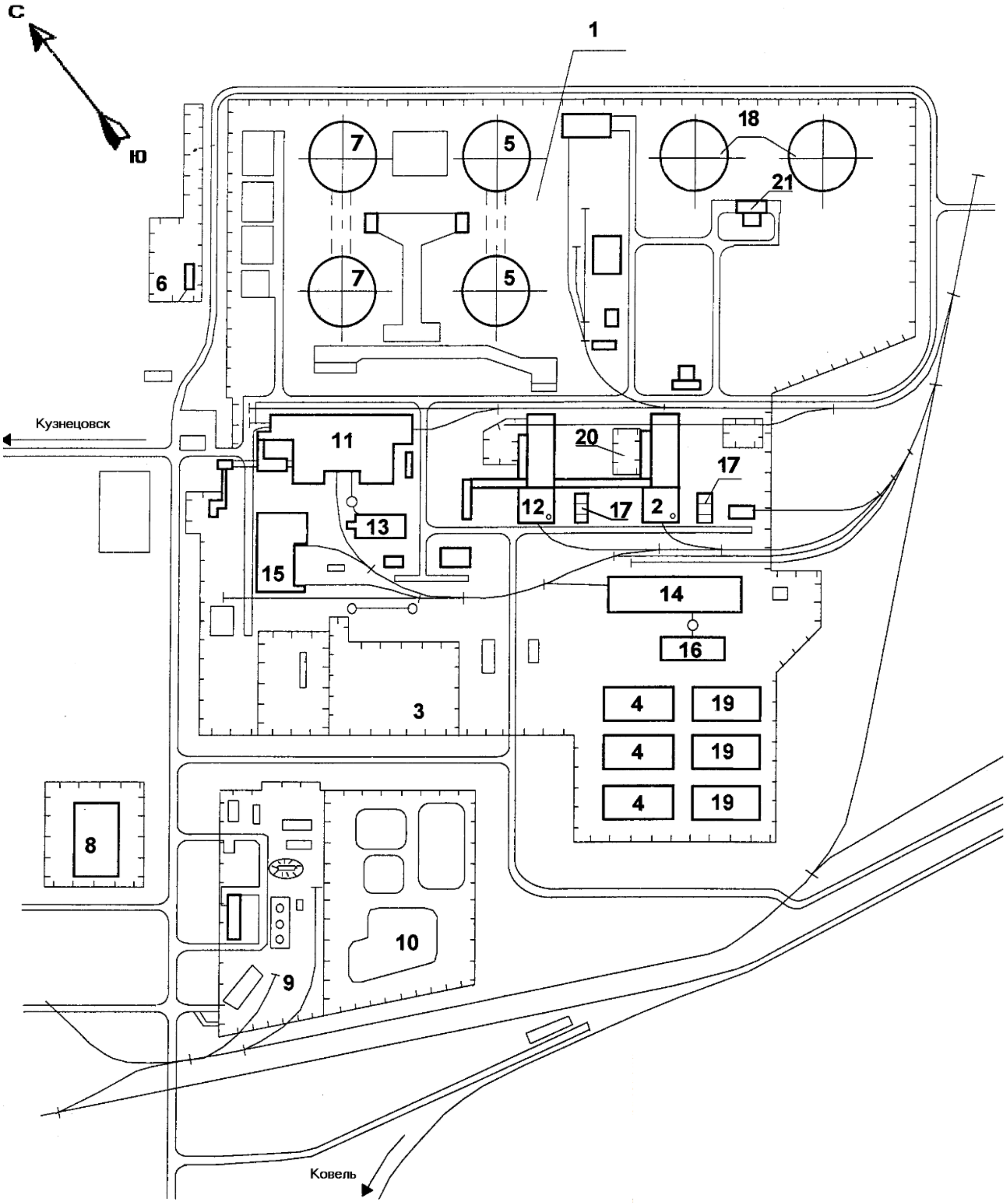

Figure 1.2 Schematic layout of buildings and structures at the SS Rivne NPP industrial site

1. NPP industrial site
2. Power units No. 1 and 2
3. Power unit No. 3
4. Power unit No. 4
5. Cooling towers of power units No. 1 and No. 2
6. Cooling towers of power unit No. 3
7. Cooling towers of power unit No. 4
8. Sprinkler pools of group "A" consumers cooling system of power units No. 3 and 4
9. Sprinkler pools of group "B" consumers cooling system of power units No. 3 and 4, including a standby one.
10. 110-330 kV outdoor switchgear
11. Special-purpose building for power units No. 1 and 2
12. Special-purpose building for power units No. 3 and 4
13. RW processing and storage building
14. Slam collecting tank
15. Fire depot
16. Structures for auxiliary water treatment
17. Start-up and standby boiler house
18. Combined auxiliary building
19. Auxiliary diesel generating station
20. Outdoor switchgear

Let's define the location of RNPP power units in Fig. 1.2: 11 - power units No. 1 and No. 2; 12 - power unit No. 3; 2 - power unit No. 4.

Rivne NPP is the first Ukraine's NPP utilizing water-water nuclear reactors, which currently are the only type of reactors in Ukraine, and the only Ukraine's NPP with power units based on the first reactors of VVER-440 series (B-213).

VVER-1000 water-water thermal neutron shell-type nuclear power reactors are intended for thermal energy generation (with the rated thermal power of 3000 MW) as part of the reactor unit. Reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel. Reactor core contains fuel assemblies that are situated at hexagonal lattice points and are made of low enriched uranium dioxide in a zirconium cladding.

The VVER-1000 reactor power unit operates in a two-loop circuit: first (hot) loop is a water circuit with direct heat extraction from the reactor; second (cold) loop is a steam circuit with heat extracted from the first loop and utilized in a turbine generator.

Within the reactor core, nuclear fuel fission energy is extracted via a coolant that is pumped through it by main circulation pumps. “Hot” coolant is fed from the reactor to the SG through the main coolant pipeline, where it transfers its heat energy to secondary water, and then is pumped back into the reactor by the main circulation pump. Dry-saturated vapour generated within the second steam generator loop is fed into the turbine generator that is equipped with a 1000 MW generator unit.

Borated water pumped at a pressure of 160 kgf/cm^2 is used as a moderator and a coolant in VVER-1000 nuclear reactors. The overall coolant flow through the reactor amounts to 84,800 m^3/h. Water temperature at the reactor inlet is 289 ºC and the outlet water temperature is 320 ºC during rated power operation.

Low-energy exhaust steam from reactor turbines is released through the water cooling system.

2 Potential radiation impact

Formation of gaseous, solid and liquid products that contain radioactive elements in the process of NPP operations is inevitable. Radiation impact of a power unit is due to the release of these elements into the environment [3–7].

During normal operation, any release of elements beyond the FE containment or partial destruction of this containment lead to a release of a certain amount of fission products into the first loop coolant. Minor amounts of radioactive products may also enter the first loop coolant following the neutron activation of structural materials. Activation product erosion and corrosion processes facilitate the release of these materials in the first loop coolant.

Radioactive fission and activation products are extracted from the coolant through ion exchange processes followed by the formation of contaminated ion exchange resins at radioactive water treatment (RWT) facilities. Periodic replacement of these resins results in the formation of both liquid and solid radioactive waste. Radioactive media handling process at RWT facilities located in the special purpose building (SPB) results in the formation of radioactive waste (RW): solid, liquid and gaseous.

Acceptable primary coolant leakage in the steam generator into the secondary circuit leads to radioactive contamination of water within this circuit.

Gases accumulated in the primary circuit during operation are extracted from the circuit. This results in the formation of a gaseous emission flow. Air emissions may also form due to ventilation of volatile primary coolant emissions from minor leaks, both controlled and uncontrolled. Such emissions usually contain tritiated water vapour, inert gases, aerosols and other gaseous particles.

Annual reactor shutdown involves pressure release from cooling systems, reactor vessel lid is taken off and one third of fuel assemblies are removed and placed for storage in the spent fuel pool. The remaining two thirds of fuel assemblies are rearranged to maintain the optimum neutron-flux density, and the core is filled with fresh fuel. Apart from spent fuel, fuel refilling procedures may lead to an increase in LRW discharge and air release from the spent fuel pool or from reactor and protective tube unit (PTU) inspection cavities. These types of waste are similar to radioactive waste released from the primary coolant.

Moreover, repair and maintenance procedures during the reactor shutdown are also sources of various RW released during opening and repair of the equipment. Certain primary components that were contaminated due to neutron exposure, as well as reactor and SPB equipment components that were exposed to radiation, may be replaced, followed by the formation of additional solid radioactive waste (SRW).

Liquid and solid RW handling and storage must be in accordance with the requirements of Sanitary Rules for Design and Operation of Nuclear Power Plants and Basic Sanitary Rules for Radiation Safety of Ukraine. Environmental release of these RW types during normal operation, design basis accidents and during the maximum credible beyond design basis accident are practically minimized and may be disregarded.

3 Assessment of environmental impact degree

The degree of environmental impact was assessed taking into account the amounts of radioactive releases, which were monitored daily or once a month.

3.1 Monitoring methods and equipment

The amounts of radioactive releases are monitored by IRG, LLN and iodine radionuclide groups in the following ventilation systems:

- VS of power units No. 1, 2;
- VS-1 at PR of power units No. 3, 4;
- VS-2 at PR of power units No. 3, 4 (during operation of 3TL-21, 4TL-21 systems);
- VS at SPB of power units No. 3, 4.

IRG release activity was measured on a continuous basis using PING-206S (units Nos. 1, 2, 3) and RKS-07P (unit No. 4) radiation detectors.

LLN and radioiodine samples were taken on a continuous basis using AFA-RMP-20 and AFAS-I-20 filters. Filters were sampled and checked using FHT-770S radio detectors on a daily basis for the purposes of in-process monitoring of LLN release (following 1 day exposure and not taking into account the activity at the time of filter installation). In-process monitoring of radioiodine was performed by γ-spectrometry at the Radiation Safety Laboratory (RSL).

For the purposes of radionuclide content monitoring, AFA-RMP-20 filters were kept for a month and then tested at the External Radiation Monitoring Laboratory (ERML) by γ-spectrometry using GEM solid-state detectors and DSPEC PLUS multichannel pulse analysers by ORTEC (USA). Release activity calculation was in compliance with the requirements of MM-I.0.03.025-14 “Model procedure for gamma-spectrometry of gamma-emitting radionuclides activity in loads sampled from NPP process media”.

The acceptable gas-aerosol release (GAR) levels are calculated in accordance with NRBU-97 requirements taking into account the limit dose rate, and are not affected by NPP capacity. The acceptable and reference GAR and liquid discharge levels at RNPP were approved by the MoH of Ukraine.

The 2017 total radionuclide release from RNPP power units as well as reference and limit releases and discharges for the past year are given in Table 3.1.

Table 3.1 - Total radionuclide release from RNPP power units in 2017

Nuclide	Activity, GBq	Reference release level, GBq	Release limit per radionuclide (radionuclide group), GBq
IRG	3.52E+04	3.18E+05	2.45E+07
Iodine	4.14E-02	5.11E+01	2.01E+03
Cr-51	1.86E-03	-	2.26E+05
Mn-54	8.65E-04	-	1.10E+03
Co-58	6.86E-04	-	3.43E+03
Fe-59	2.23E-04	-	3.61E+03
Co-60	5.29E-03	4.20E-01	6.20E+01
Nb-95	1.57E-03	-	9.12E+03
Zr-95	4.13E-04	-	4.74E+03
Ag-110m	5.04E-03	-	1.79E+02
Cs-134	1.04E-03	5.76E-01	1.46E+02
Cs-137	5.70E-03	5.04E-01	1.28E+02
Sr-90	3.77E-04	-	1.76E+02
H-3	1.63E+03	6.24E+03	3.39E+05

The technology (equipment, sampling method, preparation) allows measuring releases in the range from the minimum actual values to those exceeding the limit values.

3.2 Doses at borders with the neighboring states during normal operation

All radionuclides with respective average annual releases, which were used in calculations, are given in Table 3.2.

Table 3.2 - Calculated values of air radionuclide releases from SS RNPP facilities during normal operation

Radionuclide group	Radionuclide name	Release, Bq/year
IRG	^{88}Kr	2.35×10^{12}
	^{133}Xe	1.69×10^{13}
	^{135}Xe	4.23×10^{12}
Iodine	^{131}I	9.43×10^{7}
	^{133}I	$5.04E\times10^{7}$
	^{135}I	1.31×10^{7}
LLN	^{137}Cs	6.28×10^{6}
	^{134}Cs	9.66×10^{5}
	^{60}Co	7.27×10^{6}
	^{58}Co	1.09×10^{6}
	^{54}Mn	1.22×10^{6}
	^{51}Cr	4.56×10^{6}
	^{90}Sr	2.60×10^{5}
	^{59}Fe	3.28×10^{5}
	^{95}Zr	5.80×10^{5}
	^{95}Nb	2.23×10^{6}
	^{110m}Ag	4.71×10^{6}
Tritium	^{3}H	1.01×10^{12}
Radiocarbon	^{14}C	1.99×10^{11}

3.2.1 Distances to the neighboring countries

The location of RNPP with respect to the neighbouring countries is shown in Fig. 3.1.

<u>The distance to neighboring countries from the Rivne NPP</u>

Belarus - 60 km
Poland - 130 km
Lithuania - 310 km
Slovakia - 340 km
Moldova - 360 km
Romania - 370 km
Hungary - 410 km
Czech Republic - 510 km
Austria - 700 km
Germany - 710 km

Figure 3.1. Distances from SS RNPP to neighboring countries

Table 3.3 - Distances from SS RNPP to borders of neighbouring countries, km

Belarus	60
Poland	130
Lithuania	310
Slovakia	340
Moldova	360
Romania	370
Hungary	410
Czech Republic	510
Austria	700
Germany	710

The absolute distances are given in Table 3.3, with weather sectors indicated by arrows in Fig. 3.1

3.2.2Calculated doses at borders with the neighboring states during normal operation

The calculation of total expected individual doses from SS Rivne NPP in representatives of the population at borders with the neighboring states, is given in Table 3.4 and in Fig. 3.2. The distances in Fig. 3.2 refer to countries in Table 3.3. Dependences of the total dose on distances for two population categories - infants under 1 YOA and adults - have been shown. Expected annual doses were calculated after 50 years of releases. As seen from the table, the critical group in this case is represented by infants who are exposed to higher doses. Calculations for the critical group represented by children under 10 resulted in mean values between adult and infant doses. This data is omitted.

Table 3.4 - Expected dose, nSv/year

Country	Infants	Adults
Belarus	1.5	1.3
Poland	0.82	0.7

Country	Infants	Adults
Lithuania	0.3	0.26
Slovakia	0.35	0.3
Moldova	0.26	0.22
Romania	0.2	0.17
Hungary	0.29	0.25
Czech Republic	0.2	0.18
Austria	0.15	0.13
Germany	0.14	0.12

However, the expected doses are rather low. The maximum value is expected to occur at the border with Belarus, which is the nearest country to RNPP. These doses are within 1 nSv/year, which is well below the limit dose rate for NPP releases, which is equal to 40,000 nSv/year (see NRBU-97 [8]) and population radiation rates during normal NPP operation in Russia, which is equal to 200,000 nSv/year for an operating NPP and 50,000 nSv/year for a design NPP [9].

So, the impact on the neighbouring countries will be well below the established dose rates and limits for individual effective annual doses of 1 mSv (1,000,000 nSv) for the population [8].

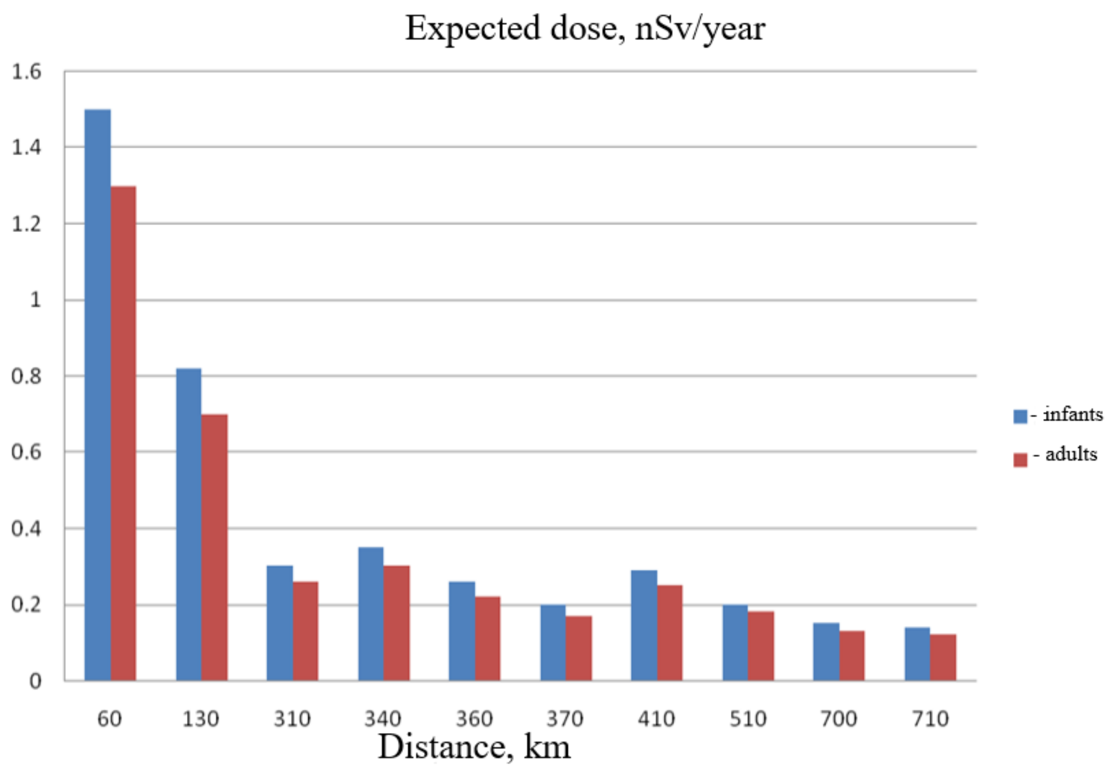

Figure 3. 2 -Total expected individual doses from the NPP in population (the distances refer to countries in Table 3.3)

Nonuniform reduction of doses based on the distance is due to the weather conditions, which are only measurable for 16 discrete sectors. Vectors from RNPP to the nearest borders of different countries (see Fig. 3.1) are located in different sectors, so, even though the doses reduce as the distance grows, the wind pattern may reverse this dependence. In Fig. 3.2, this is true for Lithuania (310 km) and Slovakia (340 km), as well as for Romania (370 km) and Hungary (410 km).

Let's analyze partial shares in full doses for different radionuclides and radiation routes in infants at the border with Poland, as an example. The relative ratios of the above data are nearly the same for other countries, however their values are proportional to the full dose.

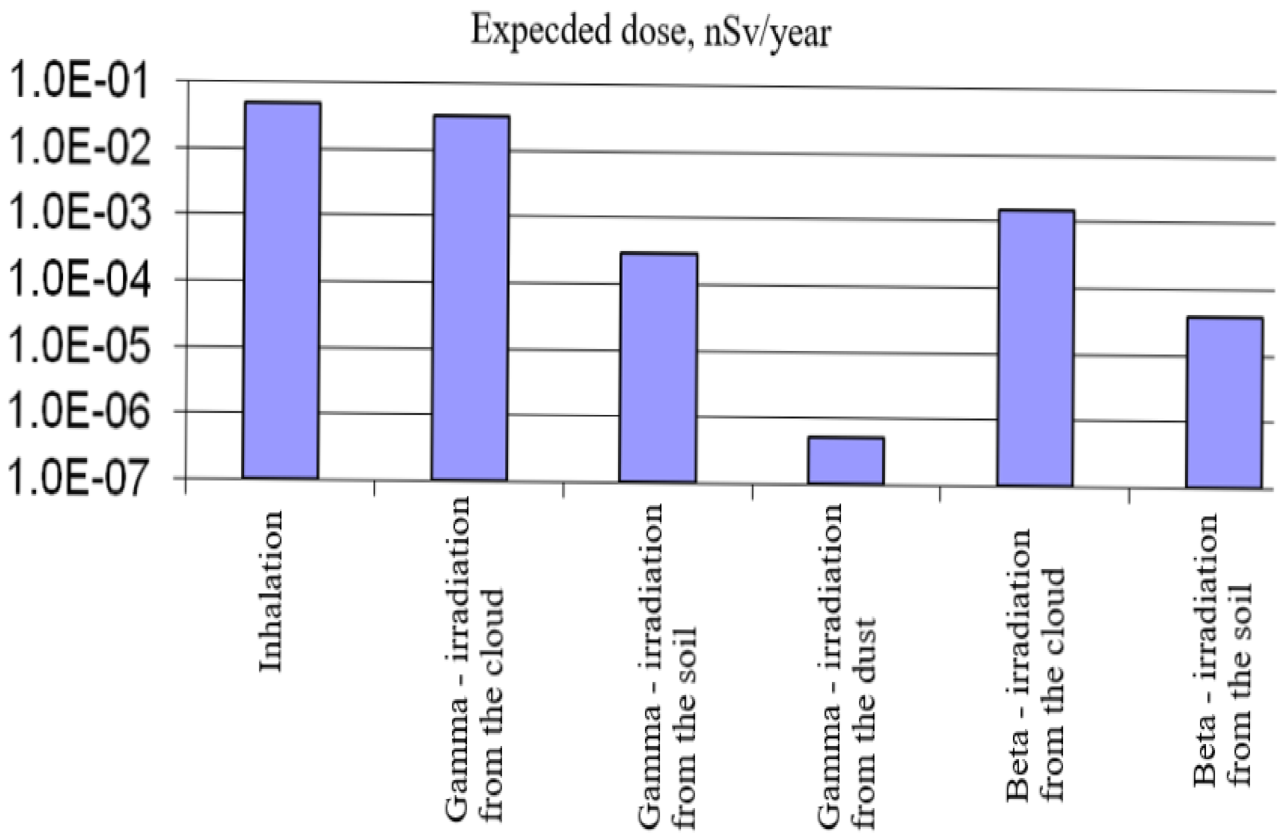

Figure 3.3 Relative share in expected individual doses for infants at the border with Poland

Fig. 3.3 shows shares (for inhalation and external radiation) in the full expected dose over a year after 50 years of releases in infants within 130 km from RNPP (at the border with Poland). The maximum share of 0.05 nSv/year is due to inhalation intake. The value is practically the same for gamma-ray photon radiation from the release cloud. The share of gamma radiation from soil is lower by two orders of magnitude. With the full dose at this distance of 0.82 nSv/year, radiation from the above sources accounts for about 5.6 %, while the rest of the dose is obtained from food products.

Fig. 3.4 shows shares in the full expected dose from different food products over a year after 50 years of releases in infants within 130 km from RNPP.

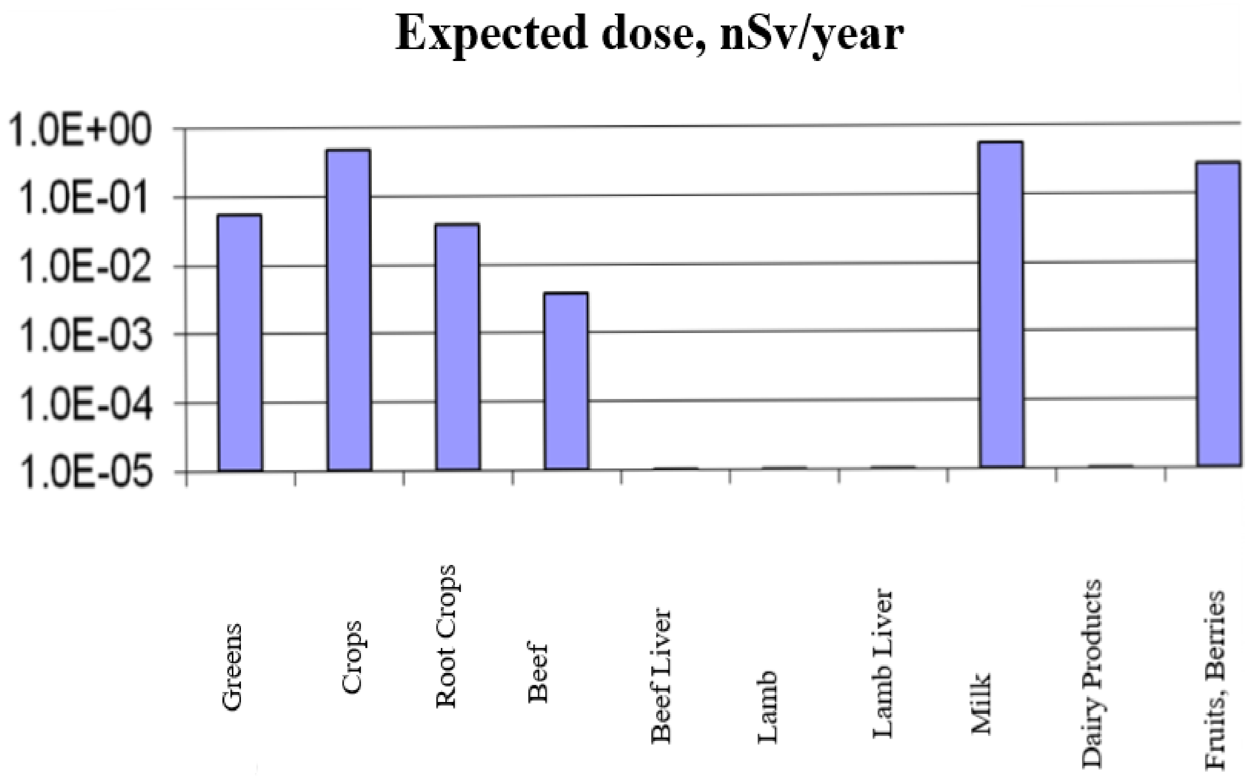

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Fig. 3.4 - Relative share in expected individual doses from different food products in infants at the border with Poland

The maximum share of 0.56 nSv/year is due to milk consumption. The share of cereals is lower; it makes 0.47 nSv/year.

The share of fruits and berries, which contain radionuclides that affect breast milk, is 2 times lower (0.27 nSv/year). Root crops and green vegetables account for a significant share, also absorbed through breast milk (see data in Fig. 3.4). Dairy products (cream, butter, cheese, etc.), similar to meat products, account for a negligible share. In general, food products provide a major share (94.4 %) in the total expected dose.

The major share in the total expected dose over a year after 50 years of releases of all radionuclides during normal operation (see Table 3.2) is due to the following radionuclides: ^{14}C, ^{3}H, ^{131}I and ^{88}Kr, see data in Fig. 3.5. This figure shows calculated shares of different radionuclides in expected individual doses in infants at the border with Poland.

It should be noted that the listed shares in the total dose reduce as the distance grows roughly the same as the total dose in Fig. 3.2.

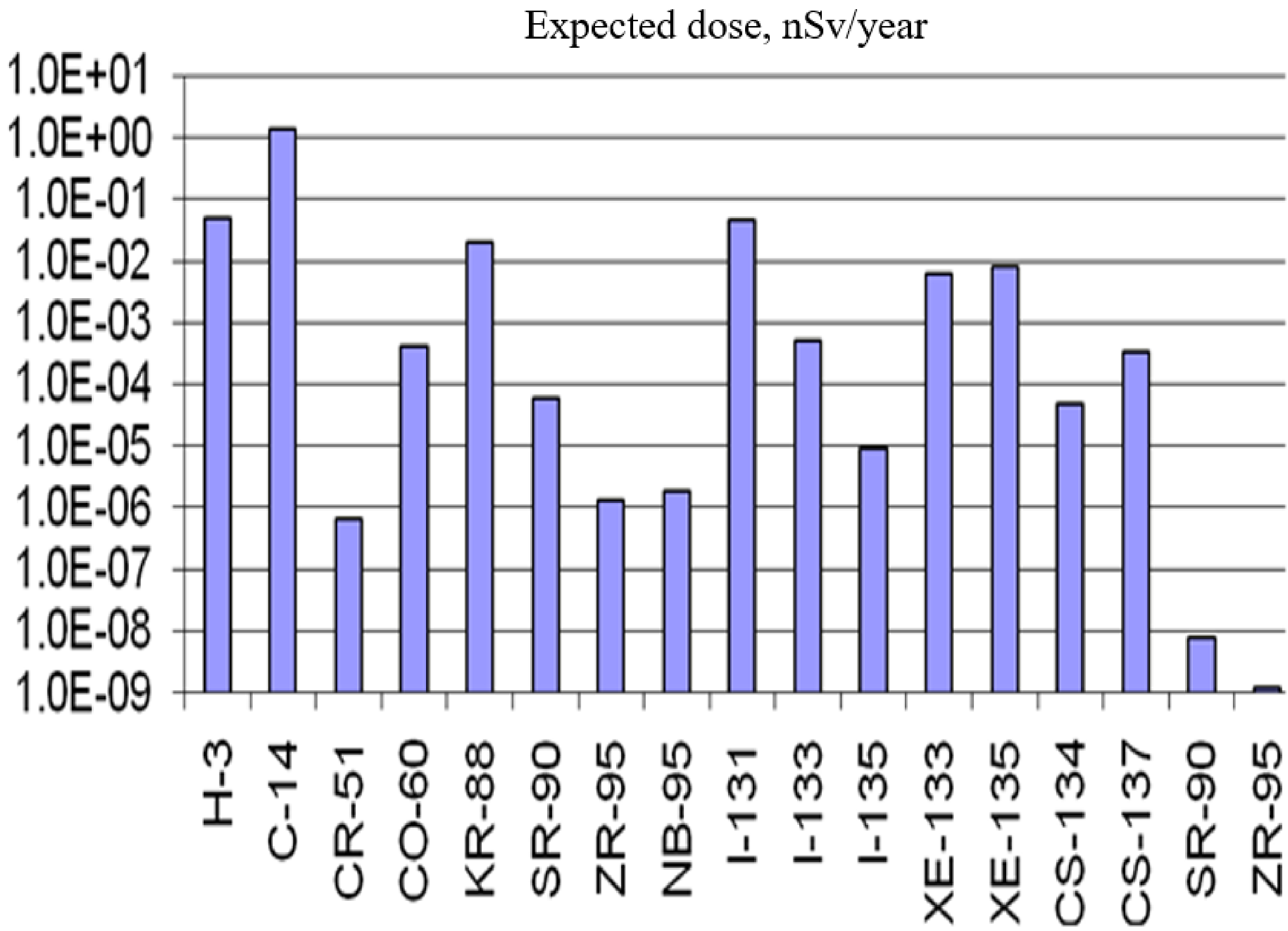

Fig. 3.5 - Relative shares of different radionuclides in expected individual doses in infants at the border with Poland

3.3 Doses at borders with the neighbouring states during accidents

The radiation impact of Rivne NPP was analysed based on the following maximum design basis accident (MDBA): an accident caused by double-ended rupture of the cooling system pipeline (loss-of-coolant nuclear reactor accident) at normal energy level.

Radionuclide intake during the beyond design basis accident (BDBA) was determined based on the limit value of environmental release of Cs-137 at the level of 30 TBq in accordance with the safety requirements of European operators for designs of nuclear power plants with light water reactors (LWR). Cs-137 isotope was chosen due to its prevalent value for long-term environmental pollution as well as its health impact.

Other isotopes in the form of aerosol (i. e. all radioactive decay products, except for inert gases and gaseous iodine isotopes) are released into the environment in proportion to this value, even if these isotopes are released into the atmospheric air.

The release activity of inert gases and gaseous iodine isotopes was calculated at 0.5 % of the total daily activity within the containment. The conservative value of the total release activity over the entire period of the release was established at the level of 7-fold release activity during day one [10-13].

The conservative release height is considered to be at the surface air level, which corresponds to the forecast release routes in case of major accidents due to containment leakage.

The total list of radionuclides that may be released in the environment, except for illustrative isotopes, includes other radioisotopes from the same group, which are present in the general member in proportion equal to that of the sum of decay products in the reactor core with respect to the illustrative isotope.

The dose of the proposed source member should be calculated taking into account the release of separate radioisotopes based on the time interval of linear duration of 0 to 24 hours following the accident - a conservative approach compared to the considered release duration of 7 days.

Table 3.5 shows radionuclide release parameters during the MDBA. The accident duration is taken to be 60 minutes. Other accidents that result in lower radionuclide releases are omitted.

Table 3.5 - Radionuclide release activities during the MDBA

Radionuclide	Half-life	Release during MDBA
Kr-88	2.84 h	2.00E+13
Sr-90	29.1 years	3.10E+11
Ru-103	39.6 days	4.50E+12
Ru-106	1.01 years	6.60E+11
I-131	8.04 days	4.98E+12
I-132	2.3 h	2.70E+12
I-133	20.8 h	4.00E+12
I-135	6.61 h	2.30E+12
Cs-134	2.06 years	7.80E+11
Cs-137	30.0 years	5.00E+11
La-140	1.68 days	8.40E+12
Ce-141	35.2 days	1.40E+13
Ce-144	284 days	8.60E+12

Primary radionuclides and their respective releases in case of the BDBA are listed in Table 3.6.

Table 3.6 - Radionuclide release activities during the BDBA at RNPP, Bq

Radionuclide	Release amount, TBq	Radionuclide	Release amount, TBq
Xe-133	3.50E+05	Cs-136	1.50E+01
Kr-85	2.10E+03	Te-131m	2.00E+01
Kr-85m	5.30E+04	Te-129m	8.00E+00
Kr-87	1.10E+05	Te-132	2.00E+02
Kr-88	1.40E+05	Sb-127	1.60E+01
Xe-131m	2.10E+03	Sb-129	4.60E+01
Xe-133m	1.10E+04	Sr-90	5.00E+00
Xe-135	1.10E+05	Sr-89	6.00E+01
Xe-135m	7.70E+04	Sr-91	7.50E+01
Xe-138	3.20E+05	Ru-103	3.00E+00
I-131	1.00E+03	Mo-99	4.00E+00
I-132	1.50E+03	La-140	5.00E+00
I-133	2.10E+03	Y-91	4.00E+00
I-134	2.30E+03	Ce-141	4.00E+00
I-135	2.00E+03	Ce-144	3.00E+00
Cs-137	3.00E+01	Np-239	4.80E+01
Cs-134	6.00E+01	Ba-140	1.00E+02

3.3.1Selection of the lowest weather conditions that result in the maximum radiation doses

Weather conditions for accidents have been selected based on calculated population radiation doses, i. e. the worst case weather conditions, which result in maximum values (conservative approach).

The dose at the reference point may vary depending on weather conditions. Six Pasquill weather stability classes are distinguished: A, B, C, D, E, F. (A - extremely unstable; B - moderately unstable; C - slightly unstable; D - neutral; E - slightly stable; F - moderately stable). According to Pasquill's approach, all weather conditions are divided into six classes: from extremely unstable “A” to stable “F”. An additional weather stability class “G” - extremely stable - is also considered.

If unstable class “A” prevails during the release, then major fluctuations in wind directions are observed, a thick release cloud mixing layer is present, and small amounts of radionuclides are transferred to great distances.

Where stable class “F” prevails, then although the cloud mixing layer is narrow, the wind speed is low still, while “dry” and “wet” washout results in a low activity of radionuclides at the reference point. These quality considerations are confirmed by quantifications, with the results shown in Fig. 3.6.

Calculated effective doses for 50 years at certain distances from RNPP are shown in Fig. 3.4 for different weather classes. The release values close to actual values were used to assess the weather dependence only. The calculations show that the maximum doses at all borders with the neighbouring countries are reached when weather class D prevails. The maximum expected dose is reached at weather class F for the smallest distance only (60 km, Republic of Belarus), but this dose exceedance is insignificant compared with class D, and in further calculations class D is used as the least safe weather category.

Calculations of the expected effective dose for the maximum design basis accident at different distances, which were performed for different precipitation levels, have shown that the maximum expected effective dose for 50 years is reached for the precipitation level of 0 mm/h for most countries (see calculated data in Fig. 3.5), except for the Republic of Belarus, where such maximum doses are expected at 1 mm/h.

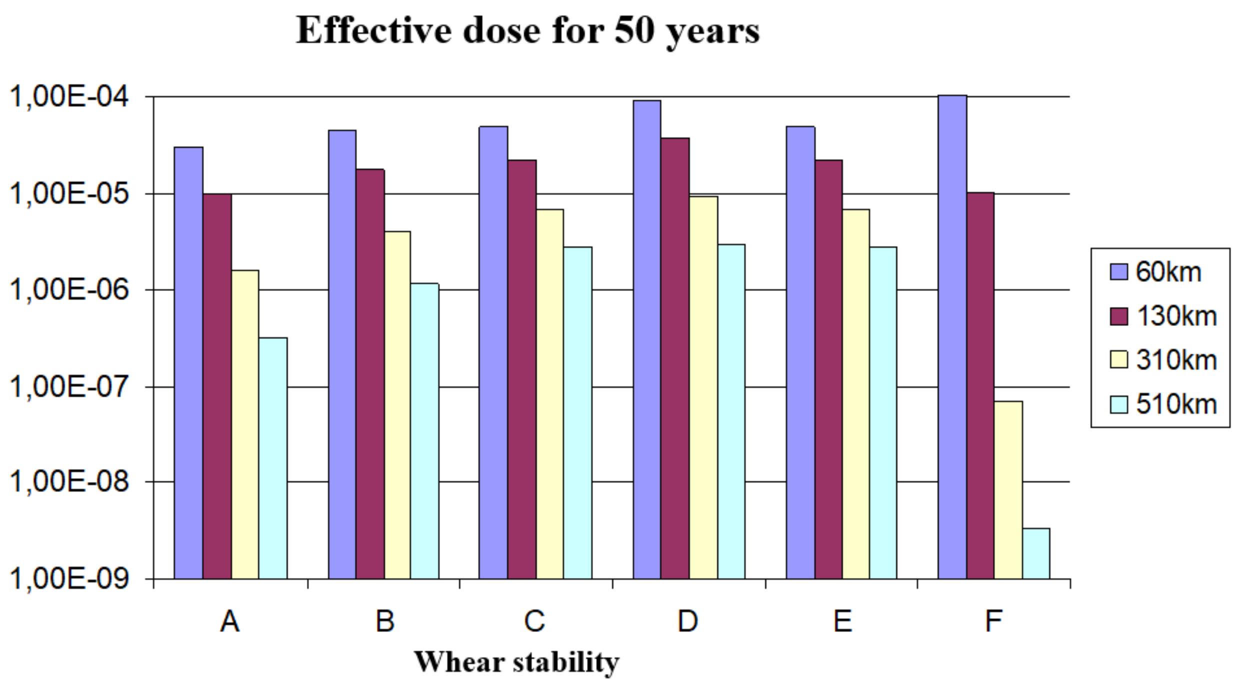

Figure 3.5 - Dependence of the effective dose for 50 years on weather stability class at certain distances from RNPP

Precipitation results in radionuclide washout from the radioactive cloud when dispersed over great distances, therefore maximum doses are expected at such distances under no-rain conditions. At small distance, rain may result in increased washout and, therefore, increase the dose. Based on the conservative approach, all further calculations will be performed for precipitation level of 0 mm/h. Rainy weather conditions will only be used for the smallest distance (60 km, Republic of Belarus).

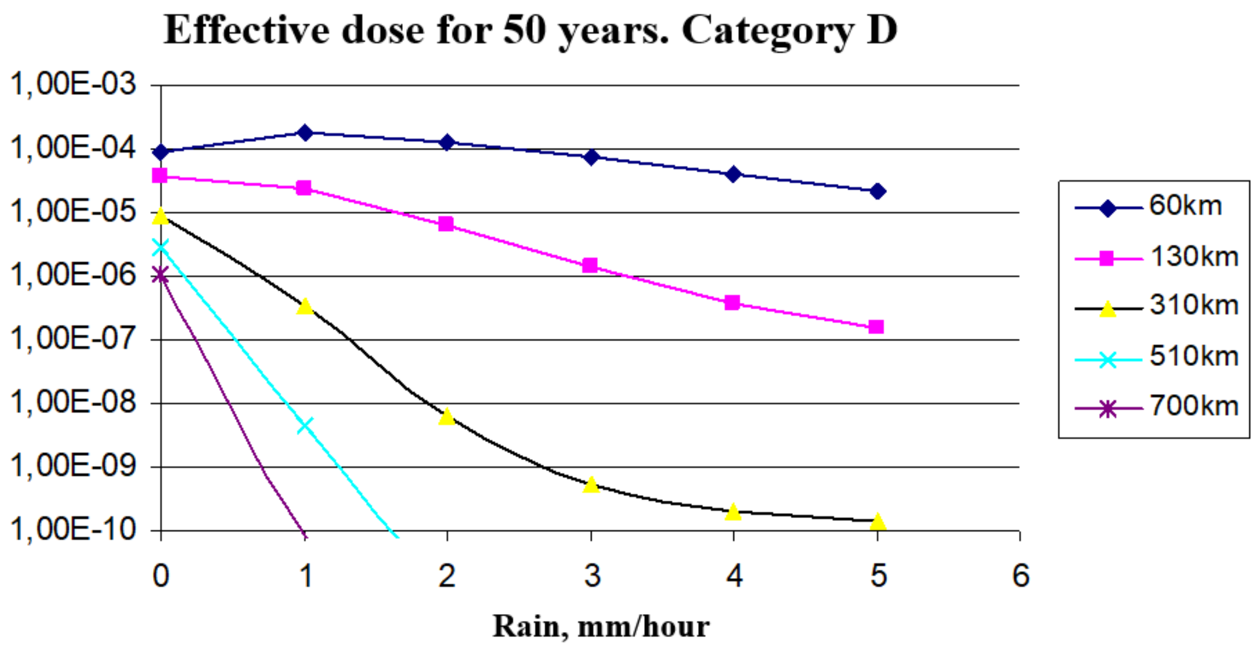

Fig. 3.5 - Dependence of the expected effective dose for 50 years on precipitation level

3.3.2 Doses at borders with the neighbouring states during accidents at RNPP

Calculations of expected effective doses for 50 years at different distances from RNPP during the MDBA and BDBA are shown in Fig. 3.6. The continuous curve in Fig. 3.6 demonstrates the dependence of the effective dose for 50 years on the distance in case of a BDBA, while dashed curve indicates the same in case of a MDBA.

Based on the data in Fig. 3.6, expected efficient doses reduce rapidly as the distance grows, and expected efficient doses during the BDBA are higher than the same during the MDBA by approx. two orders of magnitude.

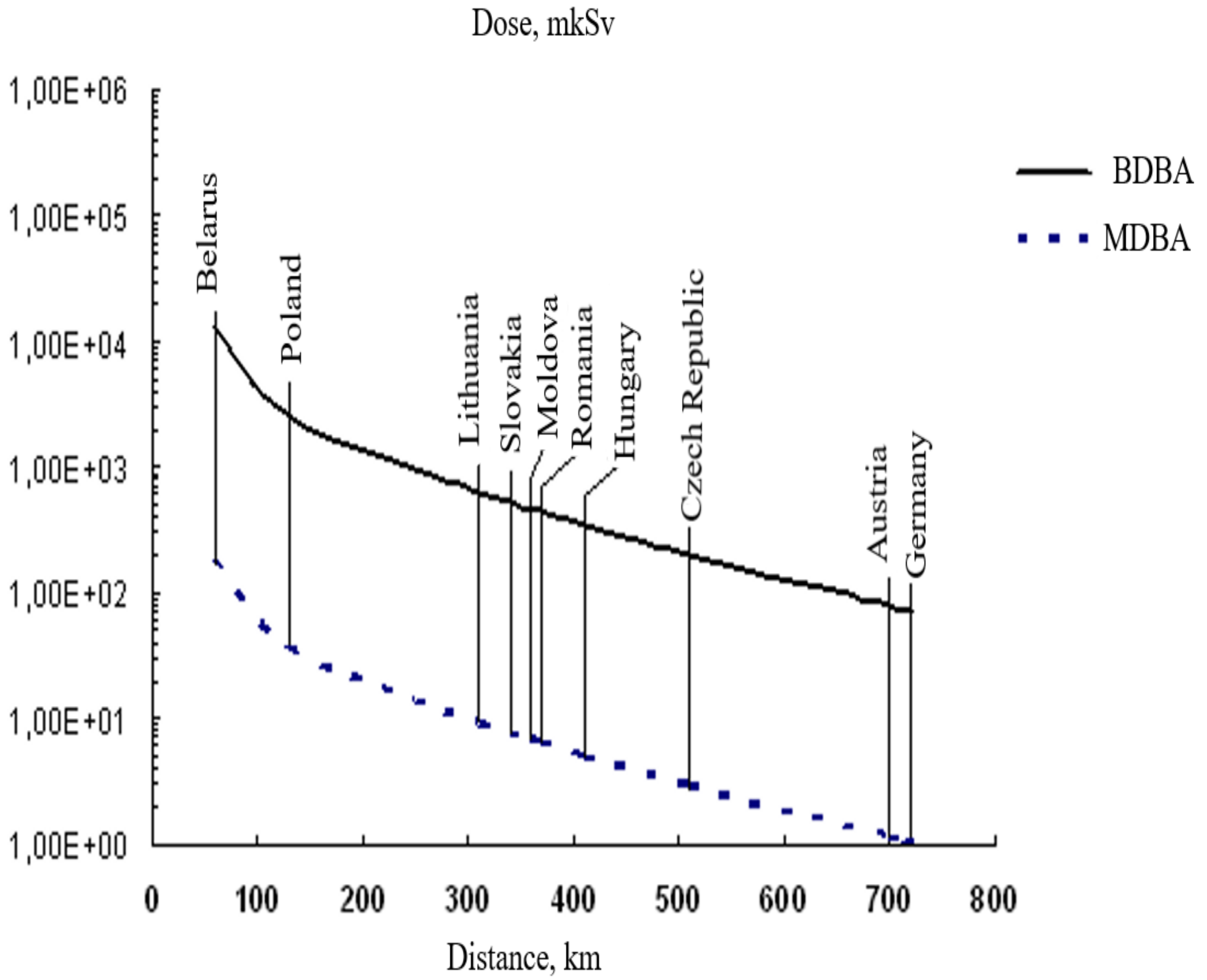

Fig. 3.6 - Dependence of the expected effective dose on distance during the MDBA and BDBA at RNPP

The maximum expected efficient dose for 50 years is observed for the Republic of Belarus and is equal to approx. 13 mSv, i. e. 0.26 mSv/year on average. The lowest weather conditions were used in the calculations for each country, so the dose dependence on distance is uniform.

The Radiation Safety Standards of Ukraine [8] set the doses that require countermeasures to protect the population (see Table 3.6) for radiation accidents.

The dose of 1 Gy for 2 days (it. 1 of Table 3.6) has not been exceeded since the total effective dose for 50 years is much below this value.

The dose of 5 mSv for the entire body for the first 2 weeks (it. 2 of Table 3.6) has not been exceeded since the calculation for the Republic of Belarus, which is the nearest country to RNPP, for the same period results in a value of 0.19 mSv for 2 weeks.

Table 3.6 - Intervention levels in case of radiation accidents

No.	Countermeasures	Dose levels
1	Unconditionally justified emergency intervention level (acute exposure)	1 **Gy** for 2 days for the entire body (bone marrow)
2	Lower justifiability limit for urgent countermeasures	5 **mSv** for the entire body for the first 2 weeks after the accident
3	Lower justifiability limit for decision on relocation	**0.2** Sv during the relocation period
4	Lower justifiability limit for decision on relocation	**0.05** Sv for the first 12 months after the accident
5	Lower justifiability limit for decision on temporary relocation	**0.1** Sv during the temporary relocation period

The doses in Table 3.6 - 0.2 Sv; 0.05 Sv; 0.1 Sv - are higher than the maximum dose for the Republic of Belarus, which makes 13 mSv. Expected doses for other countries are even lower, so no intervention is necessary.

Expected effective doses for the population after the MDBA or BDBA are low compared to the natural radiation background. In accordance with the 1993 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the United Nations General Assembly [14], the annual effective dose from natural radiation sources in regions with normal radiation backgrounds is equal to 2.4 mSv, i. e. 120 mSv for 50 years. The same dose for 50 years for all countries during the BDBA is below 13 mSv.

Therefore, the population dose for 50 years in the neighbouring countries will be less than 13 mSv, which is rather low compared with the natural radiation background.

Let's show different shares in the total dose based on radionuclide intake routes (see Fig. 3.6), using Slovakia as an example.

The relative share of different nuclides in the expected effective dose at a distance of 340 km from RNPP during the BDBA is shown in Fig. 3.7.

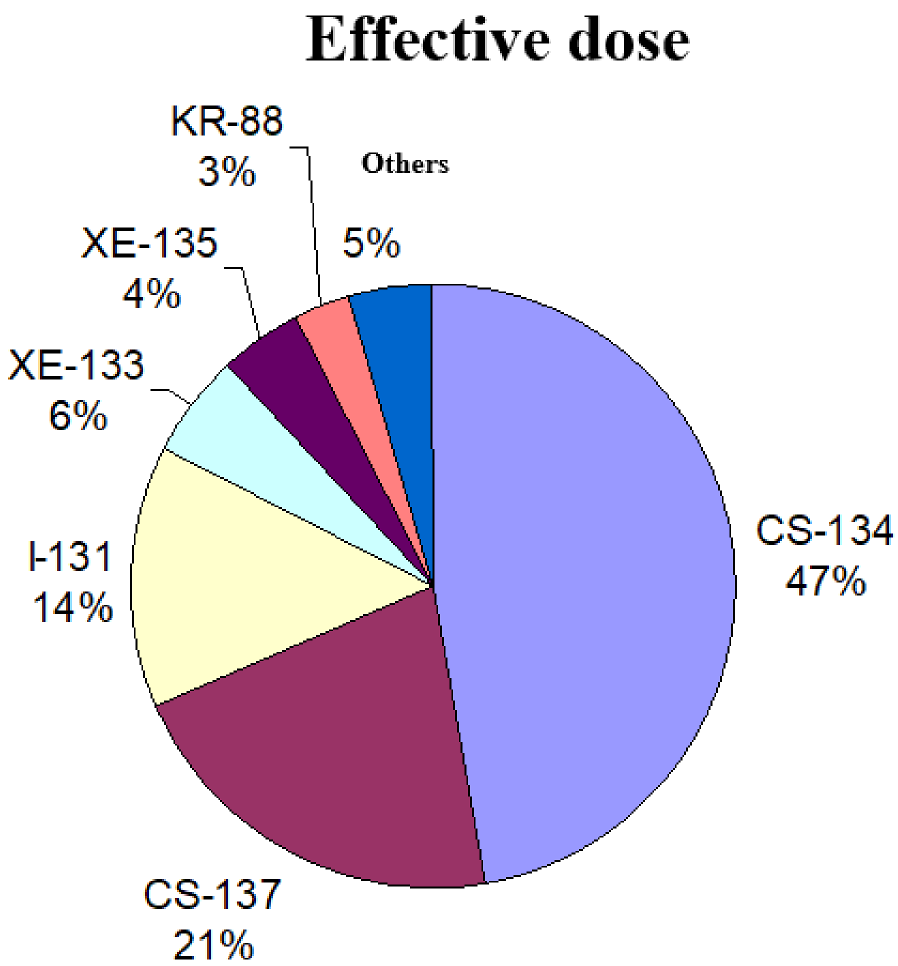

Fig. 3.7 - Relative share of different nuclides in the expected effective dose at a distance of 340 km during the BDBA

As seen from the data in Fig. 3.7, the greatest shares are represented by caesium isotopes: ^{134}Cs - 47 % and ^{137}Cs - 21 %. Inert gases - ^{133}Xe, ^{135}Xe and ^{88}Kr - also make a significant share in the total effective dose. The total share of 29 other nuclides during the BDBA is under 5 %.

Calculations indicate that the dominant share in the total effective dose among various radiation routes is due to food consumption (81 %; see data in Fig. 3.8). Dose from a radiation cloud makes a share of 14 %, dose from soil radiation - 4 %, and radiation by inhalation - 1 %. Other radiation routes can be neglected.

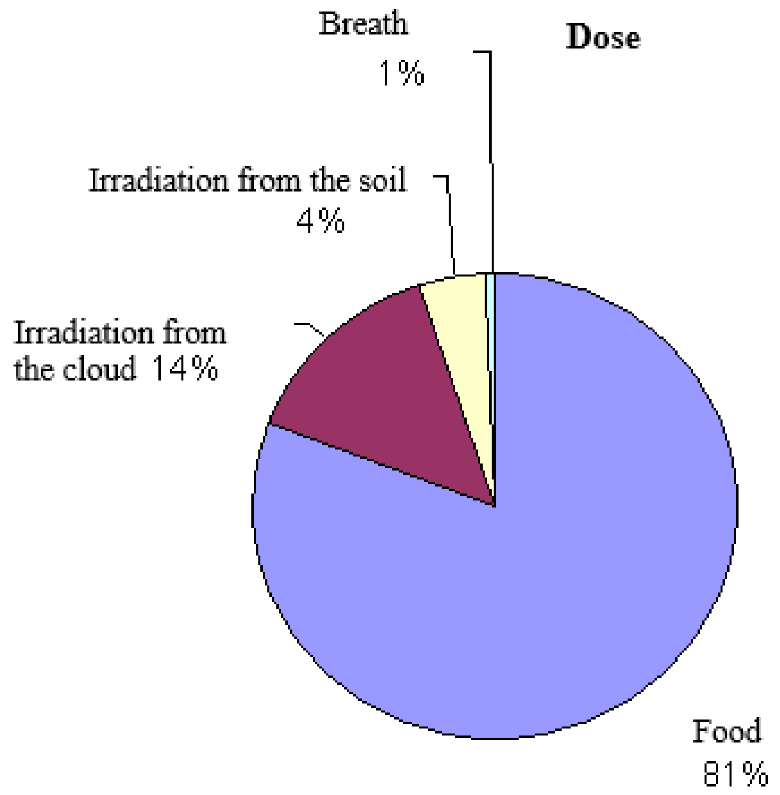

Fig. 3.8 - Relative share of different radiation routes in the expected effective dose at a distance of 340 km from RNPP during the BDBA

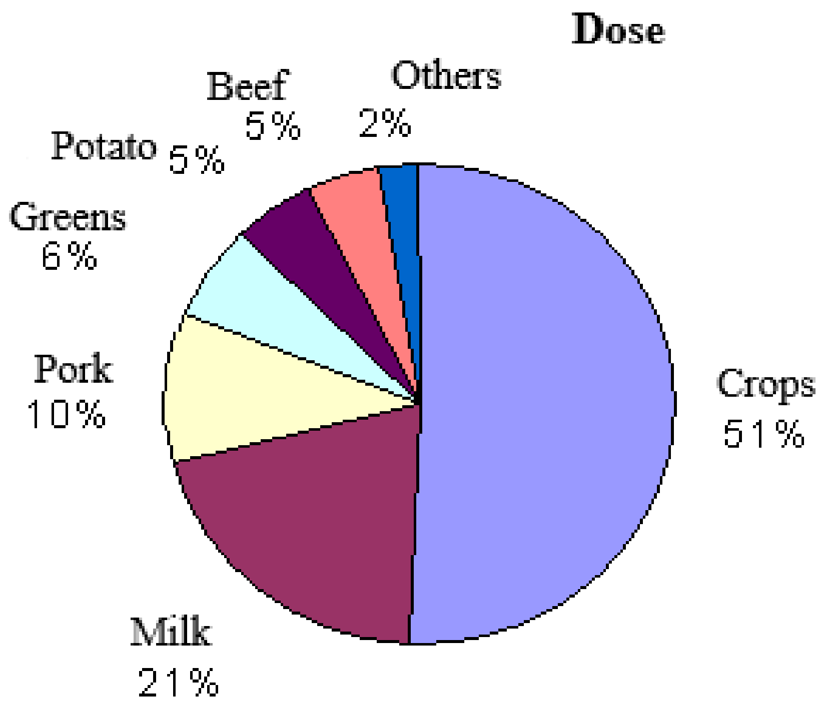

Fig. 3.9 - Relative share of basic food products in the expected effective dose at a distance of 340 km from RNPP during the BDBA

Of all food products, a significant share in the total effective dose is made by cereals, milk/dairy and meat products, vegetables and potatoes (see data in Fig. 3.9).

The total share of other food products is 2 %.

4 Measures to mitigate environmental impact

Environmental releases may be reduced by consistent implementation of in-depth staged protection strategy [15] based on the following:

- system of physical barriers in the way of environmental propagation of ionizing radiation and radioactive substances;
- system of technical and organisational arrangements to secure the physical barriers and keep them effective in order to protect the population and the environment;

The successive barrier system includes:

- fuel matrix;
- FE cladding;
- reactor coolant boundary;
- leak-tight reactor enclosure;
- biological protection.

During normal operation, the above barriers as well as the necessary technical control and protection means shall be operational, and shall be in a state that allows their proper functioning. If this condition is violated, the power unit must be set to safe state in accordance with the operating documentation.

The main purposes of in-depth staged protection strategy implementation include timely detection and elimination of factors that cause abnormal operation, occurrence of emergencies, preventing their development into accident, as well as limiting and elimination of the accident consequences.

5 Description of environmental impact assessment methods

PC CREAM (Consequences of Releases to the Environment: Assessment Methodology) software suite developed for the EU by NRPB (National Radiological Protection Board) (UK) in cooperation with a number of scientific institutions in the EU, was used to model propagation of released radionuclides over distances up to 1,000 km during normal operation of the plant.

5.1 PC CREAM

5.1.1 Brief model description

PC CREAM software suite and its separate modules are described in [17]. The system is designed for calculating radiation impact of continuous (accident-free) air releases and river/sea discharges of radioactive substances. The key features of the software suite are:

- assessment of individual and collective doses from air releases and sea discharges, as well as individual doses from river discharges;
- effective doses (as per ICRP Publication No. 60 [18]) are calculated using dose factors from ICRP Publication No. 72 [19] (ICRP recommendations are also used when developing radiation safety regulations in Ukraine);
- three age groups are considered: infants under 1 YOA, children under 10 YOA and adults;
- reference data include averaged releases and discharges per year;
- the suite allows for choosing from 5 integration times (1, 50, 500, 1000 years and infinity) for collective doses and from 3 integration times (1, 5 and 50 years) for individual doses;
- integration time following the intake of radionuclides by the human body is set to 50 years for adults and 70 years for children;

- dose integrated by n years for 1 year of release and/or discharge is numerically equal to an average dose on n^{th} year for continuous release and/or discharge;
- the model covers distances up to 3,000 km;
- air release models take into account all irradiation exposure pathways, while water discharge models do not take into account the possibility of water use for agricultural irrigation.

In PC CREAM, atmospheric dispersion is assessed using Gaussian model, dry deposition using source depletion model, wet deposition using washout factors. The atmospheric dispersion model used accounts for sedimentation of a single daughter product during spot motion. Following deposition, radionuclide transport is represented by separate compartment models for soil and food products [20].

External air radionuclide exposure is calculated in PC CREAM using finite and infinite cloud models for gamma and beta irradiation, respectively.

5.1.2 Mathematical plume dispersal models

Plume dispersal is modelled by modified Gaussian equation [20]:

$$\overline{A}(x,z) = \frac{Q}{(2\pi)^{\frac{3}{2}} x \sigma_z \mu} \sum_{s=0}^{\infty} \exp\left[-\frac{(2sL \pm h_{eff} \pm z)^2}{2\sigma_z^2} \right] \qquad (5.1)$$

where $\overline{A}$ is mean air activity at point (x, z), Bq/m^3;

Q is radionuclide stack emission rate, Bq/s;

x is downwind distance, m;

μ is average wind speed, m/s;

σ_z is vertical dispersion factor, m;

h_{eff} is effective stack height, m;

L is mixing height, m;

s is 0, 1, 2, 3, etc.

PC CREAM uses fixed wind rate and mixing height values for each atmospheric stability class in Table 5.1.

Table 5.1 - Wind rate and mixing height values used in PC CREAM

Pasquill stability class	Wind rate at 10 m, m/s	Mixing height, m	Rain
A	1	1300	No
B	2	900	No
C	5	850	No
D	5	800	No
E	3	400	No
F	2	100	No
C	5	850	Yes
D	5	800	Yes

a. Dispersion factors

Vertical dispersion factor σ_z, which is used to calculate dispersion:

$$\sigma_z = \frac{ax^b}{1+cx^d} F(z_0, x) \tag{5.2}$$

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

$$F(z_0, x) = \ln\left(fx^g\left[1+\frac{1}{hx^j}\right]\right), \text{ at } z_0 > 0.1 \text{ m}, \tag{5.3}$$

$$F(z_0, x) = \ln\left(fx^g\left[\frac{1}{1+hx^j}\right]\right), \text{ at } z_0 \leq 0.1 \text{ m}, \tag{5.4}$$

where z_0 is soil ruggedness height, m; see values of a, b, c and d factors in equation (5.2) and f, g, h and j in equations (5.3) and (5.4) in Table 5.2.

Table 5.2 - Factors to calculate vertical dispersion factor and factors for ruggedness correction

Pasquill stability class	**a**	**B**	**c**	**d**
A	0.112	1.06	$5.38 \cdot 10^{-4}$	0.815
B	0.130	0.950	$6.52 \cdot 10^{-4}$	0.750
C	0.112	0.920	$9.05 \cdot 10^{-4}$	0.718
D	0.098	0.889	$1.35 \cdot 10^{-3}$	0.688
E	0.0609	0.895	$1.96 \cdot 10^{-3}$	0.684
F	0.0638	0.783	$1.36 \cdot 10^{-3}$	0.672

Soil ruggedness, m	**F**	**G**	**h**	**j**
0.01	1.56	0.0480	$6.25 \cdot 10^{-4}$	0.45
0.04	2.02	0.0269	$7.76 \cdot 10^{-4}$	0.37
0.1	2.72	0	0	0
0.4	5.16	-0.098	18.6	-0.225
1.0	7.37	-0.0957	$4.29 \cdot 10^{3}$	-0.60
4.0	11.7	-0.128	$4.59 \cdot 10^{4}$	-0.78

b Plume depletion

c Dry deposition

Dry deposition model is as follows: $R_{dry} = V_r \cdot A$, where R_{dry} is radionuclide deposition rate per unit area (Bq/(m^2·s)); V_r is deposition rate (m/s); A is concentration of radionuclides in the surface air layer (Bq/m^3).

d Wet deposition

Fraction of radionuclides deposited from the plume with rain or snow is modelled using the following equation:

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

where R_{wet} is surface deposition rate (Bq/(m^2·s)); Φ is washout factor (s^{-1}); Q'_{wet} is radionuclide activity that remains within the plume when a point under consideration is reached (x (m) from the release point) over the entire time (t) (Bq/m^3):

$$Q'_{wet}(t) = \frac{Q_0 f_{wet}}{m_1 - m_2}\left[(m_1 + \Phi)e^{m_2 t} - (m_2 + \Phi)e^{m_1 t}\right], \tag{5.5}$$

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

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

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

P_{dry} and P_{wet} are dry and wet weather probabilities, respectively; α is sector angular width, rad; μ is average wind speed.

e Depletion factor

Fraction of radionuclides depleted from the plume:

$$F = F_{wet} \cdot F_{dry} \cdot F_{decay}\ .$$

Fraction of radionuclides depleted with precipitation:

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

where

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

at $\sigma_z(x) < L$, and $F_{0dry}(x) = F_{0dry}(x_L)-(x-x_L)/L$ at $\sigma_z(x) \geq L$. x_L here is such that $\sigma_z(x_A) = L$.

$F_{decay} = \exp(-\lambda x/\mu)$. Daughter product concentrations are calculated by substituting Q with QR_d in equation (5.1), where:

$$Rd = \frac{\lambda_d}{\lambda_m - \lambda_d}\left[\exp\left\{-\lambda_{\partial}\frac{x}{\mu}\right\} - \exp\left\{\lambda_{\text{м}}\frac{x}{\mu}\right\}\right]$$

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

5.1.3Compartment exponential models

The impurity exchange dynamics within the systems are modelled using first-order differential equations [20]:

$$\frac{dA_i}{dt} = \dot{A}_{0,i} + \sum_n k_{ni}A_n - \sum_j k_{ij}A_i \, , \tag{5.6}$$

where A_i is the content of radionuclides within Link i;

$\dot{A}_{0,i}$ is radionuclide intake rate in Link i from outside the system;

k_{ij} is the constant of radionuclide migration from Link i to Link j.

Positive terms of the sum in (5.6) represent the impurity intake rate within Link i from other links, and negative terms represent impurity outflow rate due to removal into other links and radioactive decay. k_{ij} A_i members are the speed of impurity migration from Link i to Link j. Solution of the set of equations (5.6) is a polynomial, in which each component accurate to a coefficient is an exponential series exp($-a_i t$), and a_i are certain constants. The key disadvantage of this model is the assumption that the result does not depend on duration of migration constants k_{ij}, while actual external radionuclide migration often is of a more complex nature.

5.1.4 Migration model for agricultural plants

The migration scheme is shown in Fig. 5.1. Link 1 is topsoil with uniformly distributed activity, Link 2 is aerial parts of plants, which are directly contaminated with radioactive fallout, Link 3 is aerial parts of plants, which are contaminated with soil grains during harvesting, Link 4 is root systems of plants, Link 5 is subsoil layer that contains roots. Constants k_{ij} (s^{-1}) correspond to transitions between links, which are due to the following processes: k_{12} - secondary radioactive fallout; k_{21} - sweeping-away with wind and rainwash; k_{13} - contamination of aerial parts of plants with dirt during harvesting; k_{14} - root absorption; k_{15} - draining out of the root soil layer; k_{22}, k_{33}, k_{44} - periodic harvesting; k_{31}, k_{41} are formal migration constants that provide for nuclides balance within links 1, 3, 4. See values of migration constants in Table 5.3 and Table 5.4.

Table 5.3 - Migration constants for agricultural plants (common for all elements, s^{-1})

Migration constant	Grain crops	Other agricultural plants	Migration constant	Grain crops	Other agricultural plants
k_{12}	7-9	7-9	k_{41}	1	1
k_{21}	2.7-4	2.7-4	k_{15}	2.2-10	2.2-10
k_{13}	8.9-9	4.4-8	k_{22}, k_{33}	3.2-8	3.2-8
k_{31}	1	1	k_{44}	3.2-8	3.2-8

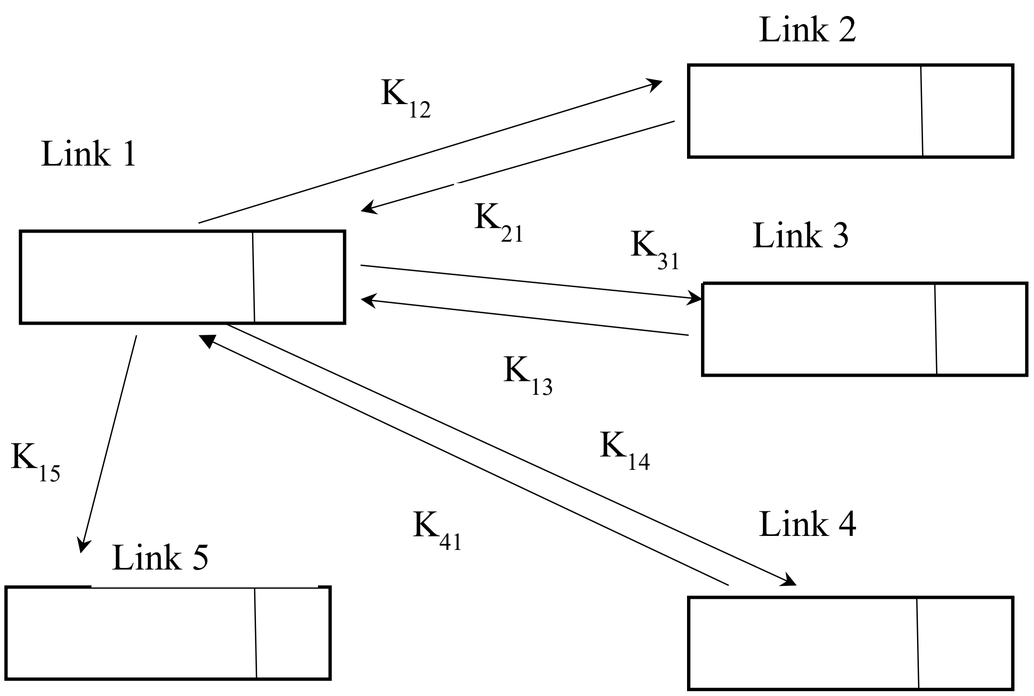

Table 5.4 - Migration constants for agricultural plants (based on chemical elements) k_{14}, s^{-1}

Element	Grain crops	Other agricultural plants	Element	Grain crops	Other agricultural plants
Cr	2.7-7	6.7-7	Ru	5.3-5	8.9-6
Mn	2.7-5	6.7-5	Ag	1.8-4	4.4-4
Fe	3.6-7	4.4-7	Sb	8.9-6	2.2-5
Co	8.9-6	2.2-6	Te	8.9-4	2.2-3
Zn	3.6-4	8.9-4	I	1.8-5	4.4-5
Rb	8.9-5	2.2-4	Cs	5.3-6	4.4-5
Sr	1.8-5	1.6-3	Ba	4.4-6	1.1-5
Y	2.7-6	6.7-6	La	2.7-6	6.7-6
Zr	1.8-7	4.4-7	Ce	2.7-6	1.6-5
Nb	8.9-6	2.2-5	Np, Pu	8.9-10	2.2-7
Mo	8.9-5	2.2-4	Am, Cm	8.9-19	2.2-7
Tc	4.4-2	0.11			

5.1.5. Mathematical models for dose calculation

5.1.5.1 Individual dose calculation based on food chains

Individual doses based on the food exposure route are calculated assuming that only local food products are consumed. This assessment provides for maximum possible radiation levels under the given conditions. These levels nearly always exceed the actual doses, since a certain share of non-local food products is usually present in food ration. For some of these products, like dairy, leaf vegetables or fruits from private garden plots, these estimates may be quite close to actual values. Based on the above assumption, the average rate for individual annual effective dose $\dot{H}$, Sv/s, of uniform fallout $\dot{A}_S$, Bq/(m^2·s), given the steady balance of environmental radionuclide accumulation/depletion processes, is calculated as follows:

$$\dot{H} = \dot{A}_S K_{fi}^{ind} B_{ig},$$

where B_{ig} is a dose factor of internal radiation exposure when radionuclides are ingested with water or food, Sv/Bq; K_{fi}^{ind} is factor that connects fallout intensity when radionuclides are ingested by a separate person with food, m^2:

$$K_{fi}^{ind} = K_{fi}\overline{S}, \tag{5.7}$$

where K_{fi} is a dimensionless factor that characterises loss of radionuclides during migration within the food chain, cooking and storage; $\overline{S}$ is agricultural area required for producing certain food products that are consumed individually, m^2. This parameter is calculated in PC CREAM using the following formulas:

for products of plant origin:

$$\overline{S} = \frac{I_{m,}}{P_y},$$

where P_y is annual yielding capacity of the culture under consideration, kg/m^2; I_m is annual individual consumption of this culture, kg;

for products of animal origin:

$$\overline{S} = \left(\frac{I_m}{P_a}\right)\sum_i \overline{S}_{a,i},$$

where I_m is annual individual consumption of meat or milk, kg (l); P_a is annual productivity of one animal (average annual increase in meat or milk per one animal, kg (l); $\overline{S}_{a,i}$ is area of ith feed crop per one animal. This parameter is calculated using the following formula:

$$\overline{S}_{a,i} = \frac{I_{a,i}}{P_{y,i}},$$

where $P_{y,i}$ is annual yielding capacity of ith feed crop, kg/m^2; $I_{a,i}$ is its annual consumption by one animal, kg.

The values can vary not only for residents of different republics, countries and regions, but for residents of the same village as well. As there is no precise data for the settlements located near NPPs and TPPs in Ukraine, and, besides, it is expedient to use the most similar parameters (without prejudice to the estimates) for comparative analysis of the impact, the average value of this parameter used for the estimates in this paper is derived from statistical data, by dividing the area occupied by this crop by the number of consumers in the country.

Value K_{fi} in (1.7) is a dimensionless factor that characterises loss of radionuclides during migration within the food chain, cooking and storage. When agricultural areas required to produce certain food products are considered, then this factor is a share of that part of the total fallout per given area of radionuclides, which will remain in products until consumed. Values of factor K_{fi} vary for different radionuclides, food products, local weather conditions, soil type, and fallout conditions (short-term or continuous).

5.1.5.2 Individual radiation doses (direct exposure)

Direct exposure means external radiation from photons and β-particles of radionuclides that are found in the air and fall out upon soil, as well as internal radiation by radionuclides that enter the body with air (inhalation route). In these cases individual doses are formed immediately in the release source area.

Photon radiation dose from a radiation cloud

Dispersed radionuclides may be sources of photon radiation. The radiation gas- or aerosol-induced dose in this case largely depends on the physical and chemical form of radionuclides and, naturally, on the radiation type and energy [20].

Source shaped as a semi-infinite space

During continuous release at a variable wind pattern and other weather parameters, a radioactive cloud is simulated by a source shaped as a semi-infinite space with activity A_V, Bq/m^3, uniformly distributed by volume. Effective dose rate, Sv/s, is then calculated using the following formula:

$$\dot{H} = A_V B_{a\gamma}, \qquad (5.8)$$

where $B_{a\gamma}$ is a dose factor of internal photon radiation, Sv·m^3/(s·Bq). For radiation 2π-geometry:

$$B_{a\gamma} = \frac{E * 1{,}602 \cdot 10^{-13} r}{2w\rho}, \tag{5.9}$$

where $E = \sum_i n_i E_i$ is photon energy efficiency, MeV/decay (n_i is absolute efficiency in decay scheme, photon/decay; E_i is i^{th} photon energy, MeV/photon); $1.602 \cdot 10^{-13}$ is energy equivalent, J/MeV; r = 1.09 is a factor of conversion from absorbed air dose into equivalent dose in biological tissue, Sv/Gy; ρ = 1.293 is air density under normal conditions, kg/m^3. 2 is a factor that takes into account the 2π-geometry of human radiation. w is Gray's energy equivalent per 1 kg of irradiated medium (in this case, air), w = 1 J/(Gy·kg).

Based on the UOM selected, dose factor (5.9) is represented as follows:

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

Photon radiation dose from radionuclides that fall out on soil

Correlation between release rate $\dot{Q}$ (Bq/s) and effective dose rate $\dot{H}$ (Sv/s):

$$\dot{H} = \dot{A}_S B_{S\gamma} \tau_{ef}, \tag{5.10}$$

where τ_{ef} is effective period that takes into account radioactive decay and radionuclide soil depletion; it is calculated using the formula $\tau_{ef} = [(T_{1/2} \, T_b)/(T_{1/2} + T_b)]/0{,}693$,

where $T_{1/2}$ and T_b are radioactivity half-life and biological half-life;

$\dot{A}_S$ is contamination intensity, Bq/(s·m^2); dose factor $B_{S\gamma}$, Sv·m^2/(s·Bq) characterises effective dose rate of contaminated soil; it depends on the form of contamination and the type photon contamination distribution.

Dose of external β-radiation

Generalized term β-radiation means the emission of electrons by radioactive nuclei. If they carry a negative charge, they are called β^--particles, if they carry a positive charge β^+-particles, or positrons. The energy spectrum for β-particles is continuous and extends from very low values to 10 MeV, however the main practically significant range is from 10 keV to 5 MeV. In the range of the above energies, electrons, when interacting with a substance, lose their energy due to the inhibition processes. There is a braking power equal to the average energy loss per unit length of the path due to Coulomb collisions with bound electrons of the medium, $S_C[-dE/dx]$ meV/cm. This process leads to ionization and excitation of atoms. The second process is the energy loss due to the inhibitory (photon) radiation in the electric field of atomic nuclei and electrons is called the radiation braking power S_r, meV/cm. In practice, the mass braking power S = S/ρ is usually applied, where ρ is the density of the medium.

Source: contaminated air

Doses in this case are calculated using the "immersion method", with a source simulated in a shape of a semi-infinite space. 2π radiation geometry shall be always observed for β-radiation. Equivalent dose rate for exposed (not protected by clothes) biological tissue $\dot{H}$, Sv/s:

$$\dot{H} = A_V B_{a\beta}, \quad (5.11)$$

where A_V is volumetric activity, Bq/m^3; $B_{a\beta}$ is a dose factor of external β-radiation, Sv·m^3/(s·Bq). See $B_{a\beta}$ values in Table 5.5.

Table 5.5 - Dose factors in basal layer, which are induced by β- particles and electrons from radionuclide conversion, which are found in a semi-infinite radioactive cloud, Sv·m^3/(hour·Bq)

Radionuclide name	$B_{a\beta}$	Radionuclide name	$B_{a\beta}$	Radionuclide name	$B_{a\beta}$
^{14}C	2.16×10^{-8}	^{99m}Te	1.78×10^{-8}	^{137}Xe	2.78×10^{-6}
^{41}Ar	7.62×10^{-7}	^{103}Ru	7.18×10^{-8}	^{138}Xe	1.10×10^{-6}
^{51}Cr	9.68×10^{-11}	$^{106}Ru/^{106}Rh$	2.19×10^{-6}	^{137}Cs	2.87×10^{-7}
^{54}Mn	4.04×10^{-10}	^{124}Sb	6.46×10^{-7}	^{135}Cs	5.43×10^{-8}
^{59}Fe	1.77×10^{-7}	^{125}Sb	1.48×10^{-7}	^{136}Cs	1.77×10^{-7}
^{58}Co	5.37×10^{-10}	^{125m}Te	1.06×10^{-7}	^{137}Cs	4.16×10^{-7}
^{60}Co	1.36×10^{-7}	^{127m}Te	6.00×10^{-8}	^{138}Cs	1.91×10^{-6}
^{85m}Kr	4.41×10^{-7}	^{127}Te	4.03×10^{-7}	^{140}Ba	5.05×10^{-7}
^{85}Kr	3.89×10^{-7}	^{129m}Te	4.14×10^{-7}	^{140}La	9.31×10^{-9}
^{87}Kr	2.10×10^{-6}	^{129}Te	9.02×10^{-7}	^{141}Ce	2.83×10^{-7}
^{88}Kr	5.85×10^{-7}	^{131m}Te	2.46×10^{-7}	^{144}Ce	1.19×10^{-7}
^{89}Kr	1.93×10^{-6}	^{132}Te	8.68×10^{-8}	^{144}Pr	1.95×10^{-6}
^{86}Rb	1.07×10^{-6}	^{129}I	1.92×10^{-8}	^{147}Pm	6.30×10^{-8}
^{88}Rb	3.06×10^{-6}	^{131}I	3.44×10^{-7}	^{154}Eu	4.31×10^{-7}
^{89}Rb	1.44×10^{-6}	^{132}I	8.79×10^{-7}	^{155}Eu	2.60×10^{-8}
^{89}Sr	9.32×10^{-7}	^{133}I	7.19×10^{-7}	^{239}Np	3.87×10^{-7}
^{90}Sr	3.02×10^{-7}	^{134}I	1.05×10^{-6}	^{238}Pu	9.81×10^{-11}
^{90}Y	1.49×10^{-6}	^{135}I	6.93×10^{-7}	^{239}Pu	8.70×10^{-9}
^{91}Y	9.85×10^{-7}	^{131m}Xe	1.98×10^{-7}	^{240}Pu	9.81×10^{-11}
^{95}Zr	1.91×10^{-7}	^{133m}Xe	3.19×10^{-7}	^{241}Pu	$3.69\times\cdot10^{-13}$
^{95}Nb	2.62×10^{-8}	^{133}Xe	1.62×10^{-7}	^{242}Pu	7.56×10^{-10}
^{90}Mo	6.73×10^{-7}	^{135m}Xe	1.80×10^{-7}	^{241}Am	3.17×10^{-10}
^{99}Tc	1.14×10^{-7}	^{135}Xe	5.99×10^{-7}	^{242}Cm	1.01×10^{-14}

Source: skin surface contamination

See values of conversion dose factor $B_{S\beta}$, Sv·cm^2/(year·Bq), based on the epidermis thickness, in Table 5.6.

Table 5.6 - Dose factor of external basal layer radiation with β-particles and electrons from radionuclide conversion in case of uniform contamination of skin with radioactive substances, $B_{S\beta}$, Sv·cm²/(year·Bq)

Radionuclide name	Epidermis thickness Δx, mg/cm²			Radionuclide name	Epidermis thickness Δx, mg/cm²		
	7	4	40		7	4	40
^{14}C	2.9×10^{-3}	7.9×10^{-3}	0.0	^{135}I	1.8×10^{-2}	2.2×10^{-2}	6.5×10^{-3}
^{32}P	2.1×10^{-2}	2.4×10^{-2}	1.1×10^{-2}	^{134}Cs	1.2×10^{-2}	1.6×10^{-2}	2.7×10^{-3}
^{60}Co	9.9×10^{-3}	1.6×10^{-2}	2.5×10^{-4}	^{137}Cs	1.4×10^{-2}	2.0×10^{-2}	2.3×10^{-3}
^{65}Zn	2.3×10^{-4}	3.3×10^{-4}	1.0×10^{-5}	^{137m}Ba	2.1×10^{-2}	2.4×10^{-3}	1.2×10^{-3}
^{90}Sr	1.6×10^{-2}	2.4×10^{-2}	3.4×10^{-3}	^{140}Ba	1.7×10^{-2}	2.2×10^{-2}	5.0×10^{-3}
^{90}Y	2.1×10^{-2}	2.4×10^{-2}	1.2×10^{-2}	^{140}La	2.0×10^{-2}	2.4×10^{-2}	9.2×0^{-3}
^{95}Zr	1.2×10^{-2}	1.7×10^{-2}	7.4×10^{-4}	^{144}Ce	8.9×10^{-3}	1.5×10^{-2}	1.7×10^{-4}
^{95}Nb	2.3×10^{-3}	6.4×10^{-3}	1.8×10^{-5}	^{144}Pr	2.2×10^{-2}	2.4×10^{-2}	1.3×10^{-2}
^{106}Rh	2.2×10^{-2}	2.5×10^{-2}	1.4×10^{-2}	^{203}Hg	9.6×10^{-3}	1.6×10^{-2}	3.7×10^{-4}
^{131}Te	2.3×10^{-2}	2.8×10^{-2}	1.0×10^{-2}	^{210}Bi	1.9×10^{-2}	2.3×10^{-2}	7.4×10^{-3}
^{132}Te	7.0×10^{-3}	$1.3\cdot\times10^{-2}$	4.7×10^{-5}	^{214}Bi	2.0×10^{-2}	2.3×10^{-2}	9.6×10^{-3}
^{129}I	1.9×10^{-3}	5.7×10^{-3}	0.0	^{235}U	1.1×10^{-3}	3.1×10^{-3}	2.9×10^{-7}
^{131}I	1.5×10^{-2}	2.1×10^{-2}	3.0×10^{-3}	^{237}Np	6.8×10^{-4}	4.3×10^{-3}	0.0
^{132}I	1.9×10^{-2}	2.3×10^{-2}	8.2×10^{-3}	^{238}Np	1.2×10^{-2}	1.8×10^{-2}	3.5×10^{-3}
^{133}I	1.9×10^{-2}	2.3×10^{-2}	7.6×10^{-3}	^{239}Np	2.3×10^{-2}	3.6×10^{-2}	1.2×10^{-3}

Internal radiation dose induced by radioactive gas inhalation

Annual effective doses of internal radiation due to inhalation of contaminated air are calculated using the following formula:

$$\dot{H} = QGVB \tag{5.12}$$

where $\dot{H}$ is the annual effective dose, Sv, Q is release, Bq/year, G is average annual meteorological dilution factor, s/m³, V is inhalation rate, m³/s. The conversion dose factor B, Sv/Bq, characterises the expected effective dose induced by nuclide inhalation with an activity of 1 Bq.

5.1.5.3 Calculation of collective doses

The collective dose assessment is necessary when choosing a site for the construction of radiation-hazardous enterprises, comparing the effectiveness of various measures to protect the population, calculating the radiation hazard from individual links of the nuclear fuel cycle, choosing the type of radiation technology, etc. The collective dose S, man Sv, is determined by the formula:

$$S = \sum_{j} N_i H_i \; ; \qquad (5.13)$$

5.2 Meteorological parameters

PC CREAM software was used for calculation of the transboundary impact under normal operating conditions. This software allows calculating the effect of radionuclide emissions at distances up to 3000 km.

The meteorological file necessary for PC CREAM software is created based on the measured weather data at SS RNPP.

Meteorological observations at the RAES RSCS meteorological station [21] were conducted by the automatic weather station MAWS-301 in Kyiv time.

Day change time:

- 00 hours 00 minutes, Kyiv time;
- 22 hours 00 minutes, Greenwich Mean Time (GMT).
- during the daylight saving time season, the day change time is 21 hours 00 minutes, GMT.

The RAES RSCS meteorological station is registered in the State Hydrometeorological Service of Ukraine since November 2005, valid registration certificate No. 02/10 GM of 28 October 2015.

The meteorological station measures the following meteorological parameters:

- wind direction;
- wind speed;
- air temperature;
- relative air humidity;

- atmospheric pressure;
- surface density of the solar radiation flux;
- radiation balance;
- amount of precipitation;
- intensity of precipitation;
- visibility;
- weather type.

The category of atmospheric stability characterizes conditions for the dispersion of impurities in the atmosphere. It depends on two main factors: turbulent diffusion and wind speed, which, in turn, depend on many meteorological factors.

There are several classification systems. The Pasquill classification scheme used in the report is recommended by the IAEA [22]. The Pasquill classification scheme uses seven categories, which are arranged by increasing the stability degree of the atmosphere from A to G.

5.2.1Meteorological parameters for the years 2006-2017

Wind speed:

- mean value 2.73 m/s;
- the maximum value of 25.6 m/s was recorded on 15.03.14.

The average windrose for 2006-2017 is given in Table 5.7

Table 5.7 - Wind rose for the observation period of 2006-2017, %

Direction	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**
2006-2017	4.73	5.42	5.3	4.24	2.53	4.89	7.84	8.89	6.95
Direction	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**Calm**	**Total**
2006-2017	7.34	9.02	7.81	7.91	5.99	6.11	5.03	7.36	100.0

The average wind speeds depending on directions are shown in Table 5.8.

Table 5.8 - Average wind speed values depending on the wind direction for the period of 2006-2017, m/s

Period	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	For the period
2006	3.21	2.98	2.48	3.07	2.45	3.21	3.11	2.99	2.48	2.33	2.62	3.09	3.13	3.01	2.74	2.97	2.74
2007	3.18	2.95	2.68	3.41	2.96	3.24	3.32	3.10	2.71	2.54	3.11	3.59	3.49	3.40	2.89	3.15	2.90
2008	3.11	3.13	2.55	3.28	2.66	3.12	3.33	3.24	2.90	2.72	3.16	3.79	3.39	3.16	2.95	3.19	2.96
2009	2.83	2.81	2.45	3.10	2.53	3.27	3.14	3.07	2.61	2.55	2.84	3.14	2.95	3.18	2.84	3.02	2.60
2010	2.95	2.57	2.94	3.56	2.88	3.18	3.16	3.25	2.72	2.80	3.24	3.52	3.17	3.18	2.82	3.08	2.76
2011	3.13	2.86	2.65	2.70	2.53	3.21	3.11	3.12	2.65	2.73	2.97	3.34	3.23	3.35	3.15	3.46	2.66
2012	3.00	2.72	2.72	2.94	2.45	2.81	3.26	2.98	2.64	2.68	3.05	3.39	3.16	3.23	3.15	3.48	2.71
2013	3.16	3.00	2.96	3.09	2.63	3.06	2.92	2.94	2.70	2.77	3.03	3.50	3.00	3.11	3.08	3.36	2.71
2014	2.90	2.71	2.76	3.30	2.90	2.97	3.14	3.06	2.66	2.53	2.91	3.33	3.31	3.12	2.75	3.03	2.65
2015	2.92	2.71	2.43	2.93	2.24	2.73	2.71	2.67	2.21	2.22	2.65	3.21	3.09	2.87	2.72	2.88	2.67
2016	2.99	2.79	2.31	2.67	2.21	2.84	3.03	3.19	2.39	2.41	2.62	2.86	2.84	2.69	2.55	2.86	2.67
2017	2.93	2.59	2.44	2.94	2.28	2.41	2.64	2.82	2.39	2.60	3.05	3.00	2.89	2.74	2.65	2.93	2.73
2006-2017	3.03	2.83	2.61	3.11	2.59	3.02	3.08	3.04	2.59	2.56	2.94	3.31	3.13	3.08	2.86	3.13	2.73

Wind speed frequency by intervals is given in Table 5.9.

Table 5.9 - Wind speed frequency by intervals for the period of 2006-2017, %

Wind speed	0.0<=v< 0.4 (no-wind conditions)	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4	0.0<=v< 0.4
2006	4.315	5.024	2.215	27.52	21.08	17.54	2.207	0.168	-	-
2007	7.297	3.385	18.09	26.38	2154	18.45	3.997	0.852	0.009	-
2008	5.866	3.233	17.66	26.33	22.31	20.23	3.789	0.571	0.003	-
2009	10.59	2.600	19.36	28.71	21.61	15.10	1.882	0.141	0.001	-
2010	10.58	1.482	15.74	29.34	22.42	17.75	2.437	0.238	0.001	-
2011	13.18	1.480	15.48	29.51	22.06	15.20	2.565	0.520	0.007	-
2012	10.31	1.907	17.52	29.36	22.07	15.69	2.814	0.329	0.001	-
2013	10.74	1.882	17.55	28.86	21.63	16.27	2.702	0.368	< 0.001	-
2014	10.92	2.547	17.25	29.09	22.04	15.60	2.337	0.220	0.002	< 0.001
2015	1.704	8.766	24.31	26.88	20.28	15.49	2.305	0.275	0.001	-
2016	1.839	8.607	23.57	27.41	20.78	15.50	2.161	0.148	-	-
2017	1.045	6.967	23.95	28.32	21.75	15.66	2.085	0.227	0.002	-
For the period	7.366	3.990	19.39	28.14	21.63	16.54	2.607	0.338	0.003	< 0.001

Air temperature:

- the average value over 12 years is +8.94 ºC;
- the absolute maximum of +35.5 ºC was recorded on 04.08.14 and 11.08.15;
- the warmest day was recorded on 29.07.12, with the average daily temperature of +28.49 ºC;
- the absolute minimum of -29.8 ºC was recorded on 03.02.12;
- the coldest day was recorded on 20.01.06, with the average daily temperature of -23.99 ºC.

Relative humidity:

- the average value over 12 years is 74.5 %
- the absolute minimum of 13.0% was recorded on 05.05.06, 27.04.09, 28.10.14 and 10.08.15.

Atmospheric pressure at the altitude of the meteorological station (altitude of the barometer gauge installation of 172.8 m above the sea level):

- the average value is 995.4 hPa;
- the absolute maximum of 1026.8 hPa was recorded on 23.01.06;
- the absolute minimum of 955.3 hPa was recorded on 29.10.17;
- the maximum pressure drop during a 24-hour period of 30.1 hPa was recorded on 18.01.07.

Total solar radiation:

- the annual average total solar energy is 4136.3 MJ/m^2;
- the annual average sunshine duration is 1961 hours 1 minute;
- the average long-term value of the total solar radiation is 221.1 W/m^2;
- the absolute maximum of one-minute solar irradiance of 1406 W/m^2 was recorded on 07.07.16.

The amount of precipitation:

- RG-13H average annual precipitation is 577.75 mm;
- PWD-11 average annual precipitation is 549.83 mm;
- the average annual snowfall height is 901.67 mm;
- the average intensity is 0.59 mm/h;

- the maximum precipitation rate of 2.45 mm/min was recorded on 14.07.08;

- the maximum amount of precipitation during a 24-hour period measured by PWD - 43.3 mm, recorded on 15.07.06;

- the maximum amount of precipitation during a 24-hour period measured by RG-13H - 51.4 mm, recorded on 13.08.12;

- the maximum amount of precipitation over a month is 161.53 mm (July 2008);

- the minimum amount of precipitation over a month is 1.6 mm (August 2015);

- the maximum fallen snow height during a 24-hour period is 183 mm (24.01.07);

- the maximum time of continuous precipitation is 46 hours and45 minutes (15.12.12 to 17.12.12), with precipitation in the form of mild and moderate snow;

- precipitation was observed 2683 days from 4377 days (61%); average annual number of days with precipitation - 224.

Average annual number of days with fog of 32.2 days was observed over the period of 2006-2017. The number of days with fog by months is presented in Table 5.10.

Table 5.10 - Number of days with fog

Month, year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2006	0	2	7	2	2	3	0	1	4	5	11	0	37
2007	0	4	3	1	1	0	1	1	2	1	4	3	21
2008	5	1	3	3	2	1	3	2	2	5	8	4	39
2009	6	3	6	1	0	4	2	2	5	2	8	4	43
2010	2	6	1	2	3	3	3	2	1	1	7	4	35
2011	6	0	1	1	1	2	1	2	4	1	5	2	26
2012	3	0	2	2	4	0	0	1	3	8	7	3	33
2013	2	1	2	3	3	2	0	2	6	8	3	4	36
2014	1	5	2	5	1	2	2	2	1	4	4	3	32
2015	4	3	1	0	0	0	1	0	6	4	5	9	33
2016	4	2	1	1	2	1	0	1	4	3	1	6	26
2017	4	6	0	4	0	0	2	0	0	2	3	4	25
For the period	37	33	29	25	19	18	15	16	38	44	66	46	386
Yearly average	3.1	2.8	2.4	2.1	1.6	1.5	1.3	1.3	3.2	3.7	5.5	3.8	32.2

The average annual values for the main meteorological parameters are summarized in Table 5.11.

Table 5.11 - Average values of meteorological parameters for the period of observations, years

No.	Parameter	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	For the period
1.	Prevailing wind direction	SSE	SW	SSE	SSE	SE	SW	SW	SSE	SE	SW	SW	SW	SW
2.	Maximum wind speed, m/s	18.3	24.0	24.3	18.8	18.8	22.1	19.0	18.8	25.6	21.2	16.9	21.0	25.6
3.	Average wind speed, m/s;	2.74	2.90	2.96	2.60	2.76	2.66	2.71	2.71	2.65	2.67	2.67	2.73	2.73
4.	Frequency of no-wind conditions, %	4.32	7.30	5.87	10.60	10.58	13.18	10.31	10.74	10.92	1.70	1.84	1.04	7.36
5.	Maximum air temperature, °C	32.2	34.7	34.7	32.3	34.5	33.7	35.4	34.0	35.5	35.5	33.7	34.0	35.5
6.	Average air temperature, °C	8.18	9.23	9.24	8.48	8.17	8.85	841	8.94	9.35	10.01	9.29	9.12	8.94
7.	Minimum air temperature, °C	-27.0	-16.6	-15.7	-22.5	-25.8	-16.8	-29.8	-19.3	-22.8	-18.7	-18.9	-21.5	-29.8
8.	Maximum air humidity, %	104	104	100	110	110	99	97	97	97	96	99	98.9	110
9.	Average humidity, %	77.2	75.9	76.4	76.8	76.8	73.4	74.1	74.5	71.1	68.9	72.6	76.1	74.5
10.	Minimum air humidity, %	13	14	17	13	17	16	15	15	13	13	19	17.6	13
11.	Maximum atmospheric pressure, hPa	1026.8	1017.9	1021.6	1013.3	1019.2	1018.9	1022.3	1018.0	1018.3	1023.4	1017.9	1020.5	1026.8
12.	Average atmospheric pressure, hPa	996.4	994.7	995.1	994.5	993.3	997.0	995.2	994.8	996.4	997.1	995.6	995.1	995.4
13.	Minimum atmospheric pressure, hPa	968.7	957.2	957.6	963.4	968.3	966.1	964.5	962.8	968.7	956.2	964.0	955.3	955.3
14.	Maximum atmospheric pressure adjusted to sea level, hPa	1051.4	1040.4	1045.1	1035.5	1043.6	1041.7	1046.1	1040.9	1042.0	1046.3	1040.2	1043.5	1051.4
15.	Average atmospheric pressure adjusted to sea level, hPa	1017.5	1015.7	1016.1	1015.6	1014.4	1018 .1	1016.3	1015.9	1017.5	1018.2	1016.7	1016.2	1016.5
16.	Minimum atmospheric pressure adjusted to sea level, hPa	989.8	977.4	978.0	984.1	988.7	987.0	985.5	984.2	989.5	976.6	984.8	975.6	975.6
17.	Maximum solar irradiance W/m^2	1352	1259	1292	1343	1263	1282	1286	1286	1324	1403	1406	1324	1406

18.	Average solar irradiance, W/m^2	218.7	215.4	207.8	220.8	218.9	233.6	226.2	220.1	231.5	230.0	220.1	212.3	221.3
19.	Total solar Energy, MJ/m^2	3992.1	4032.1	3898.3	4138.9	4052.5	4316.7	4234.5	4120.8	4311.0	4329.8	4186.9	4022.7	49636.4
20.	Sunshine duration	80 d., 20:34	78 d., 17:05	77 d., 10:06	81 d., 00:03	80 d., 10:22	86 d., 22:46	83 d., 07:10	81 d., 10:15	85 d., 05:24	86 d., 10:24	80 d., 12:38	78 d., 05:27	2 yr. 250 d., 12:14
21.	Maximum radiation balance, W/m^2	858	874	925	887	863	836	863	906	904	1053	1017	952	1053
22.	Average radiation balance, W/m^2	35.9	39.1	36.6	38.5	38.4	38.1	39.9	40.2	45.2	49.8	48.3	48.2	41.5
23.	Minimum radiation balance, W/m^2	-500	-458	-418	-398	-199	-198	-198	-198	-199	-199	-199	-199	-500
24.	Total radiation balance, MJ/m^2	1116.1	1231.9	1158.7	1209.8	1200.2	1196.2	1260.4	1265.3	1424.4	1570.6	1525.6	1517.8	15677.1
25.	Amount of precipitation (RG-13H), mm	568.8	527.6	695.0	600.6	583.8	485.8	681.4	554.8	525.0	511.6	494.6	654.0	6933
26.	Amount of precipitation (PWD-11), mm	578.59	521.42	701.01	580.64	527.49	481.42	627.86	535.39	437.20	460.30	478.13	668.50	6597.96
27.	Average precipitation rate (PWD-11), mm/h	0.62	0.62	0.68	0.55	0.50	0.58	0.63	0.56	0.55	0.61	0.52	0.65	0.59
28.	Maximum precipitation intensity (PWD-11), mm/min	1.015	1.559	2.453	1.011	0.943	1.677	1.166	1.918	0.721	1.630	1.484	1.476	2.453
29.	Height of fallen snow, mm	1093	814	594	1013	1291	620	1277	1463	437	283	852	1083	10820
30.	Duration of precipitation	38 d., 17:30	34 d., 19:22	43 d., 00:59	43 d., 21:10	44 d., 06:41	34 d., 15:17	41 d., 10:27	39 d., 13:20	33 d., 10:06	31 d., 07:14	38 d., 03:04	43 d., 00:17	1 yr 101 d., 05:27
31.	Maximum duration of continuous precipitation	18:35	20:46	16:52	24:00	17:52	14:30	24:00	24:00	14:22	10:45	15:14	16:35	24:00:00
32.	Minimum visibility, m	35	30	87	83	25	60	66	40	88	95	54	66	25
33.	Duration of reduced-visibility conditions	14 d., 04:13	6 d., 17:51	8 d., 07:08	10 d., 22:57	11 d., 18:37	8 d., 08:10	9 d., 17:37	11 d., 17:44	7 d., 07:06	8 d., 10:04	5 d., 23:54	8 d., 15:37	112 d., 02:58

34.	"No precipitation" weather conditions, min	293 d., 19:02	315 d., 14:03	307 d., 21:43	303 d., 06:25	300 d., 08:47	314 d., 14:15	307 d., 20:43	308 d., 11:27	318 d., 02:27	321 d., 01:21	315 d., 11:02	307 d., 05:35	10yr. 63 d., 16:50
35.	"Mist (V > 1 km)" weather conditions, min	00:19	-	-	-	-	-			00:03	-	-	-	00:22
36.	"Haze" weather conditions, min	4 d., 02:34	20:56	1 d., 01:10	1 d., 11:14	1 d., 20:19	1 d., 21:07	1 d., 06:03	2 d., 04:18	1 d., 11:09	2 d., 00:32	1 d., 05:01	1 d., 13:22	20 d., 21:45
37.	"Fog" weather conditions, min	5 d., 17:11	2 d., 08:10	3 d.,13:13	3 d., 16:27	3 d., 23:19	2 d., 04:40	3d; 01:53	3 d., 02:59	2 d., 13:07	2 d., 21:39	2 d., 02:59	2 d., 23:12	38 d., 04:49
38.	"Drizzle " weather conditions, min	3 d., 04:37	2 d., 10:53	5 d., 17:06	3 d., 10:23	1 d., 17:20	4 d., 02:56	1 d., 07:15	2 d., 08:09	2 d., 05:32	4 d., 08:40	2 d., 16:24	2 d., 10:57	36 d., 00:12
39.	"Rain" weather conditions, min	21 d., 13:24	26 d., 00:33	33 d., 21:12	28 d., 03:01	23 d., 18:47	21 d., 23:19	24 d., 17:06	22 d., 04:59	25 d., 16:28	28 d., 01:44	28 d., 14:23	34 d., 12:09	319 d., 03:05
40.	"Snow" weather conditions, min	28 d., 20:09	16 d., 23:46	13 d., 03:00	23 d., 05:14	30 d., 08:37	18 d., 15:57	27 d., 16:53	25 d., 14:12	14d , 07:10	6 d., 10:07	15 d., 20:27	16 d., 02:18	237 d., 03:50
41.	Meteorological station operation time	359 d., 07:35	364 d., 08:51	365 d., 07:58	363 d., 07:42	362 d., 01:11	363 d., 11:00	365 d., 22:03	364 d., 05:03	364 d., 18:35	364 d., 20:16	365 d., 22:27	364 d., 21:19	11y 353 d., 16:36

Table 5.12 for the distribution of atmospheric stability categories is given below.

Table 5.12 - Frequency of stability categories, depending on wind direction and speed for 2006-2017,%

Category	**Speed**	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**Total**
		N	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	
A	**0.0<=v<0.4**	0.006	0.006	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.006	0.008	0.007	0.007	0.006	0.006	0.006	**0.087**
	0.4<=v<1.0	0.014	0.012	0.012	0.010	0.008	0.009	0.009	0.010	0.011	0.012	0.013	0.014	0.013	0.014	0.015	0.013	**0.190**

	1.0<=v<2.0	0.069	0.059	0.054	0.042	0.038	0.043	0.055	0.057	0.065	0.069	0.084	0.072	0.073	0.073	0.081	0.072	**1.007**
	2.0<=v<3.0	0.083	0.075	0.066	0.045	0.040	0.056	0.094	0.097	0.087	0.086	0.100	0.075	0.085	0.098	0.117	0.102	**1.306**
	3.0<=v<4.0	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.001**
	4.0<=v<6.0	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	-	-	-	<0.001
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.171	0.152	0.136	0.100	0.090	0.111	0.163	0.168	0.169	0.173	0.206	0.168	0.179	0.191	0.220	0.193	**2.592**
B	**0.0<=v<0.4**	0.018	0.017	0.014	0.008	0.006	0.006	0.009	0.010	0.016	0.028	0.043	0.029	0.020	0.017	0.020	0.016	**0.278**
	0.4<=v<1.0	0.016	0.014	0.012	0.008	0.007	0.007	0.009	0.010	0.014	0.021	0.032	0.023	0.016	0.015	0.018	0.016	**0.238**
	1.0<=v<2.0	0.073	0.080	0.083	0.043	0.036	0.044	0.064	0.078	0.097	0.109	0.116	0.083	0.082	0.083	0.090	0.079	**1.239**
	2.0<=v<3.0	0.143	0.157	0.144	0.080	0.063	0.093	0.206	0.247	0.204	0.189	0.213	0.141	0.161	0.171	0.185	0.168	**2.566**
	3.0<=v<4.0	0.202	0.172	0.150	0.109	0.077	0.127	0.298	0.317	0.229	0.220	0.263	0.165	0.211	0.228	0.259	0.251	**3.278**
	4.0<=v<6.0	0.133	0.106	0.091	0.066	0.029	0.052	0.143	0.166	0.119	0.123	0.149	0.101	0.134	0.118	0.133	0.138	**1.803**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.583	0.546	0.493	0.315	0.220	0.329	0.729	0.828	0.678	0.691	0.815	0.542	0.624	0.631	0.707	0.669	**9.402**
C	**0.0<=v<0.4**	0.024	0.026	0.027	0.012	0.007	0.008	0.010	0.012	0.021	0.042	0.061	0.039	0.032	0.023	0.025	0.019	**0.388**
	0.4<=v<1.0	0.011	0.013	0.014	0.008	0.007	0.007	0.008	0.009	0.015	0.021	0.034	0.025	0.019	0.015	0.015	0.011	**0.232**
	1.0<=v<2.0	0.061	0.081	0.091	0.047	0.042	0.045	0.059	0.071	0.098	0.112	0.121	0.096	0.102	0.093	0.098	0.067	**1.285**
	2.0<=v<3.0	0.182	0.205	0.178	0.101	0.084	0.122	0.221	0.250	0.241	0.221	0.270	0.185	0.208	0214	0.231	0.193	**3.106**
	3.0<=v<4.0	0.205	0.187	0.154	0.123	0.075	0.126	0.290	0.315	0.197	0.209	0.309	0.217	0.262	0.239	0.249	0.230	**3.388**
	4.0<=v<6.0	0.212	0.185	0.145	0.150	0.054	0.107	0.278	0.312	0.170	0.207	0.332	0.274	0.349	0.249	0.231	0.235	**3.490**

	6.0<=v<8.0	0.026	0.026	0.018	0.020	0.004	0.005	0.019	0.032	0.020	0.027	0.041	0.038	0.043	0.025	0.019	0.025	**0.390**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.721	0.723	0.626	0.462	0.274	0.419	0.886	1.001	0.762	0.839	1.168	0.875	1.015	0.857	0.869	0.781	**12.279**
D	**0.0<=v<0.4**	0.077	0.095	0.137	0.084	0.071	0.059	0.061	0.070	0.126	0.203	0.242	0.163	0.142	0.083	0.076	0.052	**1.740**
	0.4<=v<1.0	0.037	0.051	0.065	0.042	0.043	0.041	0.041	0.045	0.068	0.103	0.139	0.117	0.100	0.063	0.051	0.035	**1.042**
	1.0<=v<2.0	0.236	0.399	0.403	0.232	0.221	0.282	0.325	0.388	0.488	0.572	0.556	0.397	0.474	0.358	0.412	0.242	**5.986**
	2.0<=v<3.0	0.471	0.604	0.502	0.325	0.237	0.469	0.660	0.817	0.741	0.647	0.765	0.582	0.631	0.535	0.619	0.447	**9.054**
	3.0<=v<4.0	0.374	0.400	0.338	0.327	0.154	0.392	0.641	0.787	0.438	0.361	0.589	0.564	0.572	0.444	0.433	0.390	**7.205**
	4.0<=v<6.0	0.343	0.343	0.296	0.481	0.124	0.410	0.556	0.604	0.235	0.291	0.651	0.856	0.749	0.519	0.372	0.386	**7.216**
	6.0<=v<8.0	0.082	0.083	0.050	0.118	0.026	0.070	0.102	0.091	0.021	0.091	0.275	0.467	0.332	0.198	0.105	0.110	**2.220**
	8.0<=v<12.0	0.008	0.014	0.002	0.007	0.001	0.003	0.006	0.004	0.002	0.012	0.048	0.106	0.060	0.037	0.014	0.015	**0.339**
	12.0<=v<25.0	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	**0.002**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	1.629	1.989	1.793	1.616	0.878	1.726	2.391	2.807	2.120	2.281	3.265	3.252	3.061	2.238	2.083	1.676	**34.805**
E	**0.0<=v<0.4**	0.012	0.014	0.012	0.007	0.010	0.009	0.009	0.013	0.015	0.031	0.031	0.024	0.022	0.014	0.010	0.006	**0.238**
	0.4<=v<1.0	0.006	0.008	0.007	0.007	0.012	0.014	0.013	0.011	0.013	0.015	0.016	0.013	0.016	0.011	0.009	0.005	**0.177**
	1.0<=v<2.0	0.053	0.079	0.055	0.040	0.050	0.069	0.079	0.091	0.093	0.107	0.113	0.090	0.116	0.087	0.091	0.046	**1.259**
	2.0<=v<3.0	0.141	0.182	0.126	0.108	0.083	0.158	0.209	0.251	0.216	0.158	0.199	0.157	0.178	0.147	0.157	0.125	**2.597**
	3.0<=v<4.0	0.091	0.115	0.108	0.110	0.047	0.156	0.192	0.229	0.144	0.084	0.147	0.133	0.145	0.122	0.110	0.113	**2.048**
	4.0<=v<6.0	0.091	0.096	0.088	0.146	0.044	0.144	0.176	0.185	0.066	0.111	0.233	0.301	0.241	0.160	0.113	0.146	**2.343**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.395	0.493	0.396	0.420	0.246	0.551	0.679	0.781	0.547	0.507	0.739	0.719	0.718	0.540	0.491	0.441	**8.662**

F	**0.0<=v<0.4**	0.005	0.007	0.005	0.004	0.003	0.004	0.005	0.006	0.008	0.016	0.016	0.010	0.009	0.006	0.004	0.002	**0.109**
	0.4<=v<1.0	0.003	0.003	0.003	0.002	0.004	0.003	0.003	0.003	0.005	0.008	0.010	0.008	0.009	0.006	0.004	0.002	**0.076**
	1.0<=v<2.0	0.017	0.028	0.023	0.016	0.022	0.023	0.021	0.029	0.041	0.043	0.045	0.033	0.039	0.032	0.035	0.014	**0.462**
	2.0<=v<3.0	0.055	0.076	0.054	0.042	0.031	0.053	0.072	0.083	0.078	0.079	0.089	0.074	0.075	0.063	0.073	0.055	**1.052**
	3.0<=v<4.0	0.077	0.087	0.070	0.071	0.035	0.076	0.103	0.117	0.084	0.076	0.124	0.119	0.118	0.087	0.091	0.088	**1.420**
	4.0<=v<6.0	0.021	0.021	0.019	0.040	0.014	0.038	0.053	0.055	0.025	0.040	0.078	0.089	0.064	0.042	0.032	0.034	**0.668**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	-	-	-	**<0.001**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.177	0.223	0.173	0.175	0.109	0.197	0.257	0.293	0.242	0.262	0.362	0.333	0.314	0.236	0.239	0.197	**3.788**
G	**.0<=v<0.4**	0.142	0.210	0.332	0.219	0.166	0.097	0.131	0.157	0.331	0.600	0.800	0.494	0.401	0.191	0.156	0.096	**4.522**
	0.4<=v<1.0	0.052	0.088	0.125	0.085	0.065	0.041	0.047	0.077	0.140	0.242	0.345	0.265	0.218	0.123	0.081	0.042	**2.037**
	1.0<=v<2.0	0.222	0.439	0.760	0.360	0.258	0.245	0.373	0.441	0.735	1.101	0.786	0.559	0.689	0.433	0.489	0.241	**8.131**
	2.0<=v<3.0	0.380	0.392	0.493	0.298	0.193	0.500	1.002	1.063	0.899	0.741	0.625	0.420	0.434	0.258	0.428	0.324	**8.450**
	3.0<=v<4.0	0.166	0.124	0.106	0.176	0.094	0.394	0.676	0.738	0.311	0.228	0.337	0.269	0.222	0.138	0.162	0.164	**4.301**
	4.0<=v<6.0	0.032	0.021	0.012	0.045	0.022	0.110	0.153	0.147	0.033	0.061	0.092	0.097	0.081	0.053	0.035	0.038	**1.030**
	6.0<=v<8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	8.0<=v<12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	12.0<=v<25.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	0.994	1.274	1.828	1.183	0.797	1.387	2.383	2.622	2.449	2.972	2.984	2.105	2.046	1.194	1.350	0.904	**28.471**
All categories	**0.0<=v<0.4**	0.284	0.375	0.530	0.337	0.266	0.187	0.229	0.272	0.523	0.925	1.200	0.765	0.633	0.339	0.299	0.198	**7.360**
	0.4<=v<1.0	0.140	0.189	0.237	0.163	0.146	0.123	0.130	0.165	0.267	0.423	0.589	0.465	0.393	0.246	0.193	0.125	**3.990**
	1.0<=v<2.0	0.730	1.170	1.470	0.781	0.667	0.750	0.978	1.160	1.620	2.110	1.820	1.330	1.570	1.160	1.300	0.761	**19.400**
	2.0<=v<3.0	1.450	1.690	1.560	1.000	0.732	1.450	2.460	2.810	2.470	2.120	2.260	1.640	1.770	1.490	1.810	1.410	**28.100**
	3.0<=v<4.0	1.110	1.080	0.926	0.916	0.483	1.270	2.200	2.500	1.400	1.180	1.770	1.470	1.530	1.260	1.300	1.240	**21.600**

	4.0<=v<6.0	0.832	0.772	0.651	0.929	0.288	0.862	1.360	1.470	0.649	0.833	1.540	1.720	1.620	1.140	0.917	0.976	**16.600**
	6.0<=v<8.0	0.108	0.109	0.068	0.138	0.030	0.075	0.121	0.122	0.041	0.118	0.316	0.505	0.375	0.223	0.124	0.135	**2.610**
	8.0<=v<12.0	0.008	0.014	0.002	0.007	0.001	0.003	0.006	0.004	0.002	0.012	0.048	0.106	0.060	0.037	0.014	0.016	**0.339**
	12.0<=v<25.0	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	**0.002**
	25.0<=v<75.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Total:	**4.670**	**5.400**	**5.450**	**4.270**	**2.610**	**4.720**	**7.490**	**8.500**	**6.970**	**7.720**	**9.540**	**7.990**	**7.960**	**5.890**	**5.960**	**4.860**	**100.00**

Data on the distribution for the sustainability categories for the period of 2006-2017 are given in Table 5.13.

Table 5.13 - Distribution of the sustainability categories for the period of 2006-2017

Category	A	B	C	D	E	F	G	Total
Probability	2.6	9.4	12.3	34.8	8.7	3.8	28.4	100

5.3 PC COSYMA

Modelling of atmospheric propagation of radioactive substances and formation of radiation doses dependent on radionuclide releases during accidents was carried out using software suite PC COSYMA by National Radiological Protection Board (UK).

PC COSYMA (Code System for MARIA) is a software suite used to model impact of accidental air release of radioactive substances. PC COSYMA was developed by joint efforts of National Radiological Protection Board (UK) and Forschungszentrum Karlsruhe (Germany) within the framework of MARIA (Methods for Accidental Radiation Impact Assessment) project of the European Commission for EU.

PC COSYMA suite and its separate modules are described in [23].

The system allows assessing the following parameters and impacts:

– integral surface air volumetric activity of radionuclides and activity of radionuclides deposited on the ground surface at certain points within the area;

– expected individual and collective doses within the selected periods;

– number of people covered by countermeasures (shelter, evacuation, dispensing of stable iodine tablets, relocation, deactivation, restricted use of agricultural products), and area on which countermeasures are taken;

– amount of agricultural products prohibited for use;

– number of latent and non-latent diseases;

– economic cost of countermeasures and treatment.

The system may be used for deterministic and probabilistic assessment. Deterministic assessment allows calculating the impact for a single user-specified set of weather conditions, while probabilistic assessment takes into account probable variations of weather conditions as may occur during the accident.

Impurities air transport models are built in MUSEMET module. This module utilises a model of segmented Gaussian spot that takes into account hourly wind speed and direction changes, atmospheric stability classes and amounts of precipitation, which impact the released substances. The model assumes that weather conditions in the entire area affected are identical. Hourly changes in weather conditions are only taken into account in probabilistic assessment. Deterministic assessment assumes that weather conditions (wind speed and direction, atmospheric stability class and amount of precipitation) remain unchanged throughout the period of time under consideration. MUSEMET utilises the mixing layer height as well as horizontal and vertical dispersion factors, which are functions of atmospheric stability. Dispersion factors have two parameter values for smooth (agricultural areas) and rugged (cities) ground surfaces.

6 Monitoring and environmental impact management program

The main document defining the scope of control during normal operation of power units and in excess of allowable releases and discharges, types, objects, frequency, methods, technical means of radiation control, list of controlled parameters, is "Regulations on radiation control at Rivne NPP. 132-1-Р-ЦРБ" [24]. When the "Emergency Plan" is put into effect, the amount and frequency of control is determined by the headquarters of the head of emergency operations at the site.

The regulation establishes the following types of control:

- on condition of protective barriers;
- radiation technological control;
- radiation dosimetric control;

- radiation control of the environment;

- radiation control over non-propagation of radioactive contamination;

- radiation control under conditions other than normal operation;

- radiation control of environments that are heated due to heat released from the NPP.

6.1 Control for the main technological environments

The radiation control system (RCS) is a complex of technical means and organizational measures designed to control the main technological environments, radiation situation in premises of the nuclear power plant and its surrounding territory. The system is aimed at ensuring compliance with the radiation safety norms and defining parameters characterizing the radiation safety for the NPP operation.

RCS solves the following tasks:

- radiation control of the status of protective barriers for the spread of radioactive substances and ionizing radiation;

- radiation control over technological environments;

- dosimetric control of internal and external irradiation of the personnel and population;

- radiation environmental control;

- radiation control for scheduled releases and discharges;

- detection of leaks in the technological equipment;

- performing accounting and reporting documents on radiation conditions at the NPP and radiation exposure of personnel.

The following provisions are suggested for the solution of the above tasks:

- automatic remote (continuous or periodic) monitoring using the permanently installed local means;

- monitoring using portable devices;

- monitoring by sampling of the media to be controlled with subsequent processing and measurement;

- monitoring using mobile express labs.

In organizational terms, the RCS consists of four subsystems:

- radiation technological control (RTC);
- radiation dosimetric control (RDC);
- individual dosimetric control (IDC);
- radiation environmental control (REC).

6.2 Monitoring of the NPP impact on population and environment

Sanitary protection zone

SPZ is set around radiation hazard nuclear facilities. Dimensions of the SPZ are determined taking into account the prognostic estimates of the radiation situation in the vicinity of the NPP during its long-term operation and are defined in the project.

Initially, the SPZ was set at a radius of 3 km. However later on, given that the size of the zone should be specified more precisely taking into account the dominant wind directions, calculations were made and in agreement with the Chief Sanitary Inspector of the USSR V. D. Turovskyi (letter of August 1984 No. 32-014/324) the size of the SPZ for RNPP was reduced to a radius of 2.5 km.

Currently, there are no residents or institutions, enterprises or facilities, except those that are a part of the NPP, within the SPZ. Only the buildings and constructions intended for auxiliary needs and serving of the NPP are located in the SPZ.

Cultivation of crops and grazing of cattle with the obligatory control over the radionuclides content in the produced agricultural products is permitted on the territory of the SPZ.

Radiation control is carried out in the SPZ.

Observation zone

According to NRBU [8], the observation zone includes the monitored area in which the radioactive releases and emissions from the radiation nuclear facility (NPP) are likely to happened. Currently, an observation zone with a radius of 30 km is set for SS RNPP. Existing boundaries of the OZ in accordance with the requirements of [24] were confirmed by calculations.

Controlled parameters, frequency and methods

The purpose of the REC is to monitor releases of radioactive substances in the environment, radiation situation in SS RNPP area and radioactive contamination of the natural environment locations [25-26]. RC of the environment is ensured by measurements given in Tables 6.1 to 6.7.

Table 6.1 - Activity and radionuclide composition of the scheduled releases of radioactive aerosols, iodine radionuclides, IRG and tritium

Name of the radiation parameter	Frequency	Measurement method
Release rate of IRG, radioactive aerosols and iodine radionuclides	Continuously	Channels of ARSMS, SPB GAR, RSCS
Activity of LLN release, radionuclides of iodine and tritium	Regularly	Laboratory control
Radionuclide composition and activity of LLN release	Once a month	Laboratory control

Table Ошибка! Текст указанного стиля в документе отсутствует.**.2 - VA and radionuclide composition of liquid discharge into the environment**

Name of the radiation parameter	Frequency	Measurement method
VA and radionuclide composition of the water in RWMT after RAWT	Regularly, after filling	Laboratory control
VA in the pits of WP, ISC1	Continuously (when discharged into the environment)	Channels of ARCS, RSCS
VA and radionuclide composition of liquid discharges of radioactive substances, including tritium	Regularly	Laboratory control
VA and radionuclide composition of LRW	Regularly	Laboratory control

Table 6.3 - Activity and radionuclide composition of SRW

Name of the radiation parameter	Frequency	Measurement method
VA and radionuclide composition of SRW	Regularly, at the DD request	Laboratory control
SRW activity in primary packaging	Regularly, with accumulation at the waste collection sites	SEG-001m spectrometer

Table 6.4 - Activity and radionuclide composition of radioactive leakages from SRWS, LRWS, RR, spray pools

Name of the radiation parameter	Frequency	Measurement method
VA and radionuclide composition of water samples from observation wells	Regularly	Laboratory control

Table 6.5 - EDR in the territory of the SPZ and OZ

Name of the radiation parameter	Frequency	Measurement method
Integral dose in the SPZ and OZ area	Regularly	TLD

Name of the radiation parameter	Frequency	Measurement method
EDR in the in the SPZ and OZ area (at the locations of RSCS CS)	Continuously	RSCS
EDR control in the SPZ and OZ, including settlements	Once a year (when replacing TLD)	Portable devices
EDR control at industrial facilities	Regularly (once a month)	Portable devices

Table 6.6 - Volumetric activity of radioactive aerosols in the air in the vicinity of the NPP

Name of the radiation parameter	Frequency	Measurement method
VA of radioactive aerosols in the air in the vicinity of the NPP	Regularly	Laboratory control

Table 6.7 - Activity in the natural environment locations

Name of the radiation parameter	Frequency	Measurement method
Samples from natural environment locations	Regularly	Laboratory control

6.3Management of environmental impact

The environment management strategy is implemented on five levels [16].

Level 1. Preventing violations of normal operation.

The main instruments for achieving the above objective are:

- selection of the NPP site in accordance with the requirements of regulatory documents;

- conservative approach to project development with maximum use of the safe-secure properties of the RU;

- ensuring the required quality of structures, systems and elements of the NPP, works on its construction, operation and modernization;

- availability of automatic technical means preventing the violation of normal operation conditions;

- operation of the power unit in accordance with the requirements of regulatory documents, technological regulations for safe operation and operational manuals;

- maintaining operating condition of safety-critical structures, systems and elements by timely detection of defects and adoption of preventive measures against their occurrence, replacement of equipment with expired lifetime, organization of high-performance control system for the structures, systems and elements, their maintenance, repair and modernization, documentation of the results for the above works;

- selection and training of personnel, ensuring the required personnel skill level;

- formation and development of the safety culture.

Level 2. Ensuring safety in case of violations of normal operation and prevention of emergencies.

The main instruments for achieving the above objective are:

- timely detection and correction of deviations from normal operation;

- availability of automatic protection and interlocks preventing transformation of deviations from normal operation into emergencies;

- actions of personnel in accordance with the requirements of instructions and technological regulations for safe operation, continuous improvement, taking into account the expertise gained and new scientific and technical data;

- training of personnel regarding actions in case of violations in normal operation.

Level 3. Accidents prevention and elimination.

The main instruments for achieving the above objective are:

- availability of safety systems (protective, localizing, supporting and controlling) designed to prevent emergencies and design accidents, eliminate their consequences and prevent their transformation into beyond design basis accidents;

- the use of normal operation systems for preventing emergencies and design basis accidents, as well as for containment of emergencies and accidents;

- availability and use of emergency operating procedures, and appropriate actions of personnel in accordance with their requirements;

- training of personnel with the use on full-scale simulators for actions in case of accidents.

Level 4. Management of beyond design basis accidents.

The main instruments for achieving the above objective are:

- the use of normal operation systems and safety systems to prevent the development of beyond design basis accidents, limit their consequences, as well as to restore the controlled state of the RU;
- availability and use of instructions on management of beyond design basis accidents aimed at stopping the fission chain reaction, efficient cooling of nuclear fuel and keeping radioactive substances within the established limits, as well as containment of serious accidents, including protection of the hermetic envelope against destruction;
- availability and use of instructions for the management of severe accidents aimed at preventing the outflow of the active zone melt from the reactor shell and violation of the hermetic envelope integrity, limiting the radiation exposure to personnel, the population and the environment, as well as creating conditions for the timely implementation of plans on protection of personnel and population;
- actions of personnel in accordance with the instructions for managing beyond design basis accidents;
- training of personnel on managing beyond design basis accidents.

Level 5. Emergency readiness and response.

The following is provided tt this level:

- establishment of the sanitary protection zone and surveillance zone around the NPP;
- availability of emergency plans, emergency response plans, which efficiency and readiness for implementation should be checked at regular intervals during emergency training and exercises;
- construction of radiation shelters and crisis centres.

CONCLUSIONS

Radiation action of gas-aerosol releases of RNPP during normal operation is much lower than the specified dose limits for the population in adjacent countries (these limits are within the range of 0.2-0.3 mSv/year for different countries). The annual individual effective dose does not exceed the value of 1.5 nSv/year at the border of the nearest country - the Republic of Belarus.

The main criterion for limiting the exposure the population in Europe due to anthropogenic sources is the limit of the individual effective dose (due to all radiation routes), which is set at 1 mSv/year. The assessment has shown that the expected total effective dose for 50 years at the border of the nearest country - the Republic of Belarus - does not exceed the value of 13 mSv in any of the accidents considered.

Under normal operating conditions of RNPP, as well as in the event of accidents, the environmental impact in a transboundary context, that is, in the territory of adjacent countries, does not arise, as the regulatory requirements for air contamination and dose limits for the population are not exceeded, and already are at a level below the limits at a distance of 60 km from RNPP.

Thus, it has been justified that planned activities have no major transboundary impact, and there is no affected party in terms of the Convention on Environmental Impact Assessment in a Transboundary Context. In execution of para. 8 Article 3 of Convention on Access to Public Information, posting the information on environmental impact of the planned activities in a transboundary context at common access Internet resources, e. g. on websites of the Ministry of Ecology and Natural Resources of Ukraine and SS NNEGC Energoatom, will suffice.

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NON-TECHNICAL SUMMARY

OF SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

2018

CONTENTS

LIST OF LEGENDS, SYMBOLS, UNITS OF MEASUREMENT, ABBREVIATIONS AND TERMS

Abbreviation	Name
BDBA	Beyond design basis accident
ChNPP	Chornobyl Nuclear Power Plant
CSFSF	Centralized spent fuel storage facility
CUF	Capacity utilization factor
EIA	Environmental impact assessment
ERS	Emergency preparedness and response system
HLW	High-level waste
IAEA	The International Atomic Energy Agency
LRW	Liquid radioactive waste
LWR	Light water reactor
MDBA	Maximum design basis accident
MPC	Maximum permissible concentration
MSK-64	Earthquake repetition scale
NPP	Nuclear Power Plant
NRBU-97	Norms of Radiation Safety of Ukraine, 1997
RNPP	Rivne Nuclear Power Plant
RW	Radioactive waste
SE NNEGC “Energoatom”	State Enterprise “National Nuclear Energy Generating Company Energoatom”
SF	Safety Factors
SNF	Spend nuclear fuel
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SPZ	Sanitary protection zone
SRW	Solid radioactive waste
SRW CT	Comprehensive treatment of solid radioactive waste
SS Rivne NPP	Separated Subdivision Rivne Nuclear Power Plant
SWP	Special water purification system
VVER-440	Water-water power reactor with a rated power output of 440 MW
VVER-1000	Water-water power reactor with a rated power output of 1000 MW

1 INFORMATION ABOUT THE DOCUMENTS WHICH ARE THE BASIS FOR ENVIRONMENTAL IMPACT ASSESSMENT DEVELOPMENT

Non-technical summary is a review document, it does not contain original assessments or independent conclusions and based entirely on the information given in the text.

The report on the environmental impact assessment of Rivne NPP site was developed in accordance with the Law of Ukraine “On Environmental Impact Assessment”.

The basis for development of materials is the Energy strategy of Ukraine for the period to 2030, approved by the Order of the Cabinet of Ministers of Ukraine No. 1071-r, dated July 24, 2013, which defines the operation of Ukrainian nuclear power plant units, Strategic plan of the State Enterprise “National Nuclear Energy Generating Company “Energoatom” development for 2017-2021, the Decision VI/2 of the 6th meeting of the Parties to the Convention on the Environmental Impact Assessment in a Transboundary Context (Espoo Convention) etc.,

Facility, which activity has been assessed in terms of impact on the environment, includes operating power units, facilities and structures integrated into technological complex located at SS Rivne NPP site, as well as other facilities within the power complex in the vicinity of NPP (Sanitary Protection Zone (SPZ) and Observation Zone (OZ).

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

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

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

– environmental support of NPP power units operation;

– development and implementation of environmental protection management system;

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

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

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

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

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

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

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

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

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

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

– SF-1 “Power unit design”;
– SF -2 “Current state of power unit systems, structures and components”;
– SF -3 “Equipment qualification”;
– SF -4 “Structures, systems and components ageing”;
– SF -5 “Deterministic safety analysis”;
– SF -6 “Probabilistic safety analysis”;
– SF -7 “Analysis of internal and external impacts”;
– SF -8 “Operational safety”;
– SF -9 “Use of other NPP experience and scientific research results”;
– SF -10 “Organization and management”;
– SF -11 “Operating documentation”;
– SF -12 “Human factor”;
– SF -13 “Emergency preparedness and planning”;
– SF -14 “Impact of NPP operation on the environment”.

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

In the reporting materials on Environmental Impact Assessment there is a description of the elements of activity of SS Rivne NPP, as well as an assessment of the environmental impact in accordance with the requirements of Article 6 of the Law of Ukraine “On Environmental Impact Assessment”.

2 GENERAL DESCRIPTION OF THE SS RIVNE NPP

2.1 General Information

SS Rivne NPP is a separate subdivision (unit) of the State Enterprise “National Nuclear Energy Generating Company Energoatom. SE NNEGC “Energoatom” carries out activities in accordance with its Articles of Association and is subordinate of the Ministry of Fuel and Energy of Ukraine, which forms the state policy in the field. In accordance with the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” adopted by the Resolution No. 1268 of the Cabinet of Ministers of Ukraine dated 17 October 1996 “On the Establishment of the National Nuclear Power Generating Company Energoatom” SE NNEGC “Energoatom” is assigned with functions of an operating organization responsible for the safety of all nuclear power plants in the country.

Rivne NPP is located in western Polissya, in the north-west of the Rivne Region, near the Stir River. The site choice was preconditioned by several reasons: low fertility of sandy land and great distance from densely populated areas. In 1973, the density of population in this territory was 55 persons/km^2, while today’s population in Varash is 3,684 persons/km^2.

According to SNiP P-7-81 “Construction in Seismic Areas”, the industrial area of SS Rivne NPP is located in the P3-5, MR3-6 zone. NPP was designed taking into account two levels of seismicity (P3) - magnitude 5 and the maximum estimated earthquake - magnitude 6. The recurrence of earthquakes according to the MSK-64 scale is 1 time in 5000 years.

SS Rivne NPP industrial site is located in a moderate climate zone characterized by mild and humid winters, relatively cold and rainy summer, wet autumn and unstable weather during the season transitions.

The terrain is even and open to the wind, which provides good ventilation of the site. Power delivery to the power system is carried out via:

- power lines -750 kV;
- power lines - 330 kV lines;
- power lines - 110 kV lines.

NPP process water supply is of circulating type, feeding from the Styr River. The Rivne NPP power units cooling system does not include cooling ponds. The entire power units cooling system is designed to use six cooling towers and spray pools. Heat is removed from circulating water via 6 cooling towers with a productivity of 100,000 m^3/h each. Spray pools are used to remove heat from critical consumers.

Each year, SS Rivne NPP generates about 13 % of the total electricity amount generated in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Varash town and Zabolottia village. The design CUF capacity utilization factor is 74.2 %.

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:

- protection safety systems;
- localizing safety systems;
- auxiliary safety systems;
- control safety systems.

SS Rivne NPP power units have been designed, built and installed in accordance with the regulative documents that were in force at that time.

In 1971, the West Ukrainian NPP subsequently renamed in Rivne NPP has entered the design stage. The power plant is designed to cover electrical loads in the western part of the country.

SS Rivne NPP is the first nuclear power plant in Ukraine based on a VVER-440 water-water power reactor. The power plant construction was commenced in 1973. The first two units with VVER- 440/213 reactors were put into operation in 1980-1981, and the third power unit, 1000 MW VVER-1000/320 - in 1986.

The construction of the fourth Rivne NPP unit was commenced in 1984, with commissioning scheduled for 1991. However, due to the introduction of the moratorium on the construction of nuclear facilities on the territory of Ukraine by the Verkhovna Rada, the works were suspended at 85 % of the unit's readiness.

Construction was resumed in 1993. Following the withdrawal of the moratorium, Unit 4 was inspected, and a program for its modernization and a completion project dossier were prepared. Power Unit No. 4 at SS Rivne NPP was commissioned on 16 October 2004.

SS Rivne NPP is located at the address:34400, city of Varash of the Rivne Region.

Mr. Pavlyshin Pavlo Yaremovich, General Director of the Rivne NPP, fulfills the overall management of the facility with the functions authorized by the President of NNEGC "Energoatom".

The general view of Rivne NPP is presented on Figure 2.1.

Figure 2.1. General view of Pivne NPP site

Technical characteristics of the power units of Rivne NPP are provided in Table 2.1.

Table 2.1. Key performance indicators of Rivne NPP

Indicators	Power unit No. 1	Power unit No. 2	Power unit No. 3	Power unit No. 4	NPP
Electric energy generated per current day, mln kW·h	4.5	4.5	n/a	10.8	19.9
Electric energy generated per current month, mln kW·h	182.5	183.3	n/a	437.6	803.4
Electric energy generated per previous month, mln kW·h	309.5	308.6	n/a	736.9	1355
Electric energy generated year-to-date, mln kW·h	1346.8	1292.6	0	4061.9	6701.4
Capacity utilization factor (CUF) per current month, %	98	99.6	n/a	98.6	63.9
Capacity utilization factor (CUF) per previous month, %	99	99.9	n/a	99	64.2
Capacity utilization factor (CUF) year-to-date, %	78.9	76.6	0	99.9	58.1

2.2 The Operation Time for Rivne NPP Power Units

The operation time for Rivne NPP power units is presented in Table 2.2.

Table 2.2. Information on the power units of Rivne NPP.

Power unit	Type of reactor facility	Series of reactor facility	Date of unit connection to the grid	Date of putting the unit into commercial operation	Date of design lifetime	Date of lifetime extension
RNPP-1	VVER-440	B-213	22.12.1980	22.09.1981	22.12.2010	2030
RNPP-2	VVER-440	B-213	22.12.1981	29.07.1982	22.12.2011	2031
RNPP-3	VVER-1000	B-320	21.12.1986	11.12.1987	11.12.2017	2037
RNPP-4	VVER-1000	B-320	10.10.2004	07.06.2005	07.06.2035	-

2.3 Brief Description of Products of Rivne NPP

SS Rivne NPP produces heat and electricity. Electricity production is accomplished at four power units with VVER-440 reactor and VVER-1000 reactor, with total installed capacity of 2835 MWt. The capacity factor is 74.2%.

Production of the electrical energy by the power units of Rivne NPP started from 1981. Figure 2.2 provides information on the amount of milliards of kWt×year of the produced electricity as per years of operation.

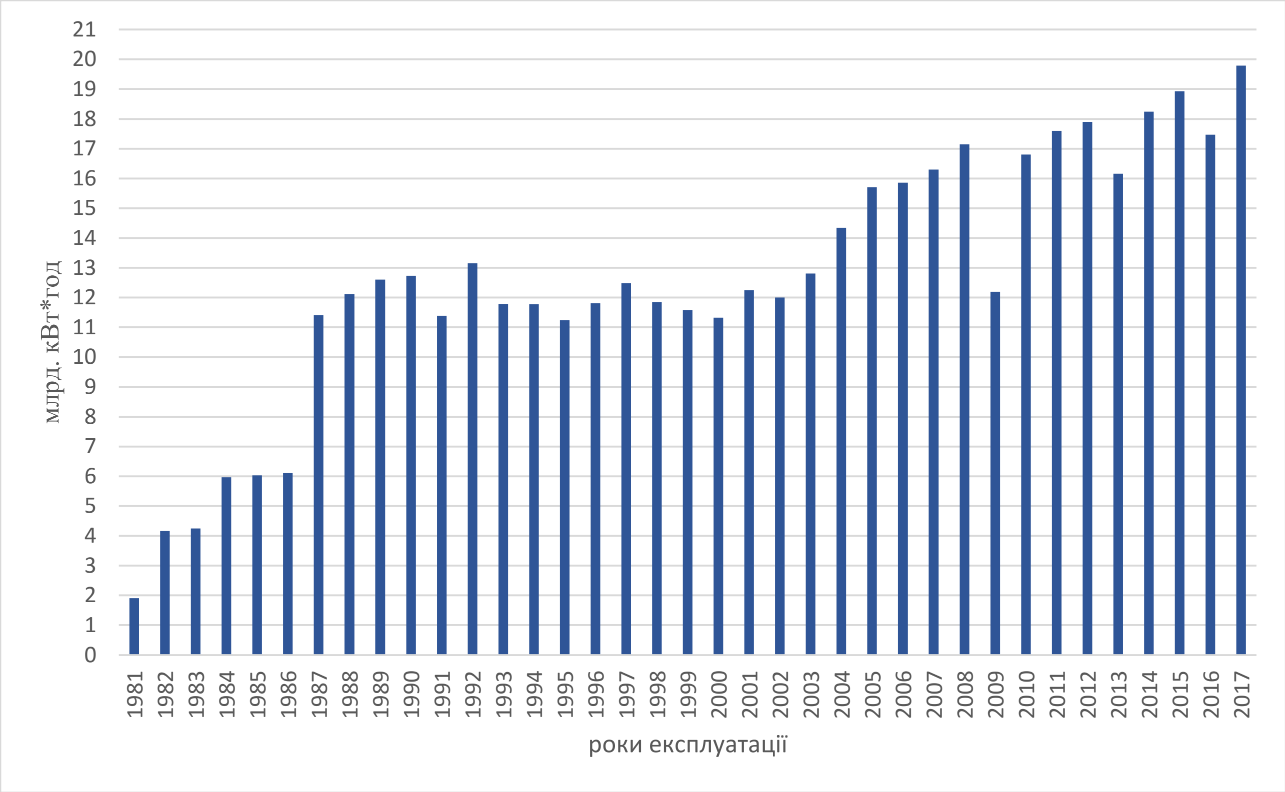

Figure 2.2. Annual electricity produced by Rivne NPP

2.4 Data on Raw Materials, Land, Water, Energy and Other Used Resources

SS Rivne NPP uses the following resources for the production needs:
- NPP territory and industrial site;
- circulating water use, evaporation of water for cooling purposes;
- auxiliary electric power.

The land plot with an area of 217.895 ha, which is intended for usage by the facilities of electricity production and distribution, is assigned for the permanent use by NNEGC "Energoatom" and certified with the state act on the right of continuous management of the land plot - series ЯЯ №252110 as of 01.07.2006, issued upon the Decision № 433 as of 28.04.2005 by the Kuznetsovsk Town Council.

In addition to the land plot used by Rivne NPP power units, NNEGC "Energoatom" also holds the right of continuous use of the land plots for servicing the production and social objects with the total area of 262,3 ha on the territory of Varash town council and Volodymyrets and Manevytskiy regions.

Preservation and rational use of the land resources is ensured by the maximum effective use of the assigned territory. The territory is arranged, the land plot used for the power units has a developed infrastructure and landscape. No additional land allocation for extended lifetime of Rivne NPP power units operation is required.

Rivne NPP includes main, auxiliary and warehouse buildings and structures. The technological process of producing electricity is characterized by stability. The main and auxiliary workshops with their characteristic sites are located on the industrial site to ensure the operation of power units at the industrial site.

In the process of production activity, the fuel materials (fuel oil, anthracite, diesel fuel, gasoline), the welding materials for repair (welding electrodes, propane-butane mixture), lubricating and cooling liquids, paint and varnish materials, chemical reagents (sulfuric acid, ammonia, nitric acid, hydrazine hydrate, monoethanolamine) are used at SS Rivne NPP. As the fuel in start-up boiler-house, the fuel oil of M-100 grade is used.

A part of the electric and thermal energy produced at Rivne NPP is used for its own needs. Other resources (inventories, works and services) for the needs of Rivne NPP are purchased from other entities.

2.5 Brief Description of Rivne NPP Power Units and Technological Processes

As of 2018, four power units are in operation at SS Rivne NPP:
- power unit I (VVER-440) with a capacity of 420 MW since 1980;
- power unit II (VVER-440) with a capacity of 415 MW since 1981;
- power unit III (VVER-1000) with a capacity of 1000 MW since 1986;
- power unit IV (VVER-1000) with a capacity of 1000 MW since 2004.

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008) and World Association of Nuclear Operators (WANO) (1988, 1989, 1993, 1995, 1997, 2001, 2003, 2005, 2012, 2014, 2015, 2016, 2018 years).

Each year, SS Rivne NPP generates about 13 % of the total electricity amount generated in Ukraine, and provides electricity for needs and keeping normal conditions of life for more than 5 million people.

SS Rivne NPP is also a heat source for the industrial site, Varash town and Zabolottia village. The design CUF capacity utilization factor is 74.2 %.

SS Rivne NPP power units include the following equipment:
- VVER-440 (B-213) reactor - units 1, 2 and VVER-1000 (B 320) - units 3, 4;
- K-220-44 turbine - units 1, 2 (2 pcs per unit) and K-1000-60/3000 - units 3, 4;
- TVV-220 turbogenerator - units 1, 2 (2 pcs per unit) and TVV-1000 - units 3, 4.

Each power unit is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

Table 2.4 provides specifications of SS Rivne NPP power units.

Table 2.4. Specifications of SS Rivne NPP power units

Parameter	Value	
	VVER-440	VVER-1000
Reactor capacity, MW	137527	3000
Pressure at 1 k (at active zone discharge) kgf/cm^2 (MPA)	125±1.2 (12.25±0.1)	160±3 (15.7±0.29)
Temperature of coolant at the reactor discharge, °C	300	320
Coolant heating in the reactor, °C	30.3	30.3
Average consumption of coolant for active zone cooling, t/h	42700400	84800^{+400}_{-480}
Steam production for all SG, t/h	2700	5880
Humidity of steam at SG discharge, %	0.25	0.2

The process of economic operations, including all environmental impact factors and technical solutions, is intended to eliminate or reduce harmful releases, discharges, leaks and radiation in the environment.

VVER-440 and VVER-1000 reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel.

2.5.1 Flow Chart of the Power Unit With VVER-440 Reactor Type

The power units of Rivne NPP have a water-cooled water-moderated power reactor (VVER). The power units with VVER reactor type have a two-circuit system, primary and secondary circuits that do not mix with each other.

Rivne NPP is special for introduction of power units operated with the reactors of VVER-440 type. Two reactors of this type are operated at the plant, specifically reactor 1 and reactor 2.

Flow chart of the power units with VVER-440 reactor type is presented on the Figure 2.3 below.

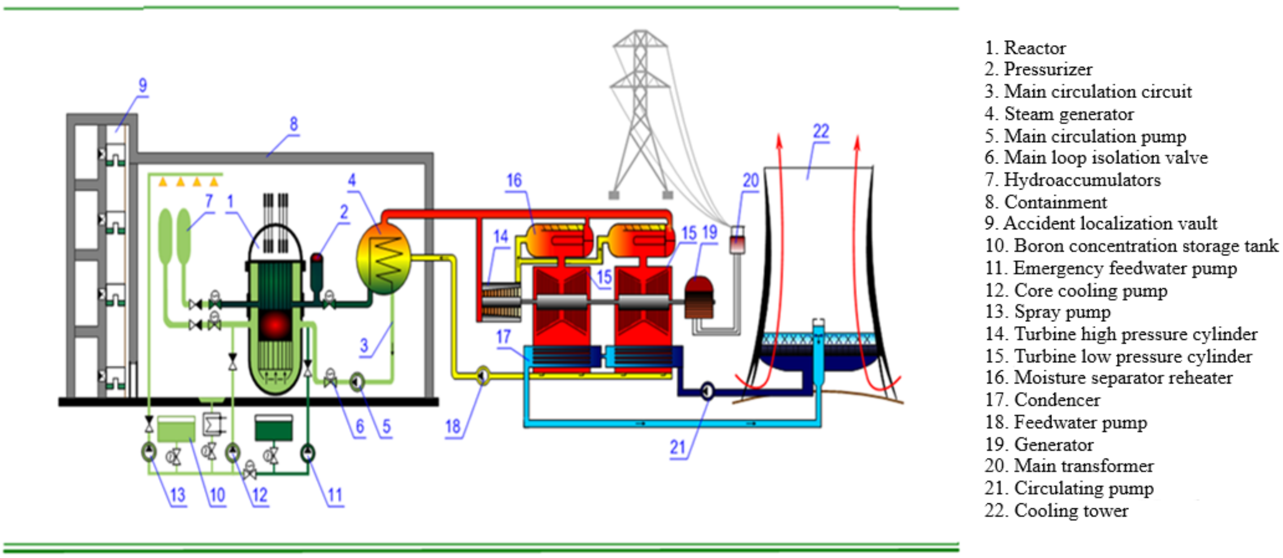

Figure 2.3. The flow chart of the power unit with VVER-440 reactor type.

The reactor primary circuit includes:
- reactor,
- steam generator,
- main circulation pumps,
- pressurizer,
- main loop isolation valves.

All components of the primary circuit are installed in the leak-tight boxes.

The coolant and neutron moderator is demineralized water.

The coolant removes heat generated during uranium fission in the operating reactor, and then it is pumped through the reactor core by the main circulation pumps and transfers heat to water of the secondary circuit in the steam generators.

The reactor core consists of hexagonal fuel assemblies, which contain fuel elements.

A fuel element is a rod made of zirconium alloy and filled with fuel pallets with uranium dioxide.

The water in the primary side heats up to 300 °C in the reactor, but it does not boil, since the pressure that is maintained by the pressurizer is 12 MPa for VVER-440 and 16 MPa for VVER-1000. The secondary circuit is nonradioactive, it includes:
- steam generators,
- steamlines,

- steam turbines,
- moisture separator reheaters,
- feedwater pipelines with feedwater pumps, deaerators and regenerating heaters.

The saturated heat generated in the steam generators is supplied to the turbine, which activates electrical generator.

The electrical energy produced by RNPP is transmitted to the unified grid of Ukraine via the open switchgears of electrical transmission lines 110, 330 and 750 kV.

2.5.2 Flow Chart of the Power Unit With VVER-1000 Reactor Type

Rivne NPP has two power units of VVER-1000 reactor type – Units 3 and 4.

VVER-1000 is a water-cooled and water-moderated reactor, where pressurized water is used as coolant and moderator. This is a second-generation light water reactor with high capacity. The electrical power is 1000 MWt, the thermal power is 3000 MWt. Nuclear reactors of this type are operated at Zaporizhzhya, Rivne, Khmelnitskiy, South Ukraine NPPs, as well as at the NPPs of Russia, Bulgaria, Check Republic and China.

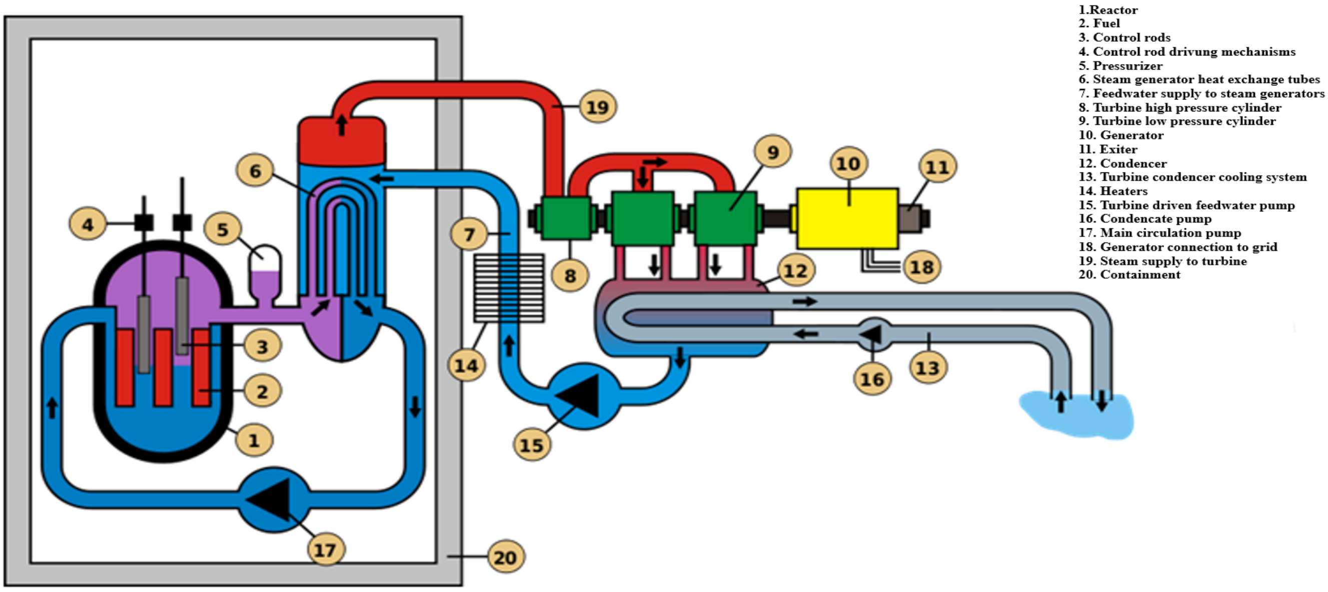

Figure 2.4 The flow chart of the power unit with VVER-1000 reactor type.

The regular demineralized water (heterogeneous reactor) is used as a neutron moderator and coolant in the energy reactors of VVER vessel-type. The core is placed in one common vessel, with water circulating through it. Two-circuit principle is applied to remove the heat. In the vessel-type unboiling reactor, the core is located in the high-strength, thick-walls steel vessel. The diameter of the core is 3.12 m, the height is 3.5 m, loading with natural uranium is 66 t, ^{235}U enrichment is 3-4%.

The reactor vessel is one of the most important structural elements and must ensure total reliability and complete leak-tightness both in normal operation conditions and in case of possible emergencies. The vessel is completely filled with pressurized water (15.7 MPa and greater).

The primary side of the reactor is fully isolated from the secondary side, which reduces radioactive releases into atmosphere. Water is pumped by the circulation pumps through the reactor and heat exchanger (the circulation pumps take suction from the turbine). Water of the reactor radioactive circuit is at the high pressure, thus regardless of its high temperature (320°C at the reactor exit, 289°C at the core inlet) it does not boil.

Water of the secondary side is at operating pressure of 6.4 MPa, that is why it is converted into steam at operating temperature of 280 °C in the heat exchanger (steam generator). In the heat exchanger – steam generator the coolant that circulates in the primary circuit transfers heat to the secondary circuit. The steam, generating in the steam generator, goes to the turbines via the main steamlines of the secondary side and gives away part of its energy to rotation of the turbine, and after that, it gets to the condenser. The condenser, which is cooled with water of the circulation circuit (so to say, the third circuit), ensures collection and condensation of the steam. The condensate, after going through the heaters system, goes back to the heat exchanger and the cycle repeats again.

For convenience of reloading and transportation, the fuel elements of the reactor are collected in the special assemblies – fuel assemblies (FAs). The assemblies have the hexagonal shape. The reactor consists of 163 fuel assemblies, which are located in the middle of the core with a pitch of 20-25 cm. All FAs in the core are assembled in the reactor core barrel (RCB). The bottom end of FAs is placed in the RCB's support tubes, and the top end (head) is supported by the guide tubes. The RCB's support tubes, the baffle and guide tubes hold the fuel assemblies in the required position.

Power units operate in a two-loop cycle: first (hot) loop is a water circuit with direct heat extraction from the reactor; second (cold) loop is a steam circuit with heat energy extracted from the first loop and converted into mechanical energy of turbine rotation, and then into electrical energy in a turbine generator.

The main building with 4 operating power units (two VVER-440 and two VVER-1000 units) includes a reactor room.

Turbine island with adjacent deaerator bay and auxiliary switchgear room.

Main process equipment of reactor unit:

- reactor;
- steam generators;
- main circulation pumps;
- pressurizer;
- emergency core cooling tank;
- connecting pipelines arranged under the containment in boxes with solid walls of heavy concrete or reinforced concrete.

2.6 Main Sources of Radiation Hazard

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

Main types of the possible radiation impact are caused by:

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

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

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

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

I – low-level;

II – medium-level;

III – high-level.

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

- contaminated dismantled equipment;
- dismantled pipelines and valves;

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

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

LRW includes:

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

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

- decontamination of air which is removed and which contains radioactive isotopes using aerosol and iodine filters;
- decontamination of process vent on filters-absorbers, where gas is held up in order to reduce relative activity (radioactive decay of the major part of inert noble gases isotopes (xenon (Xe), Krypton (Kr);
- air releases from the premises of reactor compartment controlled access area and auxiliary building through vent stacks of 150 m high, that provides necessary dispersion of radioactive substances in atmosphere;
- establishment of barriers to prevent propagation of radioactive substances by way of the reactor compartment containment, lining of the premises with LWR sources by corrosion resistant steel;
- implementation of closed process and component cooling systems to prevent discharges of liquid substances containing radioactivity;
- implementation of special system for SRW collecting, as well as SRW and LRW storage;
- prevention of non-controlled releases and discharges;
- arrangement of NPP's SPZ;
- organization of continuous technological dosimetry monitoring of discharges and releases, air, soil, vegetation, water contamination monitoring in the SPZ and OZ.

2.7 Main Sources of Danger of Non-radiation Origin

2.7.1 Chemical Impact

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

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

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

Spent oils and lubricants (motor, turbine, industrial, transformer), spent storage batteries, broken glass, waste metal and paper (except for technical documentation, accounting and other documents to be destructed) have been transferred to Rivne department of SS "Warehouse" as raw-materials.

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

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

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

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

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

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

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

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

- boundary gross release – "Project standards for maximum permissible releases from stationary sources of Rivne nuclear power plant".
- concentration of harmful substances in the atmosphere – "State Sanitary Rules for Protection of Atmospheric Air of Populated Areas (from chemical and biological contamination) ДСП-201-97, approved by the Order of the Ministry of Health of Ukraine No. 201, dated July 09, 1997 and State Environmental Safety Administration in Rivne oblast, dated April 09, 1999.
- "The list of harmful substances released into atmosphere and those subject to monitoring in the area of environmental protection" approved by the Resolution of the Cabinet of Ministers of Ukraine No. 343, dated March 09, 1999.

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

Discharge of domestic waste water from NPP into public water bodies is not carried out.

2.7.2 Physical Impact

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

- thermal impact on the air environment associated with operation of NPP process equipment cooling systems (spray cooling ponds and cooling towers);
- increased humidity due to the evaporation of water into the atmosphere from spray cooling ponds and cooling towers;
- thermal impact on the water environment associated with the discharge of blowdown water from the main cooling system;

- impact on the water environment (the Styr river) associated with the irretrievable water consumption;

- impact of the electric field of 330/750 kVt transmission lines;

- noise during equipment operation and traffic.

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

Table 2.5 presents the values of heat releases of Rivne NPP into atmosphere.

Table 2.5. Amount of heat removed by the cooling water from the plant components and released into atmosphere.

Plant equipment	Heat release, Gcal/year
Circulation systems of service water supply	5220
Group A service water supply system	60
Group B service water supply system	100

The existing regulatory documents do not have requirements to the allowed limits of heat releases. Monitoring of heat releases is performed by measuring the consumed water, which is collected from the River Styr for service needs and consumed water that returns to the river.

Taking into account that impact of the plant cooling systems is quite insignificant on the climate parameters, and that impact of the cooling towers and spray ponds is practically implicit on the microclimate and environment outside the sanitary protection zone within the radius of 2.5 km, no special activities are foreseen with regard to limitation of these influences during NPP operation.

2.8 Scheme for Spent Nuclear Fuel Treatment

In the process cycle of the nuclear power plant, one of the most important elements is the spent nuclear fuel (SNF), which generates as a result of the energy produced in the nuclear reactors.

The time of using the nuclear fuel in the reactors is defined by the value of allowed burn-up of the fissionable isotopes. After the planned burn-up is achieved, the nuclear fuel is unloaded from the reactor and considered to be spent fuel, since it cannot be used any longer for energy generation.

After unloaded from the reactor, the spent nuclear fuel is loaded to the near-reactor spent fuel pit (SFP). The SNF is stored in the pits for the limited time, necessary for reduction of energy release, due to decay of fission products, to the allowed values. After SNF storage in the SFP during limited time, the spent fuel assemblies (SFAs) should be transported from the power unit and shipped for storage (disposal) or processing. This is done because the capacity of SFP is limited and it should always have free volume for loading of the nuclear fuel from the reactor core or periodic inspections of the reactor vessel and in-vessel internals of VVER reactors.

During SNF management, it is also necessary to consider the factors, which relate to the specifics of this material: high radioactivity level and presence of valuable elements in SNF (uranium, plutonium, germanium, erbium, palladium, zirconium etc.), which in the perspective can be used in other fuel cycles (nuclear fuel for the fast-neutron reactors, MOX-fuel for light-water reactors). Taking into account the above mentioned, the SNF does not refer to radioactive waste.

The current state of the nuclear energy field in the world shows that, given the modern level of technologies, the final conclusions cannot be made as for the economic viability of SNF processing or disposal, i.e. the final phase of the nuclear fuel cycle (NFC). In light of this, Ukraine like most other countries that develop nuclear energy, took for themselves the so-called “deferred decision”, which implies long-term storage of the spent nuclear fuel. The “deferred decision” allows the country to take a decision later on the final phase of NFC, considering the technologies development in the world and economic benefit for the country.

At present, Ukraine has two storage facilities in operation, designed for temporary storage of the spent nuclear fuel: wet type interim spent fuel storage facility at Chernobyl NPP and dry-type spent fuel storage facility at Zaporizhzhya NPP. Besides, Ukraine is constructing two more storage facilities: ISF-2 at Chernobyl NPP and Centralized spent fuel storage facility (CSFSF) for the SNF of VVER reactors.

SNF from Rivne, Khmelnitskiy and South Ukraine nuclear power plants is currently transported to the Russian Federation. SNF from VVER-1000 reactors is shipped for storage, and SNF from VVER-440 (power units 1, 2 of Rivne NPP) is shipped for reprocessing.

To accomplish "Action Plan for 2006-2010 with regard to implementation of the Energy Strategy of Ukraine for the period up to 2030" (approved by the Decree of the Cabinet of Ministers of Ukraine № 427 as of July 27, 2006), the operator SE "NNEGC "Energoatom"" signed the contract with the American Company "Holtec International" for construction of the CSFSF in Ukraine. The SCFSF will be used for storing the spent nuclear fuel of Rivne, Khmelnitskiy and South Ukraine NPPs based on the dry-type storage technology applied at Zaporizhzhya NPP.

In accordance with the legislative provisions, the operator NNEGC "Energoatom" developed "Feasibility Study for construction of the CSFSF for VVER reactors types". Following the complex state expert review, the document was approved by the Cabinet of Ministers with the Decree № 131-р as of 04.02.2009.

The specified Feasibility Study justified the economic viability for the long-term storage of SNF in Ukraine, compared to SNF shipment to the Russian Federation, and construction of one centralized storage facility was substantiated compared to any other option of SNF storage.

The CSFSF is designed to store 12500 SFAs (spent fuel assemblies) from VVER-1000 reactors and 4000 SFAs from VVER-440 reactors for the period of 100 years.

On 09.02.2012 by the Law of Ukraine № 4383-VI "On Spent Nuclear Fuel Handling with regard to Location, Design and Construction of the Centralized Spent Fuel Storage Facility for VVER reactors", the Verkhovna Rada of Ukraine took a decision with regard to CSFSF siting on the territory of the Exclusion Zone, as well as CSFSF design and construction.

On 30.04.2013, the State Nuclear Regulatory Committee of Ukraine agreed the document of NNEGC "Energoatom" "Task Order for modification of the SNF shipment technology from VVER-1000 reactor (B-320) to ensure its transportation to the CSFSF".

On 23.04.2014, with the Decree №399-р of the Cabinet of Ministers, NNEGC "Energoatom" received a permission for development of the land survey project with regard to siting of lands with the total area of 45.2 ha, located between the former villages Stara Krasnytsya, Buryakivka, Chystogolivka and Stechanka of Kyiv Oblast in the exclusion Zone, that were contaminated due to the Chernobyl catastrophe. The lands shall be allocated to the specified enterprise for the permanent usage and the target application will be changed for construction of the CSFSF and railway access road.

On 22.07.2015, the State Nuclear Regulatory Committee of Ukraine agreed the updated "Licensing plan for establishment of the centralized spent nuclear fuel storage facility" (PN-Д.0.46.527-15), developed to replace PN-Д.0.46.527-11.

On 23.07.2015, the State Nuclear Regulatory Committee of Ukraine agreed the proposals of the operating company with regard to the content and scope of the Explanatory Note "Construction Plan for the Centralized Spent Fuel Storage Facility for VVER reactors of Ukrainian NPPs" and provided recommendations as for the CSFSF construction.

On 12.10.2015, with the Order № 926 of NNEGC "Energoatom", the Steering Committee was established with regard to implementation of the Holtec technology for SNF handling at Rivne, Khmelnitskiy and South Ukraine nuclear power plants, which included the representative from the State Nuclear Regulatory Committee of Ukraine and State Scientific and Technical Center.

On 05.10.2016, by the Directive № 721-р of the Cabinet of Ministers, the land plot with the area of 45.2 ha was extracted from the permanent use of the State Agency on Exclusion Zone Management and assigned to the permanent use by NNEGC "Energoatom" for construction and operation of the Centralized Spent Fuel Storage Facility.

On 03.11.2016, by the Directive №08 of the SNRIU Board, the Conclusion was agreed with regard to the state review of the preliminary safety analysis report for CSFSF.

On 07.12.2016, NNEGC "Energoatom" received registration of declaration № ІУ030163421149 for beginning of preliminary works.

On 07.06.2017, the Cabinet of Ministers by Decree №380-р approved the project "Construction of the centralized storage facility for spent nuclear fuel of VVER reactor type".

On 29.06.2017, the State Nuclear Regulatory Inspectorate of Ukraine issued NNEGC "Energoatom" with the license for implementation of activity at the phases of lifecycle of "construction and commissioning of the nuclear facility (centralized spent fuel storage facility for VVER reactor type)".

On 09.11.2017, the special ceremony was held with regard to the beginning of CSFSF construction in the urban-type village Buryakivka (Exclusion Zone)

In addition, the following tasks were accomplished by SNRIU in 2017:

- review of 15 packages of the technical specifications for safety important equipment, with the preliminary comments provided to "Energoatom";
- preliminary agreement was made, following the state review of nuclear and radiation safety of three technical specifications;
- state review and submittal of the preliminary comments to three programs on acceptance tests at the manufacturer's factory;
- review of series of Technical Solutions related to the Holtec technology on SNF preparation for storage in CSFSF to be implemented at the Ukrainian NPPs;
- participation in the meetings of the Steering Committee with regard to the Holtec technology on SNF preparation for storage in CSFSF to be implemented at the power units of Rivne, Khmelnitskiy, South Ukraine NPPs.

2.8.1 Treatment of High-level Waste of Radioactivity Formed After Processing of Spent Nuclear Fuel of SS Rivne NPP

According to the Agreement between the Government of Ukraine and the Government of the Russian Federation on the scientific and economic cooperation in the nuclear energy field as of 14.01.1993 and contractual obligations of NNEGC "Energoatom", the spent nuclear fuel of VVER reactors is transported for the technological storage and reprocessing to the entities of the Russian Federation (Federal State Unitary Enterprise (FSUE)"Mayak Production Association and Federal State Unitary Enterprise "Mining and Chemical Plant"). To Ukraine, the products of reprocessing are expected to be returned in the form of vetrified high-level waste (HLW)[1], obtained after SNF reprocessing. The waste will be returned to Ukraine in compliance with the conditions and terms specified in the relevant contracts between the entities of the Parties.

Starting from 1993, the SNF of Rivne NPP VVER-440 is transported to the FSUE "Mayak" for storage and reprocessing.

Amount of the vetrified HLW that returns to Ukraine is calculated on the agreement by the regulatory authorities of Ukraine and Russia in accordance with the document СОУ-Н ЯЕК 1.027:2010 "Methodology for calculation of high level radioactive waste that returns to Ukraine after storage and reprocessing of SFAs of VVER-440" (put into effect by the Order of the Ministry of Fuel and Energy of Ukraine as of 25.08.2010 № 332).

[1] After reprocessing of the SNF from the VVERs, the valuable products of processing also have to be returned (oxides of uranium, plutonium and neptunium), solid HLW (structural elements of SFAs, residues of cladding of heavy and light fraction) and cemented intermediate-level waste.

At present, the parties are in the process of agreement of the Technical Conditions for the vitrified HLW from the reprocessed SNF of Rivne NPP VVER-440, that will be returned to Ukraine, and the passportization procedure and Quality Assurance Program for SNF processing.

Construction of the storage facility at the site of “Vector” Complex, for interim long-term storage (100 years) of the vetrified HLW from the reprocessed SNF of VVER-440, is planned in Task 3 of “National Target Environmental Program on Radioactive Waste Management” approved by the Law of Ukraine № 516-VI as of 17.09.2008.

In 2012, the Feasibility Study (FS) was developed with regard to construction of the storage facility for the interim storage of the vetrified HLW that are returned from the Russian Federation after processing of the spent nuclear fuel from VVER-400 reactors of the Ukrainian NPPs. The FS received a positive expert report after the State Construction Review. The state review showed that the Technical Solutions accepted in the FS are in compliance with the current construction norms and design rules applied in Ukraine, as well as in compliance with the requirements to the nuclear and radiation safety. Since the FS, due to some objective reasons, was not approved in the corresponding ministries and government departments, the activities are being performed now with respect to its repeated state review.

In addition, a full package of the design and estimates documentation (“draft” stage) was developed, which is also submitted for the state construction review.

According to the design, the lifetime of the storage facility is 15 years for the mode of acceptance and HLW preparation to storage and 100 years for the mode of interim storage and off-loading of HLW (for disposal). The capability of reverse HLW uploading is considered when the interim storage finishes in the facility.

The construction will be conducted in two queues (it is planned to have two commissioning complexes, the first one for 350 m^3, and the second one for 200 m^3).

The decision on locating the HLW at the site of “Vector” Complex has several advantages:

- a closely situated operating railway;
- a quite developed network of roads;
- availability of labor resources;
- possibility to use an existing infrastructure of the first queue of the “Vector” Complex, engineering and telecommunication systems, systems of radiation control and environmental monitoring.

The spent nucler fuel of Khmelnitskiy, Rivne and South Ukraine NPPs with VVER-1000 (until 2001 Zaporizhzhya NPP as well) is transported for the temporary storage with further reprocessing to the Federal State Unitary Enterprise "Mining and Chemical Plant” (Krasnoyarsk, Russian Federation). At present, reprocessing of the SNF from VVER-1000 of Ukrainian NPPs is not performed in the Russian Federation. Returning of the products of reprocessing to Ukraine, including HLW, can start from 2025.

Two documents agreed and approved by the Russian Federation and Ukraine must define the amount and nomenclature of the products after reprocessing of SFAs from VVER-1000. They are Methodology for defining the amount of high-level waste and products of reprocessing, which return to Ukraine after technological storage and reprocessing of the batch of SFAs from VVER-1000, and Technical Conditions for products after reprocessing of SFAs from VVER-1000.

The radioactive waste after reprocessing of SNF from VVER-1000 has to be shipped to the facilities for interim storage with further transition for disposal in the deep geological formations. At present, such facilities in the infrastructure of the operating RW management entities is absent in Ukraine.

Construction of the modern high-technology, centralized spent nuclear fuel storage facility, designed for storage of the SNF from South Ukraine, Rivne and Khmelnitskiy NPPs, will enable to resolve the problem with the spent nuclear fuel handling in the long-term perspective. This is confirmed by the positive experience of the dry spent nuclear fuel storage at Zaporizhzhya NPP.

The government of Ukraine issued the Directive №399-р as of 23.04.2014 on giving the permission to NNEGC "Energoatom" for development of the land survey project as for allocation of the land plot for storage of the spent nuclear fuel from the nuclear power plants of Ukraine. NNEGC "Energoatom" is assigned as the operator of the nuclear facility - centralized facility for storage of the spent nuclear fuel from VVER reactors of Ukrainian NPP (which is part of the complex for spent nuclear fuel handling at the specialized entity "Chernobyl NPP").

According to the estimations, the expenses for construction and operation of the CSFSF will be almost four times less than the total costs spent by Ukraine today for transportation of SNF to Russia; investments into the CSFSF will be compensated in less than four years of the facility operation.

Design, production and supply of the SNF handling equipment will be accomplished in line with the contract with "Holtec International".

Commissioning of the CSFSF will be performed by the stages, starting from 2018. This will allow Ukraine to refuse from the SNF shipment to the Russian Federation, which will significantly increase the energy safety of Ukraine and eliminate risks of shutting the power units down due to overloading of the spent fuel pits.

2.9 Project Decisions on Radioactive Waste Treatment

During the plant operation, it is inevitable to have the production waste: solid, liquid and gaseous.

Production of the electricity at the nuclear power plants comes along with generation of radioactive waste in the course of the main technological process, as well as during routine and maintenance operations. The stable development of the nuclear energy field in the country requires safe management of the radioactive waste at all phases of waste formation and existence. The RW management system is an important component in the entire safety systems while using nuclear energy.

The main principles of the RW management at the NPP is minimization of waste formation and interaction between all phases – from formation to disposal.

The strategy on RW management in Ukraine, approved by the Cabinet of Ministers of Ukraine and National Target Environmental Program for Radioactive Waste Management approved by the Law of Ukraine, specifies withdrawal and processing of radioactive waste accumulated during plant operation. It should be done through establishment of the infrastructure for radioactive waste specification, conditioning and packaging using the method applicable for its further transportation for storage and/or disposal.

Radioactive waste management at Rivne NPP is accomplished in line with:

- Law of Ukraine "On radioative Waste Management", dated 30.06.1995 № 256/95 –ВР;
- Law of Ukraine "On Usage of Nuclear Energy and Radiation Safety" as of 08.02.1995 № 40/95 – ВР;
- Law of Ukraine "On National Target Environmental Program for Radioactive Waste Management" as of 17.09.2008 №516-VI;
- Radioactive Waste Management Strategy in Ukraine, approved by the directive of the Cabinet of Ministers of Ukraine, as of 08.2009 № 516- VI;
- Integrated Program for Radioactive Waste Management in NNEGC "Energoatom" ПМ-Д.0.18.174-16, put into force with the order as of 12.10.2016 №927-р.

The national regulatory authorities for radioactive waste management are the State Nuclear Regulatory Inspectorate of Ukraine and the Ministry of Health Protection of Ukraine, the national governing body is the Ministry of Energy and Coal Industry of Ukraine.

The State Special Enterprise "Central Radioactive Waste Management Enterprise" (CRWME), the storage facilities operator, within the State Agency of Ukraine on Exclusion Zone Management (SAUMEZ) is responsible for acceptance and storage (if required, long-term storage) of the conditioned

RW. Currently, NPP RW shipping for the long-term storage or disposal at the facilities is not accomplished, but activities were initiated on RW preparation for shipping to the special enterprise.

Planning of the activities on radioactive waste management at RNPP is accomplished in accordance with "Integrated Program for Radioactive Waste Management in NNEGC "Energoatom" ПМ-Д.0.18.174-16. The program specifies main areas and a list of activities related to radioactive waste management in NNEGC "Energoatom". These activities are: minimization of RW generation, improvement of the current RW management systems at NPPs sites, construction of complex lines on RW processing for its preparation to transference to the ownership of the state, provision the plant with the equipment for RW storage, harmonization and improvement of the regulatory framework in the area of RW management.

During planning the activities in the field of radioactive waste management, NNEGC "Energoatom" applies the following main principles:

– ensure corresponding safety level in the field of radioactive waste management;

– minimization of generated RW volumes during plant operation;

– selection of optimal RW treatment technologies considering such factors as:

- ✓ individual and collective radiation doses of the personnel;
- ✓ cost of RW processing;
- ✓ amount of generated RW;
- ✓ duration and cost of short-term RW storage;
- ✓ requirements to the end product accepted for disposal;
- ✓ capability of using selected methods of RW processing both during plant operation and its decommissioning;

- ensure capability of processing, immobilization, and temporary storage of RW generated during extended lifetime of the plant;

- application of the advanced technologies during RW processing and immobilization to provide for RW safe transportation and disposal;

- ensure quality of all processes and works related to the radioactive waste management at the plant.

The main activity on improvement of the radioactive waste management system at Rivne NPP is construction of a complex for the radioactive waste processing (CRWP). The Program ПМ- Д.0.18.174-16 indicates commissioning of CRWP in 2018. A separate permission was obtained from the SNRIU for operation of the new facility of the infrastructure - radioactive waste processing complex.

SNRIU ensured regulatory follow-up of the activity, review and agreement of the complex testing programs and corresponding technical solutions regarding putting of CRWP into trial operaiton at Rivne NPP within other process facilities:

- extraction of SRW from the SRW storage compartments;
- SRW sorting and fragmentation;
- SRW supepressing;
- SRW cementation;
- SRW activity measurement;
- metal decontamination;
- spent oil treatment.

Implementation of the RW complex will allow for:

- reduce the amount of accumulated SRW and waste generated during operation;
- condition the SRW to ensure its safe long-term storage and disposal;
- obtain additional free volumes in the existing storage facilities for the short-term storage of the containers with SRW under the ownership of the state.

RW management at Rivne NPP is accomplished like at any other operating NPP in compliance with the principle flow chart presented below at Figure 2.5.

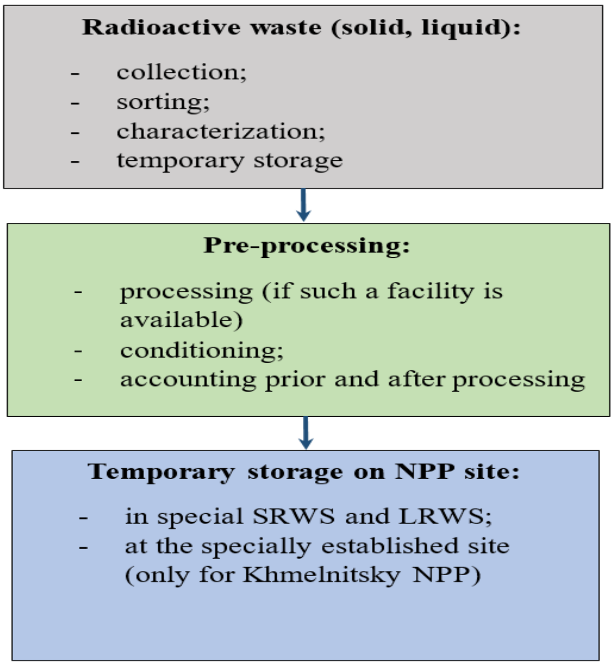

Figure 2.5 Principal flow chart for radioactive waste management at NPP

The condition of RW management at Ukrainian NPPs is characterized with absence of completed technological cycle from the processing to obtaining of the end-product, acceptable for further long-term storage or disposal.

At present, due to unreadiness of the Operator of CRWME storages, which is under subordination to the State Agency of Ukraine for the of Exclusion Zone Management, with regard to receiving the NPP RW for its long-term storage and disposal, RW transfer to this specialized enterprise is not accomplished.

2.9.1 Solid Radioactive Waste Treatment During Plant Operation

The solid radioactive waste (SRW) generates in the process of normal plant operation, during maintenance and repair activities and during accidents.

The main source of SRW generation is maintenance and repair activities at the power units, which include:

- operation of the plant components, buildings and facilities;
- reconstruction and modernization of equipment;
- decommissioning of components, including replacement of steam generators;
- decontamination of equipment, rooms, buildings and facilities of NPP;
- equipment maintenance and repair;
- activities on mounting, dismantling and replacement of thermal insulation;
- construction and reconstruction works;
- replacement of worn and spent part of equipment, consumables;
- replacement of worn work clothes, personnel protection means;
- implementation of sanitary and health protection measures in the Sanitary protection zone.

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 RW processing at the burning facility;
- reactor internal devices and elements of reactor hall systems.

Transportation of SRW containers to the SRW storage located in the special building of Rivne NPP site is performed using special transport, as shown on Figure 2.6.

Figure 2.6. Special vehicle OT-20 on the chassis ISUZU

SRW distribution by types of treatment is presented on Figure 2.7.

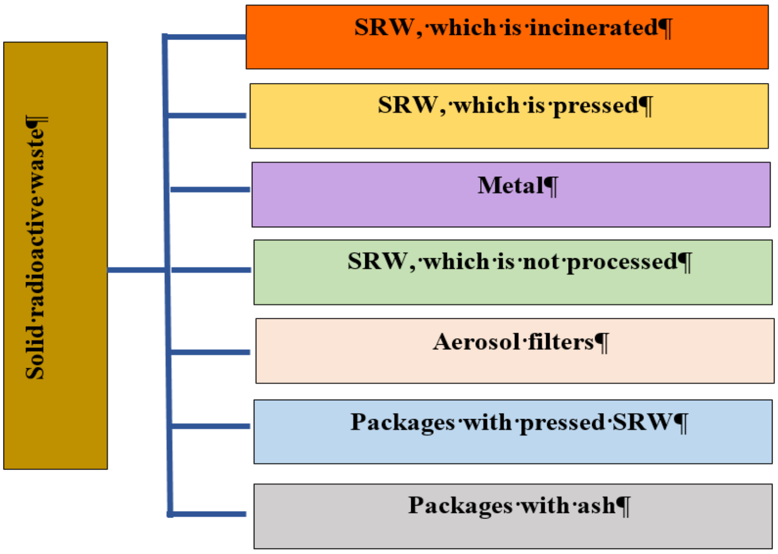

Figure 2.7. SRW distribution by types of treatment

Solid RW are classified by the following types:
- Short-lived ($T_{1/2}$ – to 10 years);
- Medium-lived ($T_{1/2}$ - to 100 years);
- Long-lived ($T_{1/2}$ – over 100 years).

SRW management at RNPP includes:
- waste collection into plastic bags at the places of waste formation;

- primary sorting of waste with fragmentation (is necessary);
- waste transportation from the places of temporary collection;
- SRW sorting by its activity to low-level, intermediate-level and high-level activity;
- SRW transportation by special vehicle OT-20 from the places of temporary collection into special building № 2 (for power units 3, 4);
- SRW acceptance by the personnel of the decontamination and RW processing departments for temporary storage;
- SRW loading by the personnel of the decontamination and RW processing departments into cells of special building №1 of SRW storage (for power units 1, 2) and special building № 2 of SRW storage (for power units 3, 4).

According to all SRW, sorted by types and classification, are allocated for temporary storage in the SRW storage in the special building at Rivne NPP site.

The diagram of the SRW management at Rivne NPP is provided on Figure 2.8.

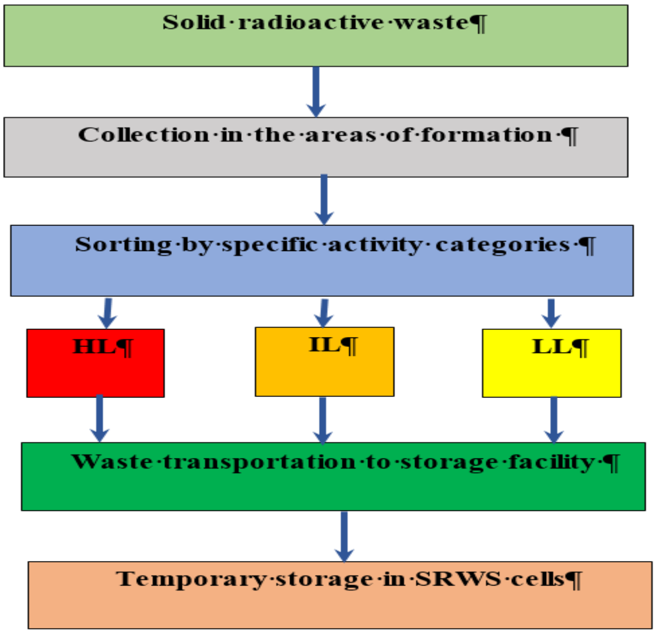

Figure 2.8. Diagram of the SRW management at Rivne NPP

All SRW, sorted by types and classified by activity, are allocated for temporary storage in the SRW storages in the special building at Rivne NPP site.

At the RNPP's Complex for radioactive waste processing (CRWP), which was jointly constructed with the European Commission under the framework of TACIS International Technical Assistance Program, the first phase of complex testing has been completed. Next in turn is the second phase, so called "hot" tests with the actual radioactive waste. The successful completion of these tests will become the beginning of operation of the first RW processing complex at the operating nuclear power plants of Ukraine.

This complex consists of seven installations. Four of them: extraction (ONET, France); SRD sorting and fragmentation (Nukem, Germany); superpressing Megane 15 (Nukem, Germany) and activity measurement HS 541 (Envinet, Check Republic) were provided within the TACIS project. The rest three installations: cementing (Envitek, Ukraine), oil purification and metal decontamination (Consortium Specenergetikos, Lithuania-Ukraine) were implemented by NNEGC "Energoatom"'s funds. In May, 2018 "cold" tests were successfully conducted on the RW simulators at CRWP.

Figure 2.9. Exterior of CRWP building

Implementation of the CRWP will increase the safety level at Rivne NPP by application of the advanced innovative technologies on radioactive waste treatment, thus promoting the RW management system of Rivne NPP to the new, modern international level.

Figure 2.10. CRWP equipment

In February of this year, the first stage of complex ("cold") tests of the additional systems and all seven installations of CRWP were completed at Rivne NPP. The tests were conducted with participation of the plant personnel and representatives of the SNRIU. The testing results were documented in the report, which was submitted to the SNRIU. In addition, the Special Permit was obtained for the second phase of "hot" tests.

The successful results of "hot" tests will transfer the facility gradually to the commercial operation. "The complex is intended for processing of "historical" low-level RW, which accumulated in the solid RW storage at the Rivne NPP site", the current waste, which formed during plant operation and the waste, which will accumulate during decommissioning of the power units of the NPP. The end product of processing will comply with the requirements of waste acceptance for disposal at the special RW treatment facilities.

Before the radioactive waste was shipped to the CRWP, the Rivne NPP personnel and guests had a chance to see the unique installation, its process line, obtain answers from the experts who will further operate the equipment of the RW processing complex.

The modern process equipment meets the high European standards. The activity implemented at CRWP of Rivne NPP will allow not only reduce the volumes of waste generated during plant operation but also increase safety and environmental compatibility of the nuclear power industry in general and preserve the environment.

The permission was issued on June 1, 2018 with duration period until the end of the lifetime of "Power Unit 4 of Rivne NPP". The decision on its issuing was taken by SNRIU based on the results of the state expert review of the safety justification documents related to implementation of the declared activity, and inspection conducted by SNRIU commission to study the capability of the operator (NNEGC "Energoatom") to accomplish works related to commissioning of the Complex for RW processing at Rivne NPP.

2.9.2 Liquid Radioactive Waste Treatment During Plant Operation

During plant operation, the liquid radioactive waste are generated in the process systems of the reactor department and auxiliary building as a result of the contact of water with fuel elements, contamination of oil systems, and operation of special water purification systems.

LRW are mainly met in the form:

- primary coolant uncontrolled leakages;
- contaminated oils;
- spent ion-exchange resins of the SWP system;
- waters that generate after decontamination;
- sewage waters from laundry hot shower drains;
- waters from hydraulic discharge of the filters;
- bottoms/residue;
- spent filtering materials of SWP system;
- SWP sludge.

Rivne NPP operates the transport bridge, which allows transmission of the drain waters and decantate of bottoms/residue from the auxiliary building 1 into auxiliary building 2. The spent filtering materials (SFM) are transported by the hydro-transportation system into the tanks of RW storage (RWS), where they are stored under the layer of water.

The diagram of LRW management system is presented on Figure 2.11.

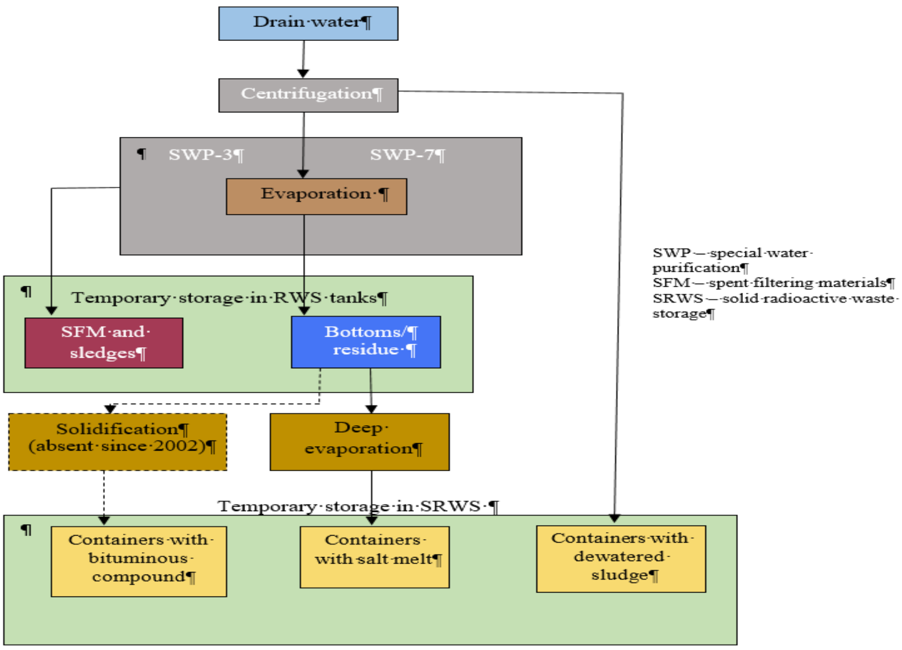

Figure 2.11. Diagram of LRW management system at Rivne NPP.

The analysis of the sources and amount of generated drains was conducted. Based on the analysis results, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, “Measures on minimization of liquid radioactive waste at Rivne NPP” were developed, which result in significant reduction of drain waters.

According to ДСП 6.177-2005-09-02 the liquid radioactive waste include:

- solutions of non-organic substances;
- pulps of filter materials;
- salt melt;
- organic liquids (oils, solvents), which have the following radiation characteristics:

- content of particular radionuclides that exceeds the allowed concentration established for water consumed by the population for drinking and household;

- content of radionuclide mixture is such that the total of ratio of specific activity of each individual radionuclide to the corresponding value is greater than one.

During normal plant operation, the equipment is collected and stored in the special tanks of contaminated environment (effluents) – drain waters. Radioactive liquids and drains are obtained from the equipment of the reactor departments, and are generated as a result of operation of the special water purification system (SWP), decontamination of equipment and special protection clothes, sanitary and household discharge, laboratory discharge etc.

Following the procedure of treatment and evaporation at the SWP drain water evaporators, the liquid concentrate of salts is generated – evaporator residue/bottoms. The residue is stored in the special storage of liquid radioactive waste in the metal leak-tight tanks made on corrosion resistant steel, equipped with automated system indicating the LRW level and alarm system in case of a leakage. To exclude accidental LRW leakage into the environment, all tanks are placed in the reinforced-concrete rooms, encased with the sheets made of corrosion resistant steel up to the elevation of accidental spillage of tanks.

From the RWS the residue/bottom is sent to the deep evaporation facility for processing, where more concentrated product is formed, which is placed to the container (with volume of 200 dm^3) and it gets into a solid phase during the cooling process. The containers with the salt melt (the product of the residue processing at the deep evaporation facility) is transported for the temporary storage to the solid radioactive waste storage facility.

The photo of 200-litre containers with the salt melt SM is presented on Figure 2.12.

Figure 2.12. Containers with the salt melt

The analysis of the sources and amount of generated drains was conducted. Based on the analysis results, the correlation of sources was identified for LRW of each power unit, auxiliary building, and Rivne NPP in general. In addition, “Measures on minimization of liquid radioactive waste at Rivne NPP” were developed, which result in significant reduction of drain waters.

The general diagram of the drain water and LRW treatment is presented on Figure 2.13.

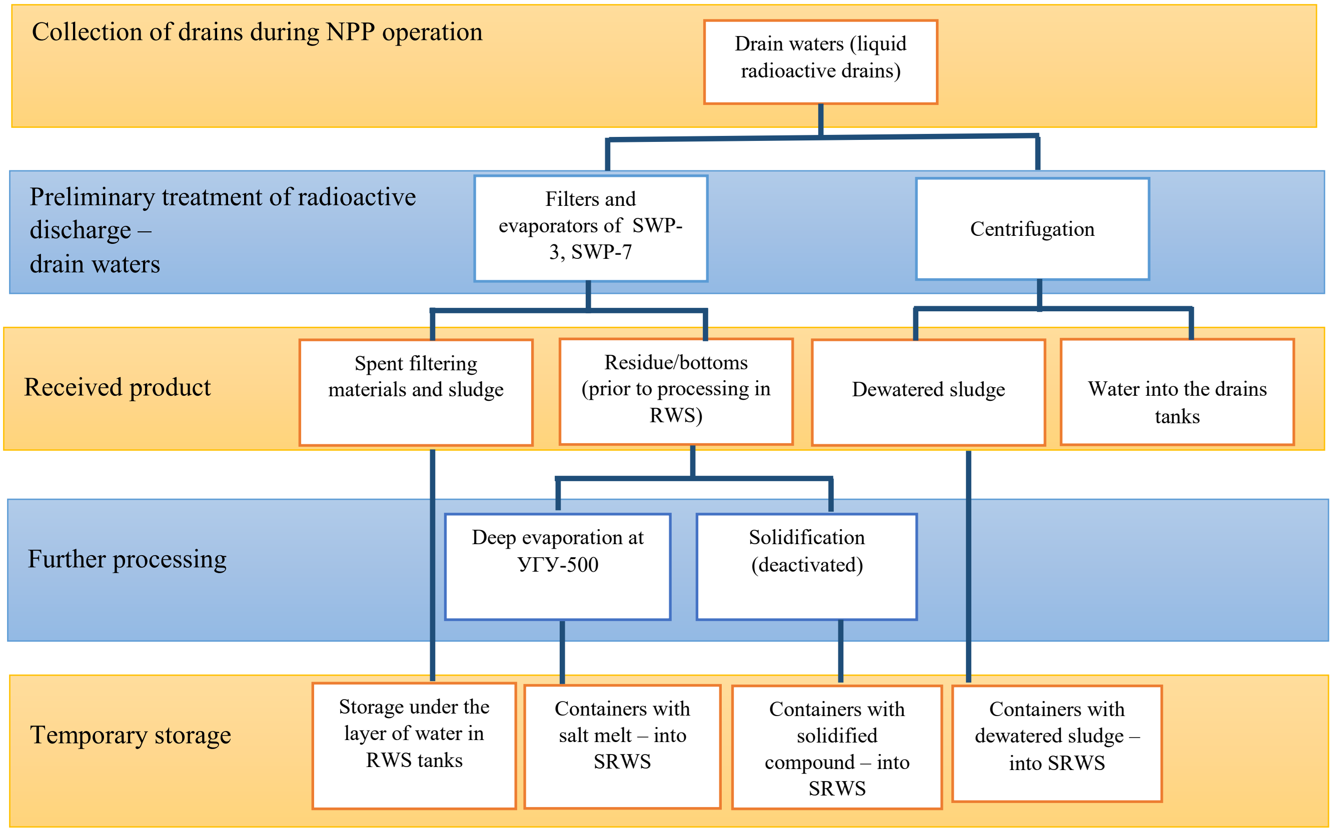

Figure 2.13. Diagram of drain waters and LRW treatment at Rivne NPP

List of available facilities/installations for LRW treatment at Rivne NPP are presented in Table 2.6.

Table 2.6. LRW treatment facilities at Rivne NPP.

Facility/installation	Main function	Design capacity
Evaporators of the drains treatment system of SWP-3, 7	Evaporation of drain waters	6 m^3/year
Deep evaporation facility (УГУ1-500М)	Deep evaporation of drain waters	500 dm^3/year
Solidification facility (with rotor film solidifier РБ-800)	Solidification of residue/bottoms	150 dm^3/year
Centrifugation facility	Purification of drain waters from mechanic residues	1.5 – 7 m^3/year

Accumulation of the liquid radioactive waste in the storage facilities at Rivne NPP as of 31.12.2017 is presented on Figure 2.14.

During 2017, the following volumes were accumulated at Rivne NPP:
- 380 m^3 residue/bottoms;
- 3.6 m^3 of spent filtering materials;
- 5.0 m^3 of dewatered sludge (25 containers);

- 77. 6 m^3 of salt melt (388 containers).

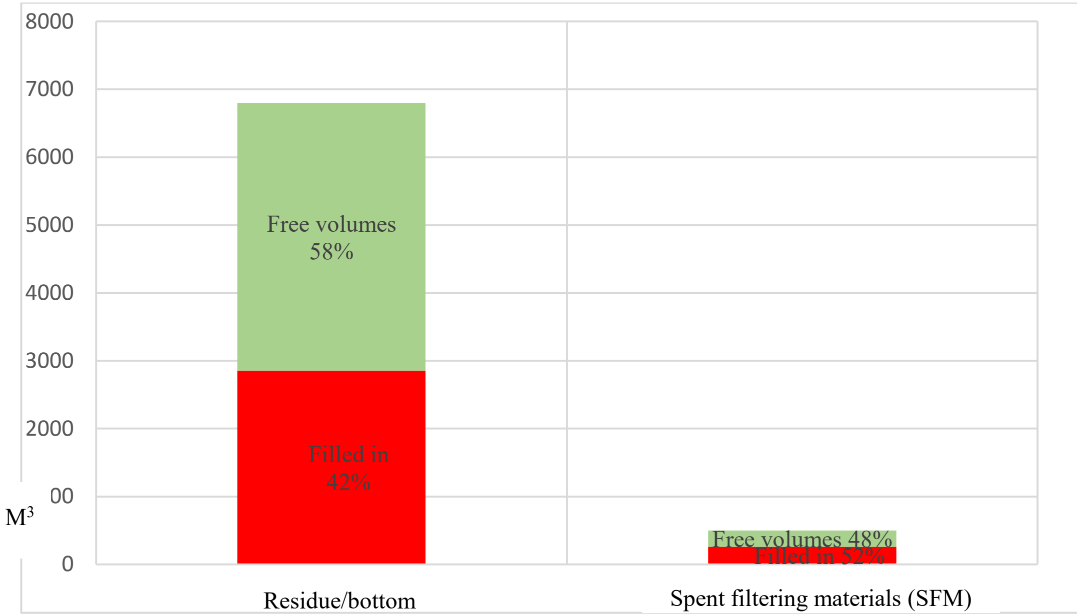

Figure 2.14. LRW accumulation in RWS at Rivne NPP

The radioactive waste management at Ukrainian NPPs is characterized with absence of the completed technological cycle from the RW processing to receiving of the end-product, suitable for further long-term storage or disposal. For this reason, the interdepartmental working group was created for solving the issues on RW optimization strategy in Ukraine, which included the representatives from NNEGC "Energoatom", NPPs, STC, SNRIU, Ministry of Energy and Coal Industry of Ukraine, KIEP, Ministry of Health Protection of Ukraine, SAUMEZ, ChNPP (Directive by NNEGC "Energoatom" as of 21.01.2015 № 60-р. It was agreed that at the first phase of the working group's work it is reasonable to focus efforts on the improvement of the radioactive waste management system in Ukraine. To resolve the existing issues, the group developed "Extended Plan on Primary Actions for NPP RW Optimization System" and got its approval on 09.03.2016. The issues related to further treatment of the SFM, salt melt, dewatered sludge are resolved with the efforts of the specified working group.

The following measures are in place: control of meeting the LRW formation and drain waters controlled levels, established in "Technical Specifications for radioactive waste formation and shipment to the storage facilities of Rivne NPP" 175-7-Р-ЦД, continuous control of LRW shipment to RWS, implementation of the minimization measures related to residue/bottoms accumulation, that reduce due to residue processing at the deep evaporation facilities. Implementation and development of the SRW management system at Rivne NPP.

Having stable operation of the deep evaporation facilities and activities implemented as per the schedule of "Comprehensive program for radioactive waste management at NNEGC "Energoatom" ПМ-Д.0.18.174-16, there will be sufficient free volumes in the RWS to ensure safe operation of power units of Rivne NPP, both during design and extended lifetime of the plant.

2.10 Non-radioactive Waste Treatment

The information, received from all the plant divisions with regard to volumes and types of non-radioactive waste to be transmitted to the specialized utilization (extraction) facility, was provided to SE "Storage Facilities" (SE SF) of NNEGC "Energoatom" for development of the plans. Transportation of the secondary material to SE SF during the reporting period was made on the basis of "Provisions on arrangement of work with the secondary material" ПЛ-Д.045.541-15.

In 2017, the ecological and chemical laboratory of the environmental protection service of Rivne NPP (according to the registration certificate № R-4/11-57-5 as of 30.05.2018) performed monitoring of the state of groundwaters and soils in the waste extraction locations. Monitoring was performed in line with the approved schedule of analytical control of the environmental state around the sludge collector and landfill of industrial and construction waste.

The facility has "Instruction on non-radioactive waste management at Rivne NPP" 083-1-I-СОНС. The persons, responsible for waste management issues, were designated in the order № 436 as of 31.05.2017.

On a yearly basis, according to the paragraph 15 of "Procedure for keeping records on the locations of waste formation, treatment and utilization" approved by the Directive of the Cabinet of Ministers № 1360 as of 31.08.1998, the information is submitted to the Rivne Oblast Administration with regard to the changes in the registration card and changes in the passports of waste extraction locations: sludge collector and landfill of industrial and construction waste.

According to the paragraph 19 of "Procedure for keeping records on the waste extraction locations" approved by the Directive of the Cabinet of Ministers № 1216 as of 03.08.1998, based on the results of surveillance and control measurements, the passports of the sludge collector and landfill of industrial and construction waste are reviewed annually. To control the waste extraction location (WEL) at Rivne NPP, the State entity "Rivne Oblast Laboratory Center" of the Ministry of Health Protection of Ukraine conducted the instrumentation and laboratory measurements of the atmospheric air pollution in the third quarter of 2017 in the waste extraction locations. The analysis of water, soil and air indicators show that WEC operation is performed in accordance with the requirements of the environmental legislation and does not cause damage to the environment.

Changes in the passports are agreed with the Department of Ecology and Natural Resources of Rivne Oblast Administration, which are recorded in the relevant documentation.

Waste management is accomplished by the entity in compliance with the regulatory documents and production instructions.

The solid household waste was transferred to the landfill of the municipal company of the town. In accordance with the document ПЛ-Д.0.45.551-13 "Provision on interrelation of SE "Storage Facility" with NPPs, SE "Atom Complekt", SE "Atomproerkengineering" and In-service Inspection Department of NNEGC "Energoatom"", the waste of used luminescent lamps, monitors, used batteries and tires were transmitted through SE SF to other specialized entities.

The used oils and lubricants (motor, turbine, industrial, transformer), used storage batteries, broken glass, metal scrap and waste paper (except for the technical documentation, accounting and other documents that must be destructed/shredded) were transmitted to Rivne department of SE "Storage Facility", as secondary materials.

Due to putting into force the law of Ukraine № 1193-VII "On introducing changes into some legal acts of Ukraine regarding reduction of number of documents of permissive character" as of 09.04.2014, issuing of permits for activities and operations in the waste management field shall be accomplished in accordance with the requirements of associated Orders (Directives) following their approval by the Cabinet of Ministers of Ukraine. Currently, the corresponding Order has not been approved (clarification letter of the Department of Ecology and Natural Resources of Rivne Oblast Administration №2560/02/2-07/15 as of 09.12.2015).

The dynamics of the non-radioactive waste accumulation in the sludge collector and polygon/landfill of Rivne NPP is presented in Table 2.7.

Table 2.7. Dynamics of the non-radioactive waste accumulation in the sludge collector and polygon/landfill of Rivne NPP

	2011	2012	2013	2014	2015	2016	2017
Sludge collector, thous. tons	139.154	161.746	184.227	161.683	132.664	116.978	133.636
Polygon/landfill, thous. tons	14.164	19.727	25.133	29.113	32.794	36.789	42.193

2.11 Sanitary Protection Zone and Observation Zone of SS Rivne NPP

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

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

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

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

Sanitary protection zone SPZ is an area around NPP where the level of the public exposure can exceed the dose limit quota for category C.

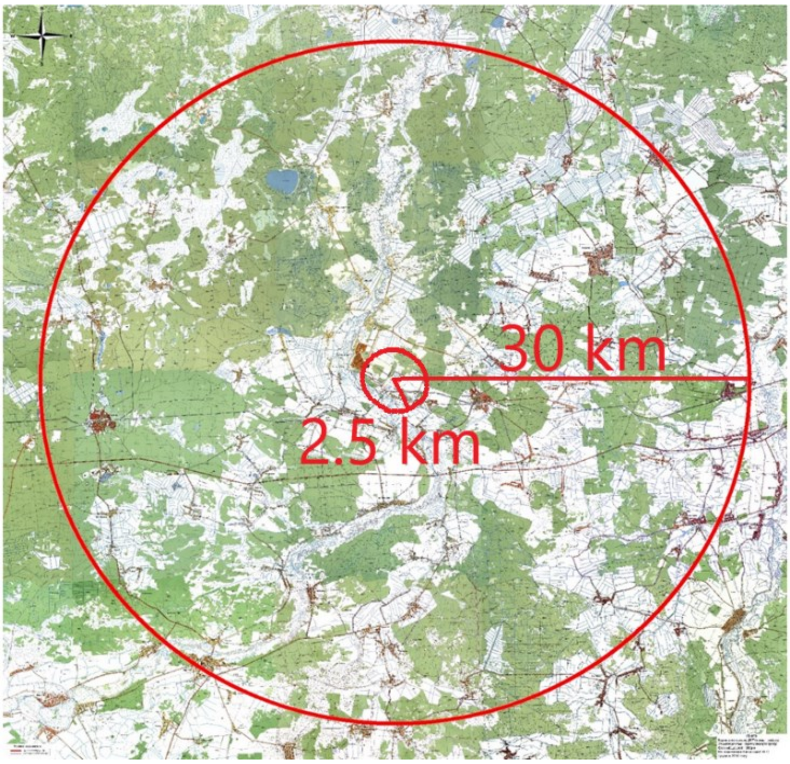

Figure 2.15 Sanitary protection zone and Observation Zone of Rivne NPP

Within the Sanitary protection zone it is prohibited to live, the restrictions on production activity not related to NPP are established, and radiation monitoring is carried out.

The size of SS Rivne NPPSPZ is 2.5 km, and OZ area is 30 km.

The size of SPZ and OZ are officially introduced in accordance with SS Rivne NPP document, namely the “Decision on the size and boundaries of Sanitary protection zone and Observation Zone of Rivne NPP” No. 132-1-Р-11-ЦРБ.

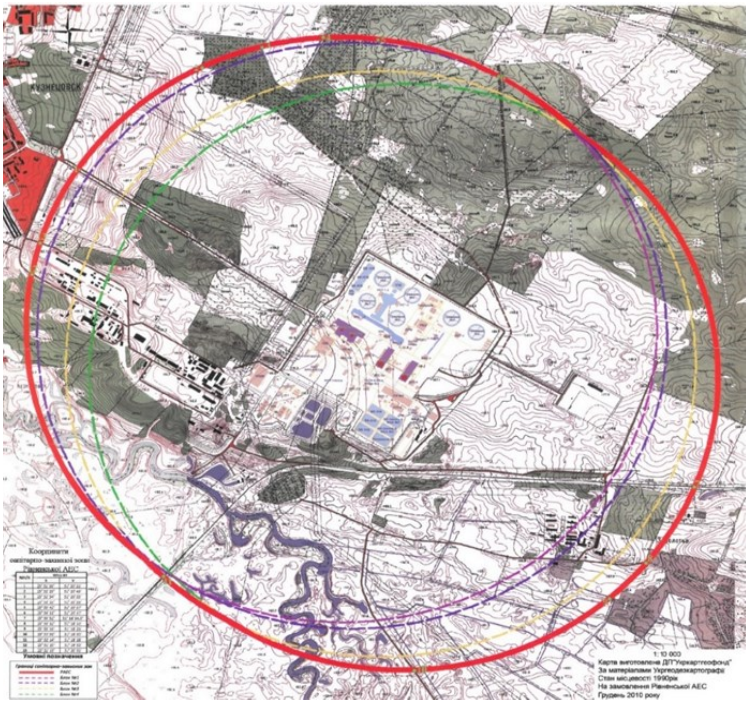

Figure 2.16. The boundary of SS Rivne NPP SPZ and the boundaries of SPZ of power units 1, 2, 3, and 4.

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

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

The boundaries of Sanitary protection zones are established around each power unit. Figure 2.16 shows the boundaries of Sanitary protection zones of power units 1, 2, 3, 4 and the boundary of Rivne NPP Sanitary protection zone.

2.12 Radiation State of Rivne NPP Location During the Pre-commissioning Period

From 1976 to 1979, the radiation state of the environment was studied in the area of the construction activities for Rivne NPP prior to the plant commissioning. This refers to as studying of “zero background”. The results of this research were used for assessment of the radiological impact of RNPP power units onto the environment during the entire period of plant operation.

According to the data of “zero background”:

- specific activity of aerosols in the atmospheric air was in the range:
  ^{137}Cs – 1.11E-05÷5.92E-05 Bq/m^3; ^{90}Sr – 1.48E-05÷1.11E-04 Bq/m^3;
- total beta-activity of the atmospheric precipitations was in the range:
  7.4E+00÷3.29E+02 (Bq/m^3)/month;
- content of ^{137}Cs in the pines was in the range:
  7.2E+00÷1.7E+01 Bq/kg; ^{90}Sr – 2.96E+01÷1.05E+02 Bq/kg;
- content of ^{137}Cs in the plants was in the range:
  2.55E+00÷9.55E+01 Bq/kg;
- ground surface contamination with ^{137}Cs prior to RNPP commissioning was in the range:
  4.44E+02÷5.07E+03 Bq/m^2; ^{90}Sr – 1.85E+02÷2.92E+03 Bq/m^2;
- specific activity of ^{137}Cs in the milk prior to RNPP commissioning was in the range:
  6.3E-01÷6.6E+00 Bq/l;
- specific activity of ^{137}Cs in the vegetables prior to RNPP commissioning was in the range:
  1.5E-02÷2.0E+00 Bq/kg;
- specific activity of ^{137}Cs in the grain crops prior to RNPP commissioning was in the range:
  8.1E-01÷1.18E+00 Bq/kg.

3 IMPACT ON ENVIRONMENT OF SS RIVNE NPP SITE

3.1 Impact on Surface and Ground Waters

3.1.1 Radiation Impact on Surface and Ground Waters

Three points are established to conduct monitoring of impact of liquid discharges from Rivne NPP into the Styr River:

- Mayunychi Village – 10 km up the river stream;
- below the drain point of industrial and storm sewage system;
- Sopachiv village – 10 km down the river stream.

The sampling is performed once per a decade and then the specific activity of natural and man-made radionuclides is determined using semi-conductive γ-spectrometers. The tritium activity is determined by the liquid scintillation radiometer Tri-Carb 3170 TR/SL.

The concentration of radionuclides is thousand times lower in the Styr River than the allowed radionuclides concentration in portable water.

The bottom sediments, weed and fish of the Styr River are sampled in August every year. The samples go through preliminary verification and γ-spectrometric analysis. The objects of the Styr River have no man-made radionuclides except for ^{137}Cs of Chernobyl origin. The specific activity of ^{137}Cs in the fresh fish is 100 times less than the established allowed level.

To control non-spreading of the radioactive materials into the ground waters, the radiation monitoring of underground waters is conducted on the territory of Rivne NPP site. To control the underground water supply sources, the content of radionuclides is measured in the artesian wellholes.

There are 35 check-wellholes, and water is sampled from the bottom layer at a depth of 10÷14 meters from the surface. The frequency of water sampling from the check and artesian wellholes is once per quarter. Each sample is measured in terms of Σβ-activity using α/β radiometer MPC-9604 and specific activity of tritium is measured using liquid scintillational radiometer Tri-Carb 3170 TR/SL. The samples of check-wellholes are averaged and are subject to γ-spectrometeric analysis. The activity of man-made isotopes in the groundwaters is thousand times less than the level of allowed concentration in the portable water.

The network of artesian well-holes consists of nine wells, organized on the territory of the water withdrawal point "Ostriv". The samples of water are taken from the special collector, and go through γ-spectrometry and measurement of tritium activity. The water of artesian wellholes has no isotopes of manmade nature.

3.1.2 Non-radiation Impact on Surface and Ground Water

The water from the cooling system returns back continuously to the river through one discharge point of the industrial storm water sewerage system, which is located 30 m below the river stream from the river (additional) water intake facility. The industrial storm sewerage system receives the blowdown water from the circulation systems continuously and other debalancing waters from the power unit sites periodically after calculation of non-exceedance of normative effluents of contaminating substances. In accordance with the permission on special water use, the allowed effluents are in the volume of up to 18409.0 thousand m^3 of water for a year ($0.7 m^3/sec$).

Monitoring of the chemical composition of sewerage water and river water discharged to the water intake station of Rivne NPP and after the discharge point is conduced by the certified laboratories of the NPP. The laboratory of chemical department take samples and performs analysis of the discharge water not less than six times a day (oil products and pH).

The ecological and chemical laboratory of environmental protection service (EPS) performs analysis of the surface and sewerage (discharge) waters three times a week using 25 indicators. The analysis of monitored indicators prove that the values of the maximum allowed effluents (in tons) were not exceeded, the sewerage water is within the purity limits, and contains the same natural impurities like the source river water, and operation of Rivne NPP does not input the significant changes into the quality of surface waters.

The hydrogeological analysis includes the following activities:

- measurement of water level and temperature in the drill holes;
- measurement of water temperature along the entire length of the shaft in the drill holes - temperature log;
- water pumping from the drill holes;
- sampling of water from the drill holes for determination of the chemical composition of the groundwaters.

The Sanitary protection zone of the first ring of the Artesian wells of the village Ostriv are subtracted and enclosed. The analysis is conducted by the ecological and chemical laboratory certified for making measurements of chemical composition of groundwaters (drill holes/wells) in the area of sludge collector and landfill for construction and industrial waste from Rivne NPP. The analysis of monitored characteristics prove that Rivne NPP operation does not input significant changes into the quality of ground waters.

3.2 Air Protection

Emissions of pollutants into the air from stationary sources are based on the permits issued by regional representatives of the Ministry of Environmental Protection of Ukraine No. 5620881201-1 and permits issued by the Department of Ecology and Natural Resources of the Rivne Regional State Administration No. 5610700000-8 dated 23.09.2013 (valid for 5 years), 5610700000-11 dated 27.12.13 (valid for 5 years), 5610700000-12, 5610700000-13 dated 24.10.2014 (unlimited validity), 5610700000-14 dated 24.10.2014 (valid for 10 years) and permit No 5610700000-16 dated 24.10.2014 (without limitation as to period of validity).

SS Rivne NPP has 164 stationary sources of pollutant emission into the atmospheric air, 14 of them outfitted with gas treatment modules. The largest sources of air pollution of SS Rivne NPP are auxiliary facilities: Start-up and standby boiler house, diesel generators, as well as transportation means. SS Rivne NPP owns 142 diesel and 148 gasoline vehicles, as well as 4 diesel locomotives, 1 rail crane, 1 gasoline locomotive and 1 motor trolley. The transport shop has a diagnostic station for measuring the toxicity and smoke content in the exhaust gases. Diagnostics is conducted quarterly with corresponding records made in accounting journals.

Data on emission of pollutants into the atmosphere from stationary sources for 2016 according to the statistical reporting form No. 2-TP (air) are given in Table 3.1. Total emissions from stationary sources in 2017 amounted to 34.785 t.

Table 3.1. Emissions of pollutants into the atmosphere from stationary sources

Contaminant, greenhouse gas and group code	Contaminants	Emissions from the beginning of the year, t
00000	Total for the enterprise (excluding carbon dioxide)	34.785
01000	Metals and their compounds	0.203
03000	Substances in a form of suspended solid particles (micro particles and fibres)	2.237
04000	Nitrogen compounds	8.582
05000	Dioxide and other sulphur compounds	1.510
06000	Carbon monoxide	3.356
11000	Non-metallic volatile organic compounds	18.810

Contaminant, greenhouse gas and group code	Contaminants	Emissions from the beginning of the year, t
12000	Methane	0.004
15000	Chlorine	0.012
16000	Fluorine and its compounds (expressed in fluorine)	0.034
18000	Freons	0.037
07000	Carbon dioxide, additionally	109.691

To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for emissions into the air by stationary sources has been developed and approved. According to the concluded agreement with the state institution Rivne Regional Laboratory Centre of the Ministry of Health of Ukraine, measurement of the pollutant contents in the scheduled emissions from stationary sources during the reporting period was carried out at the SS Rivne NPP (Record No. 45 dated 07.06.2016)

In 2017, mobile sources of SS Rivne NPP utilized 507.072 t of diesel fuel and 397.989 t of unleaded petrol.

3.2.1 Condition of Radiation Pollution of Atmospheric Air

Sampling and monitoring of the radionuclides content in the surface air are carried out in accordance with the radiation control regulations in force at Rivne NPP once every 10 days at 16 control stations. The volumetric activity of anthropogenic radionuclides in atmospheric air over 37 years of observations did not exceed the standard values as per NRBU-97. The volumetric activity for ^{90}Sr and ^{137}Cs is within the “zero background”.

Air pollutant emissions from the NPP are 2-3 thousand times less than that from a coal-fired TPP with a similar installed capacity.

Gas-aerosol emissions of radioactive substances released to the atmosphere through ventilation pipes are dissipated in the atmosphere and form a so-called “cloud of emissions”. Aerosol particles fall out of the cloud and settle on the ground, migrating into elements of ecological systems adjacent to NPPs.

Laboratory of external radiation control uses stainless steel pans with an area of 0.25 m^2 to collect atmospheric precipitations. The tray bottom is lined with a filter paper in accordance with DST 12026-76.

The pans are located at 22 monitoring points in accordance with the history of long-term pre-launch meteorological observations at the construction site of SS Rivne NPP (according to the Windrose diagram), mainly in settlements within the OZ. In accordance with the Regulation, atmospheric precipitation sampling frequency is 1 time per month.

Long-term observation results indicate that the total β-activity of precipitations and content of ^{90}Sr and ^{137}Cs during the observation period are within the “zero background” and do not depend on the distance from an observation point to SS Rivne NPP.

The assessments have shown that the major share of gas-aerosol release within the dose during operation of power units of SS Rivne NPP will be by inert gases through irradiation from the cloud. The maximum annual average concentrations of these radionuclides in the air were obtained in the east direction at a distance of about 1.5 km from the plant. They made: 1.351×10^{-11} Ci/m^3 (0.5 Bq/m^3) for ^{133}Xe; 2.703×10^{-13} Ci/m^3 (0.01 Bq/m^3) for ^{85}Kr; 5.406×10^{-14} Ci/m^3 (0.002 Bq/m^3) for ^{41}Ar.

Non-exceedance of the effective dose of 100 mrem/year (1 mSv/year) per population (Category B) is possible when maximum air concentrations of these radionuclides are as follows: 26.489×10^{-8} Ci/m^3 (9.8 kBq/m^3) for ^{133}Xe; 54.06×10^{-8} Ci/m^3 (20 kBq/m^3) for ^{85}Kr; 0.973×10^{-8} Ci/m^3 (0.36 kBq/m^3) for ^{41}Ar, which is 10^3-10^6 times higher than the maximum design concentrations of radioactive noble gases (RNG) during normal operation of the power units.

3.3 Impact on Soils

Pollution of observation zone of Rivne NPP consists of a superposition of global falls, falls as a result of Chernobyl accident and overshoots due to aerosol emissions from the working units of SS Rivne NPP. The last source of pollution is so insignificant that virtually its eduction from total pollution is impossible and it is confirmed by spatial distribution of radiocesium contamination around the NPP, which does not correlate with the windrose of the region.

Soil contamination is determined by the hazard class of some toxicants. Malignity classes are included:

I-class - arsenic, cadmium, mercury, selenium, lead, zinc, fluorine, benz(a)pyrene;

II-class – boron, cobalt, nickel, copper, molybdenum, antimony, chromium;

III-class – barium, vanadium, tungsten (wolfram), manganese, strontium.

Their content in soils can be estimated in both gross and moving forms of elements.

The results of chemical analysis are compared with maximum permissible concentrations (MPC). The level of contamination by hazardous substances for which MPC concentrations are not established are estimated in comparison with background values of these substances in soil; it gives the opportunity to objectively evaluate the degree of soil pollution in a zone of influence of industrial activity of SS Rivne NPP and, if necessary, to take remedial measures.

The list of chemically parameters of soils and muds for control is given in Table 3.4.

Table 3.4. Chemical parameters of soils and muds for control.

No	Name	Physical units	MPC
1	Ammonium nitrogen	mg/kg	not standardized
2	Aluminium exchange	mg/kg	not standardized
3	Bicarbonate ion	Mmol/ 100 g soil	not standardized
4	Hydrogen index	unit pH	not standardized
5	Iron (mobile forms)	mg/kg	not standardized
6	Potassium	mg/kg	not standardized
7	Calcium	mg/kg	not standardized
8	Cobalt (mobile forms)	mg/kg	5.00
9	Magnesium	mg/kg	not standardized
10	Manganese	mg/kg	1500.0
11	Cooper (mobile form)	mg/kg	3.0
12	Sodium	mg/kg	not standardized
13	Petroleum products	mg/kg	not standardized
14	Nickel (mobile form)	mg/kg	4.0
15	Nitrates	mg/kg	130.0
16	Lead (mobile forms)	mg/kg	20.0
17	Sulphates	mg/kg	160.0
18	Specific electrical conductivity	mSm/cm	not standardized
19	Phosphorus (mobile forms)	mg/kg	not standardized
20	Chlorides	mg/kg	not standardized
21	Zinc	mg/kg	23.0

One of the direction of environmental monitoring of SS Rivne NPP is the laboratory control of soil conditions in the area of waste disposal sites – sludge collectors and landfills for construction and industrial wastes.

The results of ecological monitoring give the opportunity to objectively assess the degree of influence of industrial activity of SS Rivne NPP on the state of soil in the vicinity of the NPP. The analysis of long-term observations of chemical composition and properties of soil cover has shown that according to the moving forms of chemical elements, which are the most environmentally significant (as they are responsible for the speed of migration in food chains), the exceedances of MPC were not detected. In case of absence of MPC of the substance, the comparison is performed with a natural background concentration.

SS Rivne NPP has little influenced on the change of water-physical properties of adjacent soils due to changes in the level of groundwater during its construction. It is possible to talk about the joint influence of SS Rivne NPP and land-use only in case of overshooting of SS Rivne NPP emissions to agricultural soils, when, as a result of agrochemical treatment, pollutants penetrate down the soil profile to the depth of plow sole and evenly mix. In fact, there is an acceleration of the migration process of those small amounts of pollutants which can settle on soil due to the emissions from a nuclear power plant.

3.3.1 Radiation Impact on Soils and Vegetation

The samples of soil from 0÷5 cm layer were selected for controlling the surface contamination of the ground with radionuclides in the territory of location of SS Rivne NPP.

The analysis in sites of sludge collector and landfill for construction and industrial wastes of SS Rivne NPP is carried out by ecological and chemical laboratory, which is authorized to perform the measurements of chemical composition of soils. The analysis of monitored parameters confirms that operation of SS Rivne NPP does not make significant changes to quality of soils.

According to "zero background", the surface contamination of soil ^{137}Cs prior to commissioning of SS Rivne NPP was in range of 0.44 ÷ 5.07 kBq/m^2; ^{90}Sr - 0.19 ÷2.92 kBq/m^2.

The soil samples were taken in the adjacent territory of SS Rivne NPP to control the possible surface contamination of soil with radionuclides in accordance with the requirements of current radiation control regulations.

Sampling is carried out annually in April-May and research is conducted on γ-spectrometers.

Table 3.5 provides data on specific soil contamination during the period from 2004 to 2016. The average values of activity are shown for each year.

Table 3.5. Specific soil contamination during the period from 2004 to 2016.

Year	^{7}Be, Bq/m^2	^{40}K, Bq/m^2	^{60}Co, Bq/m^2	^{131}I, Bq/m^2	^{134}Cs, Bq/m^2	^{137}Cs, Bq/m^2
2004	4.11E+02	9.87E+03	<2.10E+01	<1.90E+02	4.96E+01	1.12E+04
2005	3.21E+02	9.97E+03	1.78E+01	<7.40E+02	3.53E+01	1.11E+04
2006	4.40E+02	9.20E+03	<2.50E+01	<1.90E+02	2.81E+01	7.99E+03
2007	2.00E+02	7.96E+03	<7.90E+00	<4.70E+01	1.47E+01	8.16E+03
2008	2.31E+02	8.98E+03	<9.60E+00	<7.90E+01	<1.40E+01	5.20E+03
2009	4.32E+02	1.06E+04	<2.10E+01	<1.0E+02	<3.20E+01	5.92E+03
2010	3.29E+02	9.53E+03	1.70E+01	<7.10E+01	<2.40E+01	4.95E+03
2011	1.56E+02	8.27E+03	<7.42E+00	<3.70E+01	<1.08E+01	3.47E+03
2012	2.02E+02	1.06E+04	<8.40E+00	<5.90E+01	<1.42E+01	5.72E+03
2013	2.62E+02	9.84E+03	<1.1E+01	<1.1E+02	<1.8E+01	4.67E+03

Year	^{7}Be, Bq/m^2	^{40}K, Bq/m^2	^{60}Co, Bq/m^2	^{131}I, Bq/m^2	^{134}Cs, Bq/m^2	^{137}Cs, Bq/m^2
2014	1.48E+02	8.19E+03	<9.00E+00	<2.40E+01	<1.30E+01	4.19E+03
2015	9.20E+01	8.18E+03	<3.9E+00	<2.2E+01	<6.80E+00	3.43E+03
2016	1,15E+02	8.91E+03	<4.2E+00	<2.4E+01	<7.20E+00	3.33E+03

During the reporting period, the maximum contribution to the specific activity of the soil is due to the presence of ^{137}Cs isotope that over all reporting years exceeds the "zero background", but this contamination is explained by the consequences of Chernobyl accident.

The ratio of the maximum activity of ^{137}Cs to the minimum observed in the zone of location of SS Rivne NPP during considered period reached several dozen times (21.2 in 2016), which indicates a significant heterogeneity of soil contamination.

Table 3.6 shows the coefficients of the pair correlation and the ratio of activities ^{137}Cs and ^{134}Cs, which is calculated for the samples with activity of ^{134}Cs higher than MPC. The mix age is determined by taking into account the initial ^{137}Cs/^{134}Cs activity ratio of 1.6:1. The data indicate that soil contamination in the monitoring zone is due to the fallout of fission products after Chornobyl catastrophe.

Table 3.6. Chornobyl ratio of activity^{137}Cs/^{134}Cs in soil

Year	Coefficient of pair correlation	Ratio of activity	Estimated age of the mixture
1994	0.98	21.1	8.2
1995	0.91	30.5	9.4
1996	0.96	42.8	10.5
1997	0.97	57.0	11.4
1998	0.96	74.1	12.2
1999	0.97	93.5	13.0
2000	0.98	128	14.0
2001	0.99	186	15.2
2002	0.89	180	15.1
2003	0.83	226	15.8
2004	0.74	267	16.4
2005	0.81	314	16.9
2006	0.54	284	16.5
2007	0.14	1280	21.4

Since 2002, there has been a decline in tendency of activity ratio of ^{137}Cs and ^{134}Cs to the isotope associated with the decay of ^{134}Cs ($T_{1/2}$ = 2,064 years) and biochemical processes in soil.

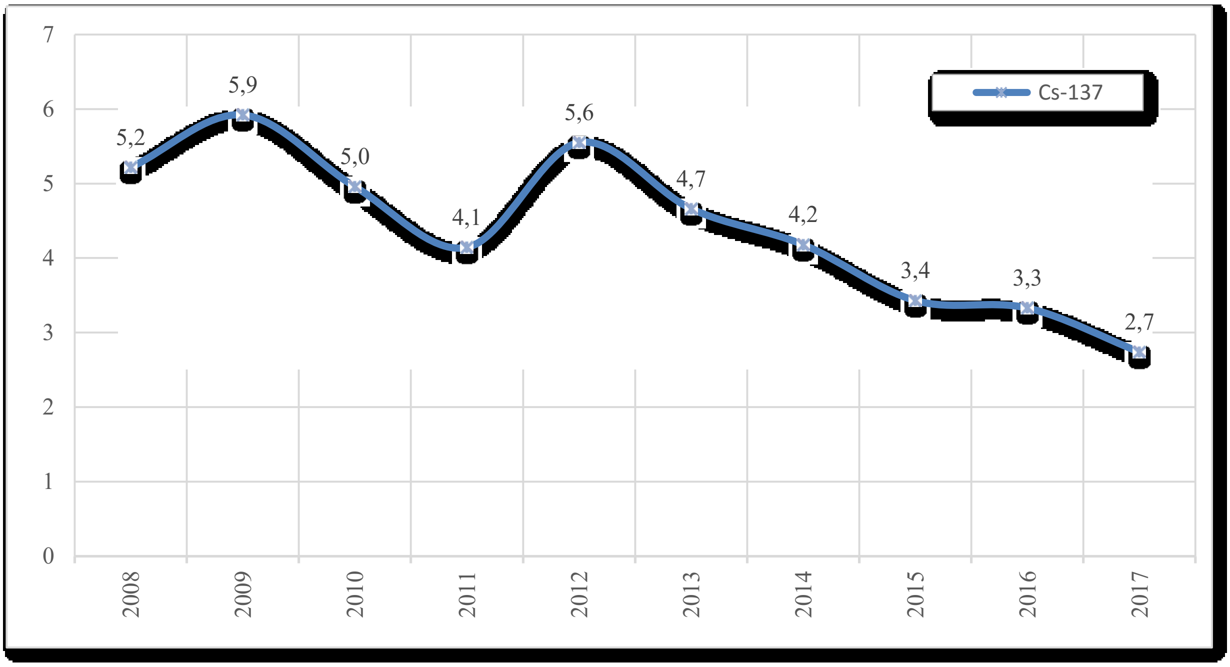

Figure. 3.1 Surface activity of soil in a layer 0÷5 cm in the zone of placement of SS Rivne NPP, kBq/m^2.

3.3.2 The Results of Control the Content of Radionuclides in Agricultural Products

The main foodstuffs of the local population were monitored in the zone of placement of the SS Rivne NPP - milk, vegetables, and grain crops. Samples were selected during maturation.

The samples were examined using γ-spectrometric analysis to determine the possible presence of radionuclides of technogenic origin, especially ^{131}I.

^{131}I was not registered in agricultural products in 2017. The presence of other man-made radionuclides, except ^{137}Cs of "Chornobyl" origin was not registered, too. The high content of this radionuclide in food is due to the higher value of transition coefficient of "soil-solution-plant" chain.

Control of Milk

The samples were taken in 12 settlements in private farms. The volume of 1 sample was 2.5 ÷ 3 litres.

All milk samples passed γ-spectrometric analysis without radiochemical preparation. According to "zero background", the volumetric activity of ^{137}Cs in milk prior to start-up of SS Rivne NPP unit was in a range of 6.3E-01 ÷6.6E +00 Bq/l.

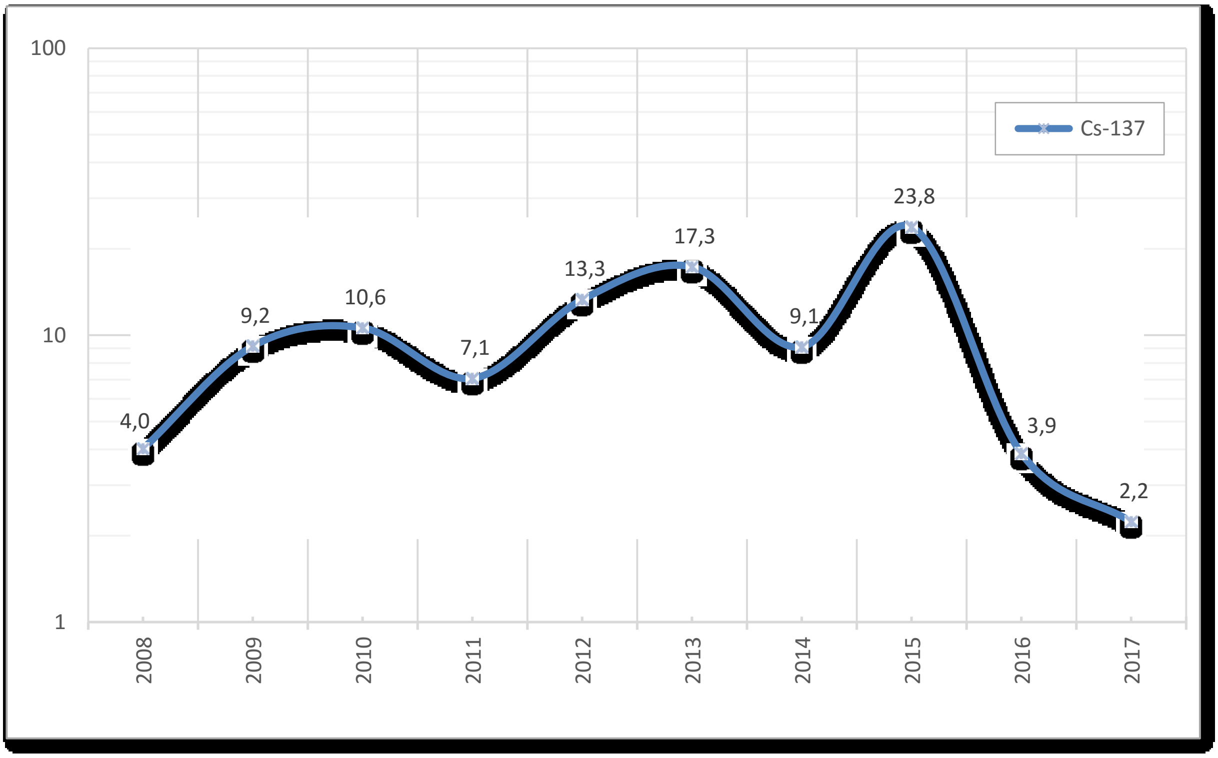

Figure 3.2. Average indicators of milk contamination in zone of placement of SS Rivne NPP, Bq/l.

Table 3.7. Volumetric activity of radionuclides in milk in 2017, Bq/l

Sampling point	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<8,7E-01	4,88E+01	<8,1E-02	<9,5E-02	<1,2E-01	<1,3E-01	3,74E-01
Bilska Volia	<6,4E-01	5,42E+01	<6,0E-02	<6,7E-02	<8,5E-02	<6,0E-02	3,85E+00
Velyka Vedmezhka	<6,7E-01	5,07E+01	<6,1E-02	<9,4E-02	<9,8E-02	<7,5E-02	1,21E-01
Zabolottia	<7,8E-01	5,24E+01	<8,0E-02	<1,3E-01	<9,8E-02	<1,0E-01	1,59E+00
Kostiukhnovka	<1,2E+00	5,10E+01	<1,4E-01	<1,5E-01	<1,5E-01	<1,3E-01	2,46E+00
Lubakhi	<4,7E-01	3,82E+01	<3,4E-02	<5,4E-02	<6,4E-02	<4,5E-02	2,94E+00
Manevychi	<8,4E-01	4,73E+01	<6,4E-02	<1,1E-01	<1,1E-01	<8,8E-02	4,95E+00
Polytsi	<1,2E+00	4,29E+01	<1,2E-01	<1,6E-01	<1,4E-01	<1,3E-01	2,96E+00
Stara Rafalivka	<5,8E-01	5,20E+01	<3,9E-02	<6,1E-02	<7,6E-02	<6,5E-02	2,29E+00
Sopachiv	<8,2E-01	4,27E+01	<6,0E-02	<9,3E-02	<1,2E-01	<9,4E-02	1,68E+00
Staryi Chartoryisk	<5,2E-01	5,25E+01	<4,8E-02	<7,7E-02	<8,2E-02	<6,0E-02	3,96E-01
Tsmyny	<5,5E-01	4,06E+01	<4,3E-02	<6,7E-02	<8,2E-02	<6,0E-02	3,30E+00

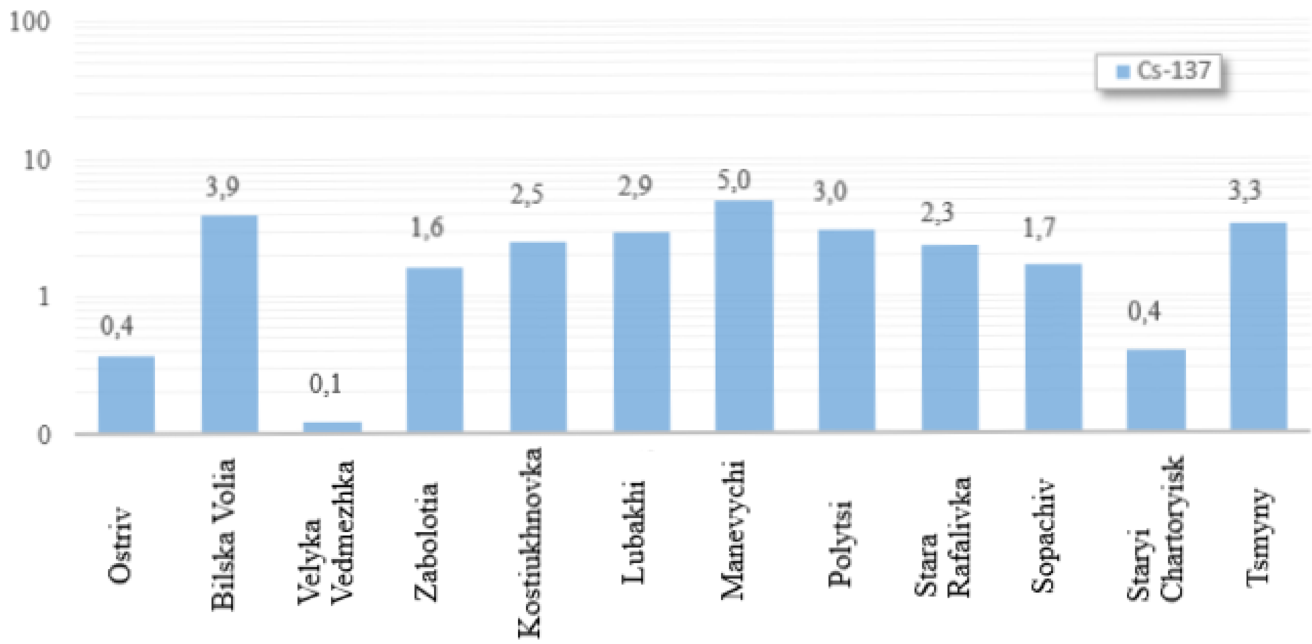

Figure 3.3. Volumetric activity of ^{137}Cs in milk of allocation zone of Rivne NPP in 2017, Bq/l.

The maximum content of ^{137}Cs was recorded in Manevychi checkpoint - 4.95 Bq/l. Permissible content of ^{137}Cs in milk is 100 Bq/l. Exceeding the upper bound of values of “zero background” by ^{137}Cs has not been fixed.

Control of Vegetables

The samples were taken in 12 settlements. The mass of 1 selected potato sample was 3 kg. According to “zero background”, the specific activity of ^{137}Cs in vegetables prior to the launch of Rivne NPP was in the range of 1.5E-02 ÷ 2.0E + 00 Bq/kg.

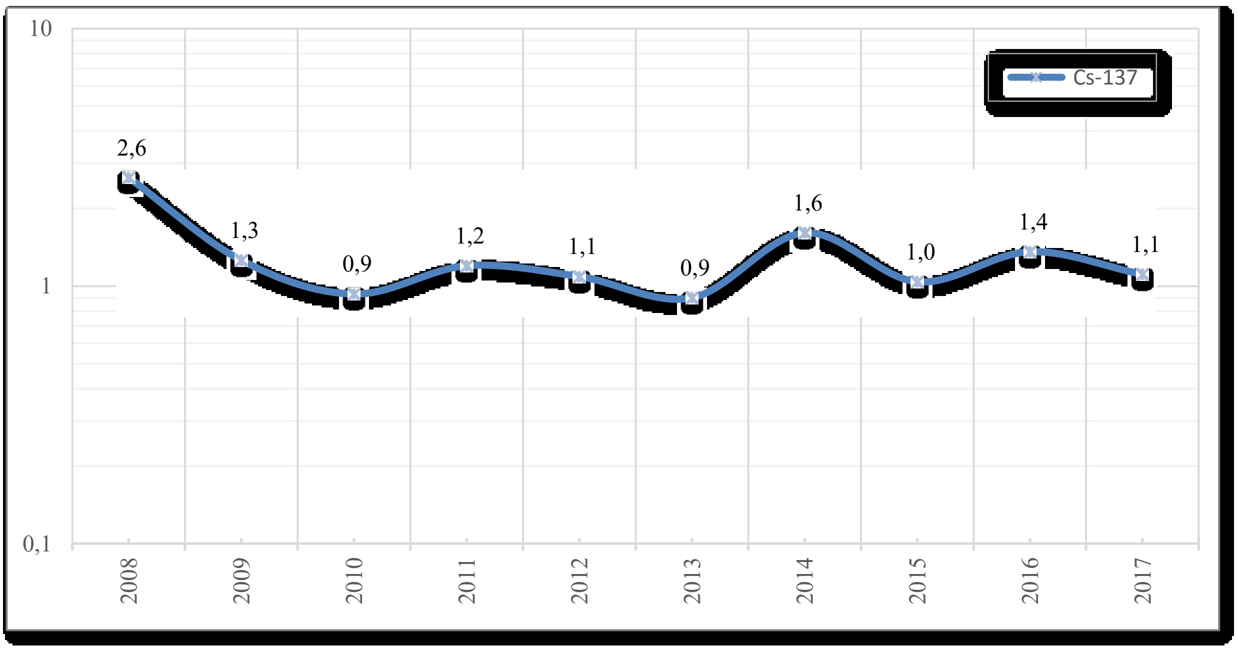

Figure 3.4. Average value of specific activity of radionuclides in potatoes in the zone of placement of SS Rivne NPP, Bq/kg

Table 3.8. Specific activity of radionuclides in potatoes in the zone of placement of SS Rivne NPP in 2017, Bq/kg

Sampling point	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	^{134}Cs	^{137}Cs
Ostriv	<2,1E-01	9,42E+01	<4,9E-02	<4,9E-02	<2,5E-02	<3,5E-02	4,41E-01
Bilska Volia	<4,0E-01	1,41E+02	<4,0E-02	<5,2E-02	<5,7E-02	<4,5E-02	2,78E+00
Velyka Vedmezhka	<2,5E-01	1,36E+02	<6,1E-02	<6,2E-02	<2,6E-02	<4,4E-02	1,90E-01
Zabolottia	<2,7E-01	1,10E+02	<2,7E-02	<3,4E-02	<4,5E-02	<3,1E-02	1,12E+00
Kostiukhnovka	<3,9E-01	1,19E+02	<4,0E-02	<6,4E-02	<5,3E-02	<4,3E-02	7,85E-01
Lubakhi	<2,8E-01	1,11E+02	<2,6E-02	<3,4E-02	<5,2E-02	<2,7E-02	4,00E+00
Manevychi	<2,3E-01	8,26E+01	<2,4E-02	<3,2E-02	<4,6E-02	<2,7E-02	8,12E-01
Polytsi	<3,5E-01	1,23E+02	<3,6E-02	<5,5E-02	<5,6E-02	<3,7E-02	1,28E+00
Stara Rafalivka	<2,7E-01	1,17E+02	<2,5E-02	<3,3E-02	<4,5E-02	<2,6E-02	4,87E-01
Sopachiv	<2,1E-01	9,87E+01	<2,4E-02	<3,1E-02	<4,4E-02	<2,5E-02	6,37E-01
Staryi Chartoryisk	<2,2E-01	9,93E+01	<4,9E-02	<5,2E-02	<2,5E-02	<3,6E-02	4,89E-01
Tsmyny	<1,9E-01	1,26E+02	<4,0E-02	<4,2E-02	<2,0E-02	<2,9E-02	2,57E-01

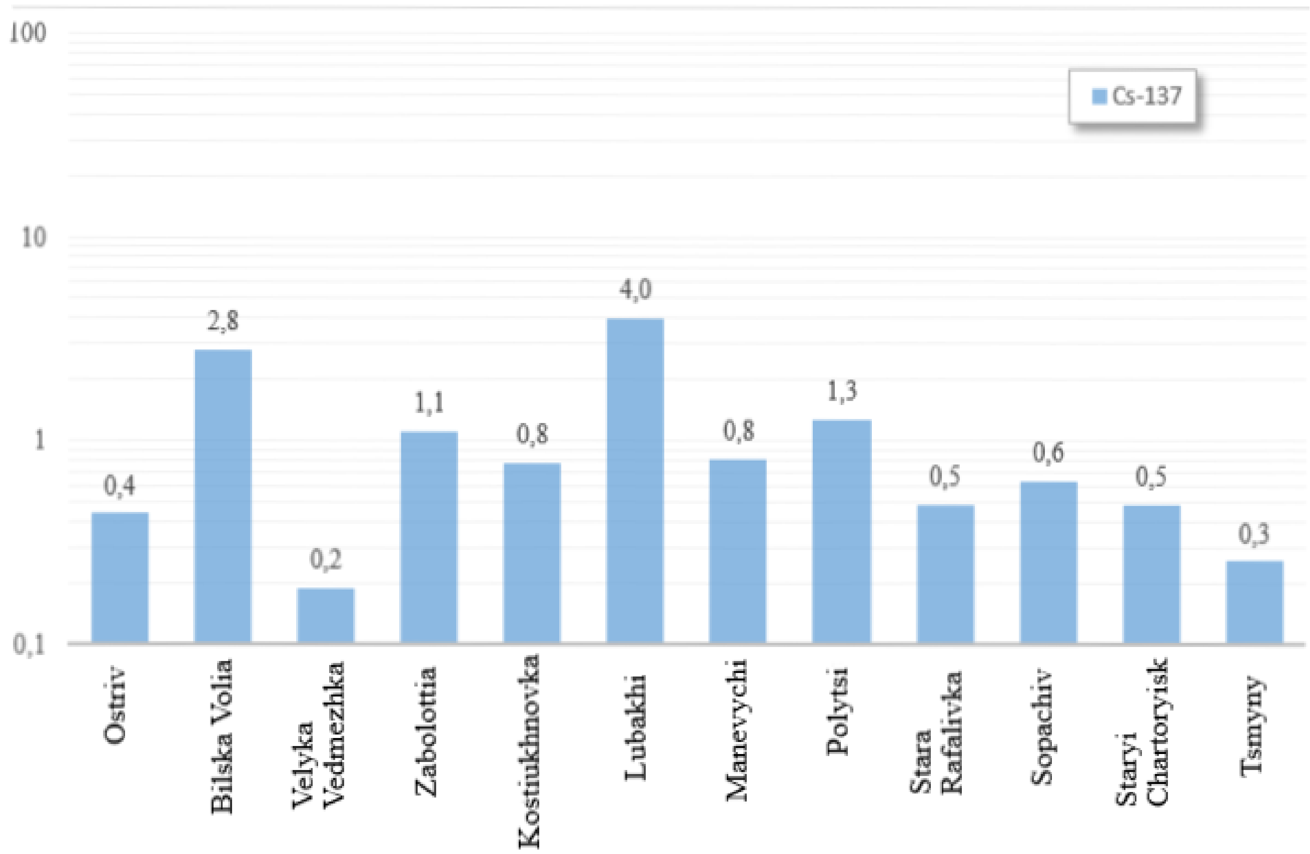

Figure 3.5. Specific activity of ^{137}Cs in potato samples of the placement zone of SS Rivne NPP in 2017, Bq/kg

The maximum content of ^{137}Cs in potato in 2017 was recorded in a control point “Liubahy” - 4.0 Bq/kg. Permissible content of ^{137}Cs in fresh potato is 60.0 Bq/kg. Exceeding the upper limit of values of “zero background” is fixed in 2 control points.

Control of Grain Crops

The samples were taken in 12 settlements in a zone of location of SS Rivne NPP. The mass of sample for each type of grain crops was 3 kg. All selected samples passed γ-spectrometric analysis without radiochemical preparation.

According to "zero background", the specific activity of ^{137}Cs in grain crops before the launch of SS Rivne NPP was in the range of 8.1E-01÷1.18E + 00 Bq/kg.

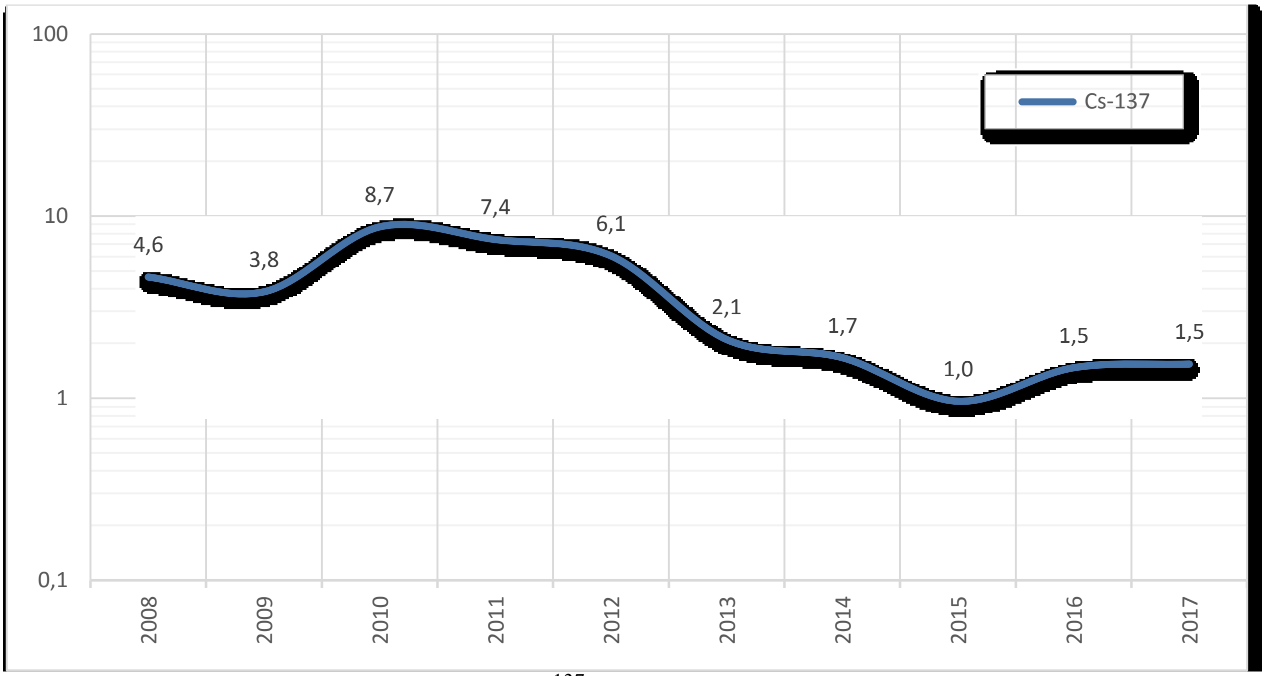

Figure 3.6. Average specific activity of ^{137}Cs in grain crops in a zone of placement of SS Rivne NPP, Bq/kg.

Table 3.9. Average specific activity of radionuclides in grain crops in 2017, Bq/kg

Sampling point	Subspecies	^{7}Be	^{40}K	^{60}Co	^{110m}Ag	^{131}I	134Cs	^{137}Cs
Ostriv	Wheat	4,33E+00	1,11E+02	<8,5E-02	<1,2E-01	<1,4E-01	<1,0E-01	2,69E-01
Bilska Volia	Wheat	2,64E+00	1,18E+02	<5,1E-02	<8,6E-02	<7,9E-02	<6,9E-02	1,69E-01
Velyka Vedmezhka	Wheat	5,31E+00	1,24E+02	<6,2E-02	<1,1E-01	<1,0E-01	<8,8E-02	2,83E-01
Zabolottia	Wheat	2,61E+00	1,31E+02	<8,1E-02	<1,2E-01	<1,4E-01	<1,0E-01	1,31E+00
Kostiukhnovka	Oat	1,07E+01	8,91E+01	<1,9E-01	<2,3E-01	<1,8E-01	<2,1E-01	4,07E+00
Lubakhi	Rye	8,75E+00	1,43E+02	<7,4E-02	<1,1E-01	<1,2E-01	<9,4E-02	6,43E+00
Manevychi	Wheat	2,17E+00	1,41E+02	<6,2E-02	<9,0E-02	<9,4E-02	<7,2E-02	2,71E-01
Polytsi	Oat	8,35E+00	1,46E+02	<9,7E-02	<1,3E-01	<1,5E-01	<1,3E-01	7,37E-01
Stara Rafalivka	Oat	5,36E+00	1,30E+02	<1,2E-01	<1,6E-01	<1,8E-01	<1,5E-01	1,86E+00
Sopachiv	Wheat	1,67E+00	1,08E+02	<8,5E-02	<1,0E-01	<1,5E-01	<1,0E-01	1,50E+00
Staryi Chartoryisk	Oat	1,60E+01	1,05E+02	<8,3E-02	<1,2E-01	<1,6E-01	<1,2E-01	1,44E+00
Tsmyny	Wheat	1,3E+00	1,28E+02	<9,6E-02	<1,4E-01	<1,4E-01	<1,2E-01	1,97E-01

The specific activity of ^{134}Cs is less than the minimum detected activity for all control points. The ratio of the maximum value of the specific activity of ^{137}Cs (point of control "Lubakhi" - 6.43 Bq/kg) to the minimum was 38.0 - this indicates uneven pollution of the area of the location of the unit of SS Rivne NPP by the given radionuclide. It is evident from the data in Table 3.9 that the activity of ^{137}Cs does not depend on the distance to the SS Rivne NPP, which implies that the ^{137}Cs has a "Chornobyl" origin.

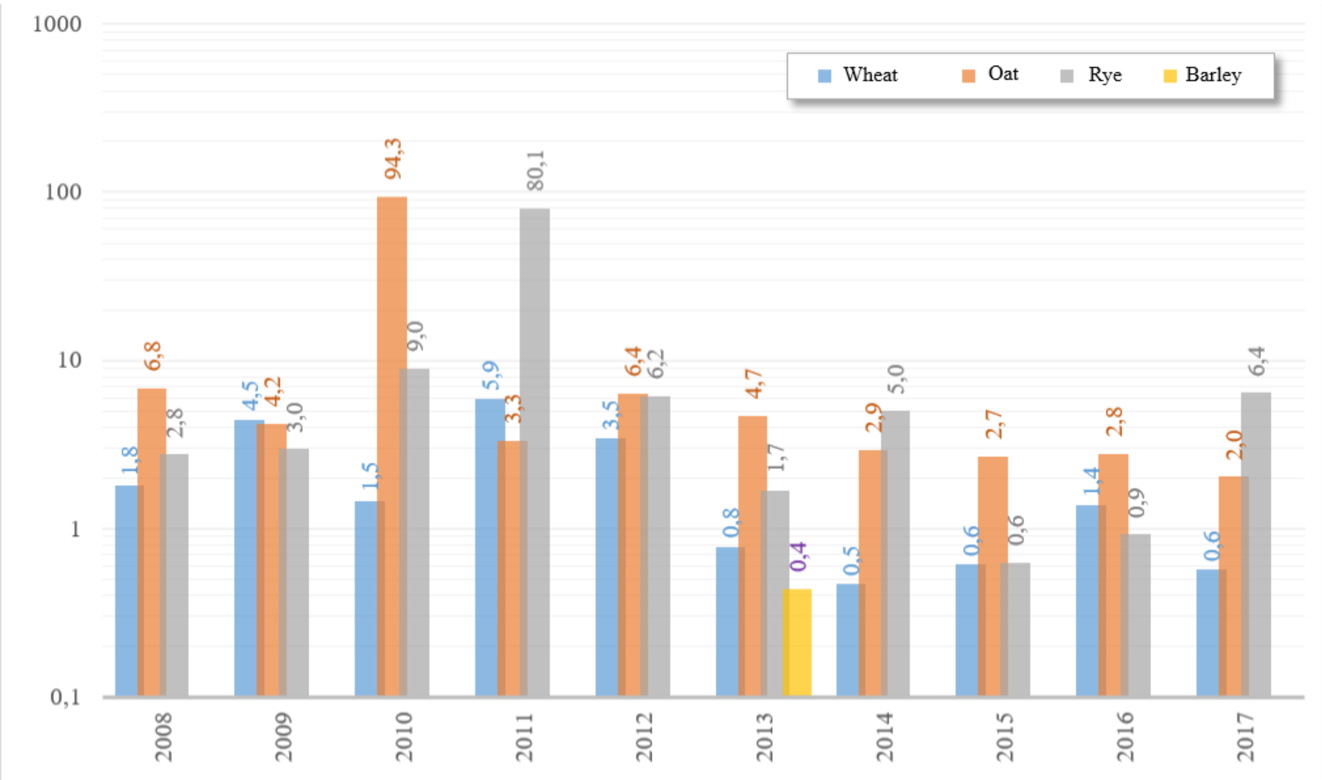

Figure 3.7. Average specific activity of ^{137}Cs in grain crops in the area of placement of the SS Rivne NPP, Bq/kg

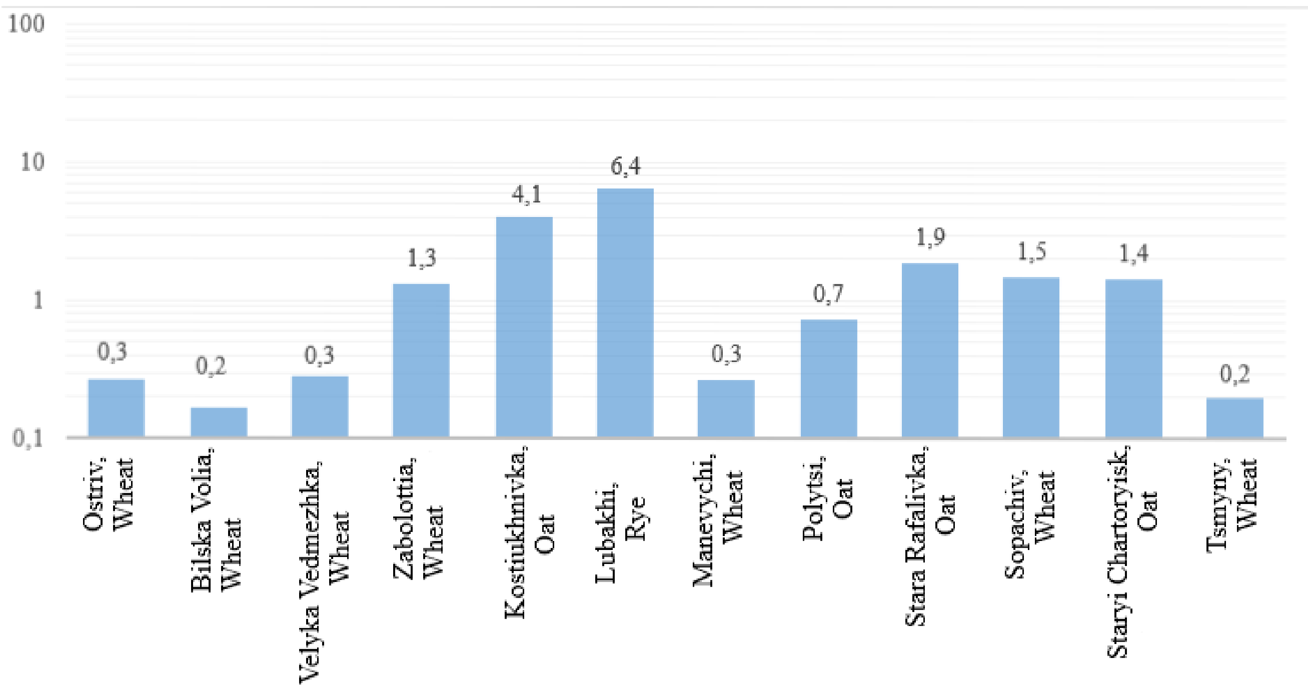

Figure 3.8. Average specific activity of ^{137}Cs in grain crops in the area of the distribution of the SS Rivne NPP in 2017, Bq/kg

For most objects of the environment, the activity of radionuclides is within the range of "zero background" measurements.

In the vicinity of location of Rivne NPP, the uneven contamination of the environment by radionuclide ^{137}Cs of "Chornobyl" origin is observed.

All soil samples which were taken from 0÷5 cm layer in 2017, the activity of ^{134}Cs was less than the level of minimum activity detected. The ratio of maximum value of the surface activity of ^{137}Cs to the minimum in the area of placement of Rivne NPP on virgin soils is 13.0, which indicates the heterogeneity of the contamination of surface layer of soil.

In 2017, the average value of specific activity of ^{137}Cs in milk was 44.6 times less, in potato - 54.1 times less than permissible values set in the document "Permissible levels of radionuclide content ^{137}Cs and ^{90}Sr in food and drinking water, 2006".

3.4 Impact on Geological Environment

The reliability of the operation of NPP buildings and structures depends on the stability of geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability — once in 100 years): magnitude 5, maximum estimated earthquake (probability — once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;
- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of geological environment and is the key factor for ensuring safe operation of SS Rivne NPP.

In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:

- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;
- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuously cooperates with leading scientific

organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013-2016.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

The analysis of control characteristics shows that the work of the Rivne NPP does not significantly change the quality of underground water. Radiation state of groundwater is satisfactory, content of ^{226}Ra, ^{137}Cs, ^{90}Sr is much lower than the values that are standardized in the Radiation Safety Standards of Ukraine.

3.5 Impact on Flora, Fauna and Objects of Nature Reserve Fund

The territory of the Rivne NPP OZ lies within the Volyn Polissya, which occupies the western part of the Ukrainian Polissya. Geographic location of this territory contributed to the formation of typical Polissya nature (predominance of moraine-fluvioglagic sedimentary deposits, domination of sod-podzolic soils, high bogginess and forest coverage). Specific features of this territory are geological structure (domination of chalk and marls of the upper Cretaceous in the base rock, and occurrence of basaltic rocks in the southern part).

Natural vegetation was mainly preserved; the share of plowed land at the most part of the territory is insufficient and varies from 10% in the northern and eastern parts to 20-25% in the western part. Only in the central part it rises to 43.5%. Forests are the dominant vegetation; the average forest coverage is 49.6%. There are a lot swamps on the territory being studied, and these swamps differ both by origin and area.

The animal world of the Rivne NPP OZ is represented by animal complexes typical for Polissya. More than 60 mammals species and about 200 birds species live there. Rodents are the dominant mammalians; however, predators (common fox, wolf, the raccoon dog, least weasel (Mustela nivalis, stoat (Mustela erminea)) are also found. A wolf, a raccoon dog, a ermine, and so on. Birds are predominantly of the tree-shrub species. Song-birds (black grouses, hazel grouses, and wood grouses) are also found in the Volyn Polissya region. The following reptile spices should be mentioned: the adder, the grass snake, the smooth snake, the anguine lizard, the viviparous lizard, fresh-water turtle.

Years of researches have shown that radionuclide emissions do not increase the activity of man-made isotopes (^{137}Cs, ^{90}Sr etc.). Accumulated radionuclides in plants during normal operation of the power plant will not exceed the permissible norms; and the current contamination by ^{137}Cs of “the Chornobyl” origin has been studied in detail within the monitoring zone. As to accumulation of radionuclides in plants, the highest contamination is currently found in marsh plants with highest concentration in mosses and mushrooms and lower concentration levels — in cranberries and blueberries.

Care must be taken as to consumption of forest and swamp products, and particularly, mushrooms. Taking into account wider ecological amplitude of blueberries, its radionuclide contamination can vary greatly depending on local conditions. Blueberries, which are currently collected and procured quite intensively, must be carefully monitored for content of radionuclides.

On the whole, based on the analysis of changes in the background concentration of radionuclides with increase of distance from the power units of SS Rivne NPP, it can be concluded that the radiation regime of the plant during its normal operation does not affect the vegetation and does not cause any changes in the radiation level of individual plant species.

Technical design solution on cooling of process water in cooling towers and spray pools (instead of a cooling pond) allowed minimizing adverse impact of the plant on the ecosystem and preserving the valuable floodplain of the Styr River with its meadow, shrub, and forest animal complexes.

4 IMPACT ON SOCIAL ENVIRONMENT

4.1 Brief Description of the Current Social Environment in the Observation Zone

The Rivne NPP is located in a mixed forest zone in western Volyn Polissia — in the northwestern part of the Rivne Region, 120 km away from the regional centre, in the Volodymyretskyi District, on the Styr River. This Ukrainian NPP is nearest to the neighbouring states.

SS Rivne NPP site choice was due to low fertility of sandy land and great distance from densely populated areas. The Rivne NPP and its satellite town Varash (former Kuznetsovsk) are located in the most stable seismic zone of Ukraine. The recurrence of magnitude 6 earthquakes according to the MSK-64 seismic scale is once in 5000 years.

The 30 km observation zone of SS Rivne NPP is within the boundaries of two regions: Rivne and Volyn. The size of population in 90 settlements over the territory of about 3,000 km^2 is about 130 thous. people.

SS Rivne NPP is located in the moderate continental climate zone. West winds are predominant. Air quality is generally good due to limited industrial activities. The Styr River is the main source of surface water. Forests cover 50 % of SS Rivne NPP territory and are of a considerable economic and environmental value. Agricultural land use accounts for 27 %. 48 territories within the OZ of SS Rivne NPP are classified as nature reserve fund.

The OZ of SS Rivne NPP, which covers 2826 km^2, includes a total of 109 settlements with 143 thous. residents, with the population density of 58.82 people/km^2 in the Region of Rivne and 37.19 people/km^2 in the Region of Volyn.

Satellite town of SS Rivne NPP, Varash, is 3 km away from the power plant and is the largest town in the observation zone. The town's population is about 42,000 people. The density of population within this territory made 55 people/km^2 back in 1973, while currently it makes 3,684 people/km^2. Other relatively large nearby settlements include the urban type settlements of Manevychi (Volyn Region), Volodymyrets and Rafalivka (Rivne Region).

Demography as of 2017 is characterized by 46.7 % of urban population and 53.3 % of rural population. Development of electricity production capacities promoted urbanization process. The highest increase in population was observed in the NPP satellite town due to labour migration. Urban population growth in the region was accompanied with decrease in rural population (due to migration).

The estimated size of actual urban population as of 1 January 2017 made 42.2 thous. people. In 2016, the population decreased by 311 people, which made 7.4 people per 1,000 people of the actual population.

The size of population increased due to natural (264 people) and migration (47 people) growth.

Natural population growth level in 2016 made 6.3 people per 1,000 people of the actual population.

The birth rate made 11.9 live-born infants per 1,000 people of the actual population, and the death rate made 5.6 dead per 1,000 people of the actual population.

Figure 4.1. Location of settlements included in the 30-kilometer zone of SS Rivne NPP

The urban type settlement of Volodymyrets with the population of about 9.0 thous. people (8.699 thous. people) and population density of 1,447 people/km ^{2} is an investment-attractive region notable for its advantageous geographical location, well-developed transport and communications infrastructure, bank system, considerable industrial and construction potential, spare qualified workforce and executive staff, and reserves of primary natural resources. This is the place where two unique deposits of high-quality basalt suitable for mineral wool and stone-cast ware manufacture are located. There also are vast deposits of peat, white silica sand, clay, amber, zeolitic tuffs, and copper.

The size of population in the urban type settlement of Rafalivka (since 1959) as of 2017 made 3.278 thous. people, and population density made 264 people/km^2. Rafalivka has a railway station of the same name on the Kovel — Sarny line. The facilities that currently operate in Rafalivka include a sawmill, an asphalt plant and a furniture plant.

According to the data of the last all-Ukrainian population census (2011), the size of population in the urban type settlement of Manevychi made 11,190 people; it increased by 17.3 % compared to the data of 1989 census (8,937 people). Manevychi is the biggest urban type settlement in Volyn. As of 2017, the size of population here made 11,119 thous. people, while the population density reached 197.89 people/km^2.

The town of Varash, which owes its uprising and development to the construction of the NPP, is the only town within the 30 km observation zone, with the population size several-fold greater than that in the Volodymyrets and Manevychi district centres.

Varash appeared in 1973 as an NPP constructors' settlement with population of 14.79 thous. people (at that time). In 1984, Varash (former Kuznetsovsk) received a city status. Its population reached 23.8 thous. people as of 1 January 1985;

36.2 thous. people as of 1 January 1995;
41.2 thous. people as of 1 January 2000;
42.2 thous. people as of 1 January 2017.

Based on the data obtained within the framework of Kuznetsovsk Master Plan correction project (now Varash) ("Dipromisto", 1996), a swell in population in 1973-1985 is mainly due to a positive migration balance, while in 1986-1991, due to the completion of the 3rd power unit and moratorium on construction of the 4th unit, positive migration balance reduced several-fold (to 365 people/year from 1987), and from 1992 until present it makes about 500 people/year.

The rate of natural population growth was also decreasing until 1991 (from 760 to 455 people/year), and starting from 1992, the natural growth rate has made about 400 people/year.

However, the population in Volodymyrets (district centre) grew from 8.26 thous. people in 1995 to 9 thous. people in 2000 (by 740 people in 5 years), and made 9.0 thous. people as of 2017. The population dynamics in Manevychi district centre is as follows: from 9.08 thous. people to 10 thous. people (increased by 992 people in 5 years); the population size makes 10.12 thous. people as of 2017.

Urban population dynamics in 1995-2017 is shown in Table 4.1.

Таблиця 4.1. Urban population dynamics in the SPZ in 1995-2017

Name of settlement	Population size (thous. people)		
	1995 р.	2000 р.	2017 р.
Town of Varash	36,2	41,2	42,2
Sett. of Volodymyrets	8,26	9,0	8,69
Sett. of Manevychi	9,08	10,0	10,12

The OZ of SS Rivne NPP is characterized by low rates of industrial development and moderate rates of agricultural development. Low-tech industrial production is predominant in the region. Available enterprises mainly operate in food, wood processing and road-building industries, as well as in construction materials production. Basic agricultural crops include wheat, rye and oat. The total area of plantings is 18,500 hectares and tends to reduce due to economical reasons.

The specifics of social and economical living conditions of population within the OZ of SS Rivne NPP is defined by annual amount of subventions invested in the regional infrastructure.

Therefore, the most important factor of impact on the demographic situation within the 30 km zone is the Town of Varash that arose due to the construction and operation of SS Rivne NPP.

Construction of the nuclear power plant involved a significant number of young people of working age, who obtained highly qualified employment during construction and operation of the NPP.

4.2 Impact of SS Rivne NPP Operations on Population Health in the Observation Zone

The ultimate goal and main task of all environmental protection measures are preserving and promoting people's health, which is the main criterion of the state of environment. In this regard, assessment of the environment may only be provided based on its actual and foretasted impact on population health.

Construction and operation of nuclear power facilities, including nuclear power plants, result in a change of radiation, environmental and health situation in the respective location areas, which may have an adverse impact on the health of population residing on these territories.

In 1976-1979, studies of radiation conditions of natural environment locations before NPP commissioning were conducted in the area of SS Rivne NPP construction, and so-called "zero background" was determined. The study results are used in assessing the radiation impact of SS Rivne NPP power units throughout their entire operation period.

The situation is currently becoming more complicated due to the fact that the major part of the Rivne NPP adjacent territory appeared to be contaminated as a result of the Chornobyl Accident in 1986. Against the background of anthropogenic environmental contamination (resulting both from operations of Rivne NPP and various industrial and agricultural facilities), emergency release of Chornobyl radionuclides caused an extra population exposure.

Figure 4.2 shows radiation contamination of a part of the territory of Ukraine with ^{137}Cs as of 10 May 1986. The Town of Varash in this map stands by its former name, Kuznetsovsk.

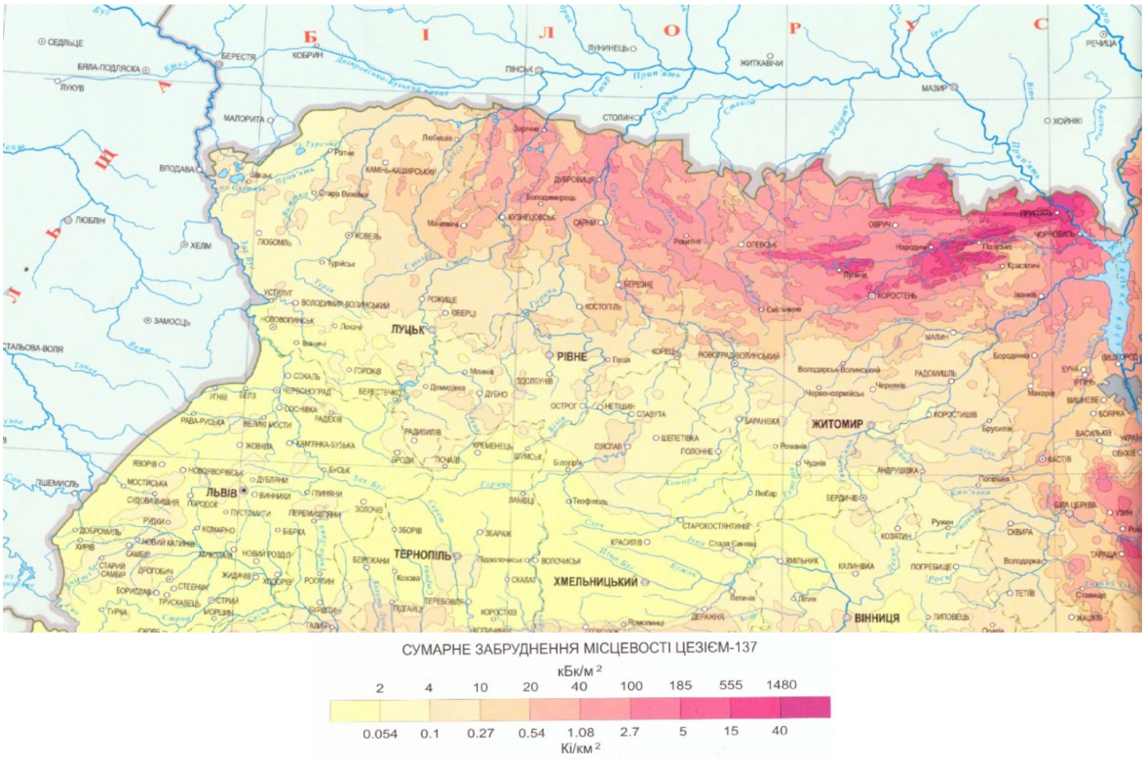

Figure 4.2. ^{137}Cs contamination of a part of Ukraine's territory.

Figure 4.3. shows radiation contamination of a part of Ukraine's territory with ^{90}Sr.

Strontium isotopes contamination is of a mixed nature: on ChNPP adjacent territories it is mainly due to a fuel component of emissions, while in regions that are 150-300 km away from the ChNPP in a south trace direction, the condensation component becomes predominant, so ^{90}Sr contamination has extended well beyond the exclusion zone.

The highest levels of ^{90}Sr contamination are observed along the west (fuel) trace and within the south trace, where fallouts had both fuel and condensation components.

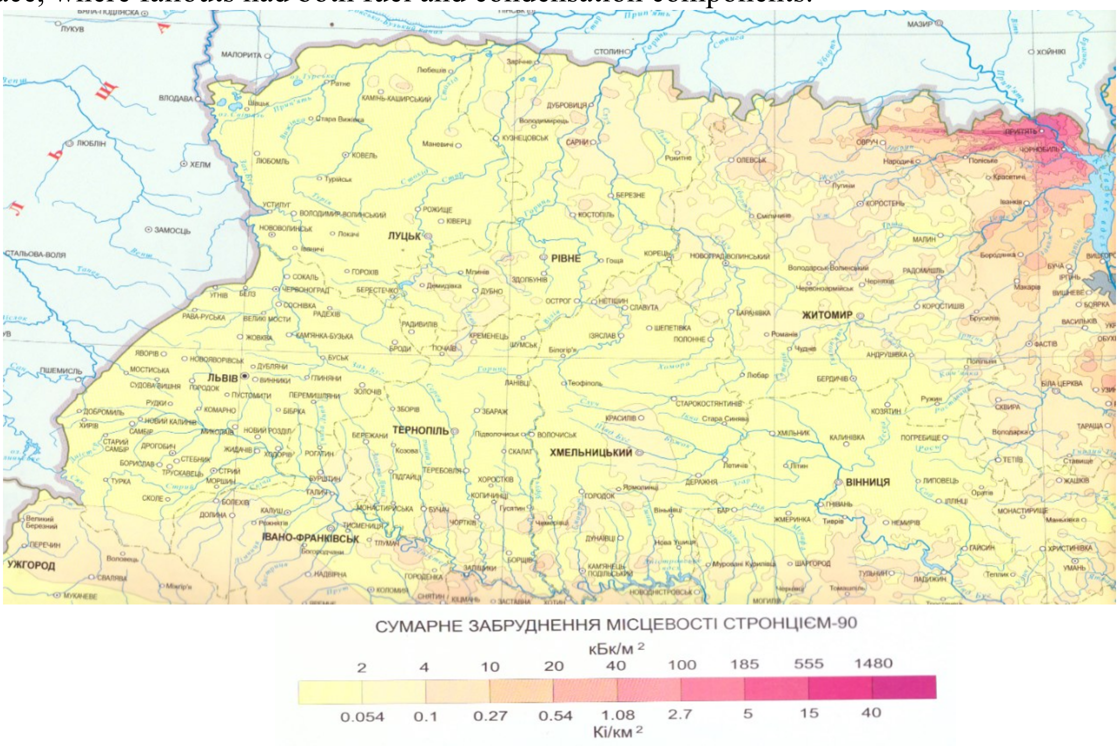

Figure 4.3. ^{90}Sr contamination of a part of Ukraine's territory.

This circumstance increases the risk of adverse anthropogenic impact on population health, since many chemical substances can change their action against the radiation background.

Numerous researches by Ukrainian and foreign authors suggest increased disease incidence in population residing within the territory that suffered contamination of various degrees after the Chornobyl Accident.

Population residing near SS Rivne NPP benefits from the environment being used by a very small number of industrial facilities, therefore it is marginally affected by industrial pollution. SS Rivne NPP is the major industrial facility in the region

During normal operation of SS Rivne NPP, the radiation conditions and population doses in the region are defined by the existing natural background radiation. SS Rivne NPP radiation impact on the population and the environment does not exceed 0.05 % of the dose level produced by natural radiation sources, and does not change the natural radiation level in the area around the NPP.

Hazardous radiation levels exist only for personnel performing radiation hazardous works, however these risks are brought to a minimum if radiation safety rules are followed. No hazardous radiation risks are present for other works and beyond working hours during normal operation of SS Rivne NPP.

Observed contribution of SS Rivne NPP in air, water and soil pollution do not exceed the permissible levels and is insignificant compared with other pollution sources. The results of long-term radiation monitoring indicate the absence of a substantial radiation impact of the NPP on the environment and, consequently, on the population health in the OZ.

The major contribution in human body radiation exposure within the OZ during normal operation of the NPP is due to natural radionuclides and their decay products. The impact of artificial radionuclides from long-range fallout, Chornobyl radionuclides and, much less, radionuclides from SS Rivne NPP releases on the radiation amount is significantly lower. The hourly dose formed from natural radionuclides exceeds the dose from annual SS Rivne NPP releases.

As a result, it can be said that Rivne NPP has no adverse effect on the population health within the SS Rivne NPP OZ.

5 IMPACT ON ANTHROPOGENIC ENVIRONMENT

5.1 Description of the Current State Within the Observation Zone

Industry within the 30 km zone around SS Rivne NPP is represented by food industry enterprises (bakery plants, dairy plants), construction material enterprises, quarries and a peat plant, motor transport enterprises, and a road construction management office. A section of the Kyiv-Kovel railway line passes 150 m south of the industrial site of the NPP. The nearest railway station Rafalivka is 5 km east of the NPP. Kyiv-Kovel state motor road passes about 20 km south of the industrial site of the NPP. There are also several gas stations, Rafalivskyi Karier PubJSC (a quarry) for the extraction of sand, gravel, clay and kaolin, Polytskyi basalt quarry, etc. within the OZ around SS Rivne NPP. In total, there are 28 industrial facilities within the OZ around SS Rivne NPP: 13 in the Volyn Region and 15 in the Rivne Region.

Public institutions are concentrated in the Town of Varash. Housing fund within the 30 km zone (except for Varash) is represented by one-story buildings with a significant degree of wear. Residential construction is not provided with district water supply, sewage and heat supply networks, even in district centres (Manevychi and Volodymyrets). Public institutions located within the zone (except for Varash) also have no utility support.

Stationary sources of atmospheric air emissions at SS Rivne NPP are concentrated on 7 production sites. Air pollutant emissions from stationary sources at each site are regulated based on separate permits.

To ensure compliance with the permit requirements, a verification schedule for compliance to the established maximum permissible pollutant emissions and permit requirements for air emissions 14 sources of air emissions are equipped with gas treatment units (GTU). Certificates were provided for each GTU. Gas treatment equipment is operated in accordance with the Regulations on Technical Operation of Gas Treatment Units. Persons responsible for the technical operation of GTUs were appointed by order of the Director General of SS Rivne NPP. In accordance with the design documents and working conditions, operating manuals for each GTU were developed and approved. Daily time records are kept for each GTU.

- Annual reports are submitted to the Main Statistics Department and the Department of Ecology and Natural Resources of the Rivne Regional State Administration according to the form 2-TP (air). Reports are developed using a calculation method based on the data on the use of raw materials, fuel, materials, and equipment operating time. During the year, stationary sources of SS Rivne NPP release 33 to 37 t of pollutants into the air, including:

- non-methane volatile organic compounds - 18-25 t;
- nitrogen compounds - 5-9 t;
- substances in the form of suspended solid particles (microparticles and fibres) -1.4-2.7 t;

sulphur compounds - 1.4-2.7 t, etc.

Air pollutant emissions from the NPP are 2-3 thousand times less than that from a coal-fired TPP with a similar installed capacity.

Sampling and monitoring of the radionuclides content in the surface air are carried out in accordance with the radiation control regulations in force at Rivne NPP once every 10 days at 16 control stations. The volumetric activity of anthropogenic radionuclides in atmospheric air over 37 years of observations did not exceed the standard values as per NRBU-97. The volumetric activity for ^{90}Sr and ^{137}Cs is within the “zero background”.

Operation of SS Rivne NPP has no adverse impact on the existing agricultural, industrial and civil buildings.

Public institutions located within the zone (except for Varash) have no utility support.

The total area of residential buildings and the main civilian facilities in Varash and in the Volodymyrets and Manevychi district centres are presented in Table 5.1.

Table 5.1. Main civilian facilities in settlements within the 30 km zone around the SS Rivne NPP

Name of settlement	Total housing area, m^2	Hospitals	Community centres, clubs	Schools	Kindergartens
Town of Varash	598719	1*	3	6	12
Sett. of Volodymyrets	126669	1**	6	6	3
Sett. of Manevychi	129540	2	2	2	-

* - the specialized primary healthcare unit No. 3 has a transfusion department, Kuznetsovsk Town District Laboratory Research Department of SE Rivne Regional Laboratory Centre of the State Sanitary and Epidemiological Service of Ukraine, Kuznetsovsk Interdistrict Disability Evaluation Board.

A network of pharmacies, dental offices, ultrasound and massage rooms is being developed in the town. A health care centre operated at Rivne NPP and insurance medicine is being actively developed.

In Varash, an English language school, language club, public library, libraries for children and youth, dance theatre school, modern choreography school, photo and video school, 12 kindergartens, 7 schools (including one gymnasium), as well as “Signal” driving school in Rafalivka and massage courses were established and operate. Sports facilities include “Energetic” swimming pool, CYSS of the Department of Education and CYSS at Rivne NPP, as well as vocational training centres VTC No. 1 and VTC No. 10.

** - Volodymyrets CDH runs a transfusion department, Volodymyretskyi District Department of Kuznetsovsk Town District Department of Laboratory Research of SE Rivne Regional Laboratory Centre of the State Sanitary and Epidemiological Service of Ukraine.

A network of pharmacies, veterinary pharmacies and medical centres is being actively developed in Volodymyrets and the region in general. The town has an optical store, a paediatrician’s office, dental offices, “Rodolad” private family medical centre, health insurance companies, etc. District department of Professional Disinfection Communal Enterprise operates in Volodymyrets.

Within the 30 km zone around SS Rivne NPP in the Volodymyretskyi District, medical facilities operate in Rafalivka, the villages of Kidra, Ozero, Velyki Tseptsevychi, and there are MOS in the villages of Sobishchytsi, Krasnosillia, Lypne, and Kanonychi.

In Manevychi, only 2 medical facilities operate: Manevychi Central District Hospital and Manevychi District Primary Healthcare Centre. The settlement has the Manevychi Children’s and Youth Sports School, a general education school levels I through III and a gymnasium. There also is a District Community Centre and a Department of Culture at Manevychi District State Administration.

5.2 Impact on Anthropogenic Objects

During normal operation, the impact of SS Rivne NPP on the anthropogenic environment is limited by the following factors:

- activities and infrastructure that may develop in adjacent territories of the NPP are restricted for security reasons: such restrictions include, in particular, potentially hazardous activities, recreational activities, flying objects, transportation of hazardous substances;
- the presence of the NPP promotes local economy, small and medium-sized businesses, providing direct or indirect services related to operations of the NPP;
- SS Rivne NPP satellite town profits from certain infrastructure investments by the NPP.

Harmful air releases and water discharges, thermal releases and discharges, as well as water consumption by the NPP do not significantly affect the anthropogenic environment.

In the case of design basis accidents at SS Rivne NPP, including the MDBA, their negative impact on the man-made objects will not exceed the permissible limits and will not require any special measures.

In the case of an analysed beyond design basis accident, temporary restrictions on the use of food produced within a restricted area along the accidental radioactive trail may be necessary.

So, during normal operation, SS Rivne NPP does not produce an adverse impact on the anthropogenic environment.

5.3 Impact of Man-made Objects on SS Rivne NPP Operations

According to the Code of Civil Protection of Ukraine, anthropogenic security characterizes the state of protection of population and territories against anthropogenic emergencies.

The reliability of the operation of NPP buildings and structures depends on the stability of geological environment under the foundation bases. In turn, the geological environment stability is defined by both natural factors (composition and state of the soil profile, geological stability, development of exogenous geological processes, etc.) and the impact of anthropogenic factors, namely operating industrial facilities.

Data of geotechnical and instrumental seismological surveys as well as formal methods for geological, geophysical and seismic data processing were used for seismic and tectonic zoning of the territory around SS Rivne NPP. The results of this set of surveys show that the seismic magnitude, based on the seismic microzoning for SS Rivne NPP site, is as follows: design basis earthquake (probability — once in 100 years): magnitude 5, maximum estimated earthquake (probability — once in 10,000 years): magnitude 6, which corresponds to the values accepted in the project.

The construction site of SS Rivne NPP was selected in 1965 by the government commission as the most favourable site in the Rivne Region of the Ukrainian SSR based on the entire set of all factors, in particular geotechnical. The site was selected in compliance with all regulatory requirements then in force, and agreed upon with the ministries and departments concerned. Over 1800 wells were drilled during the design process. No caverns were found during the survey of the territory.

However, in April 1982, a crater with a diameter of 3 m and a depth of 2.5 m was formed in the excavation for workshop in the special building of unit No. 3, which was under construction. The results of additional geotechnical surveys demonstrated that karst-suffosion processes in the geological section of SS Rivne NPP site in chalk rocks (depth of occurrence of 25 ÷ 40 m) are possible. In connection with the individual manifestations of this process that occurred at SS Rivne NPP site, the commission formed by the Council of Ministers of the USSR in 1983 and the Ministry of Energy of the USSR determined the appropriate measures to ensure reliable and safe operation of operating power units No. 1 and No. 2, unit No. 3 (which was under construction), and unit No. 4 (which was on the design stage).

To ensure the operational reliability of buildings and structures as well as to prevent karst processes:

- cemenation of the chalk layer and basalt contact zone under the main buildings and structures of SS Rivne NPP was performed;
- at the same time, soils that cover the chalk layer were reinforced with bored piles;
- measures to limit the impacts on the groundwater regime were developed and implemented, in particular, repair and waterproofing of water communications were performed;
- programs for hydrogeological environment monitoring were developed and implemented to study the development of karst-suffosion processes and control the geological environment stability.

Essential structures of power unit No. 4 were built on piles, which are based on basalts and, consequently, completely cut through the layer that is exposed to karst processes, which ensures the reliability of their operation. Soil cementation was carried out under the rest of buildings and structures of power unit No. 4.

On 20 April 2002, a meeting of an independent expert group chaired by V. M. Shestopalov, Member of the National Academy of Sciences of Ukraine, was held at SS Rivne NPP to discuss the geotechnical state of the industrial site and base soils of structures at Rivne NPP. The following was established by the expert group:

- the structures were operated in a stable mode, levels of soil subsidence and core samples from the buildings over the entire period of operation were well below the design values;
- the efficiency of the anti-karst measures under buildings of power units No. 1-3 (in particular, cement grouting of the chalk layer) is confirmed with time;
- continuous attention at SS Rivne NPP was paid to the geological and anthropogenic state of the environment and to the reliability of operation of the buildings;
- the possibility of building power unit No. 4 on piles based on basalts, which will cut through the chalk layer, raises no doubts.

Over the last 35 years of observations in the territory of SS Rivne NPP, no karst-suffosion processes were observed on the soil surface. Permanent monitoring of soil and groundwater conditions, buildings and structures of power units No. 1-4 and the industrial site confirms the stability of geological environment and is the key factor for ensuring safe operation of SS Rivne NPP.

- In order to provide anthropogenic safety, SS Rivne NPP provides permanent monitoring of the state of soils, buildings and structures of power units No. 1-4 and the industrial site:
- hydrogeological observations of the groundwater regime (measurements of the level and temperature of groundwater, determination of their chemical composition) in 193 observation hydrogeological wells;
- monitoring of humidity and density of soils under the bases of buildings and structures of the site using the method of radioisotope logging in 193 geophysical wells;
- control of subsidence and deformation of buildings and structures at 3,288 subsidence points;
- inspections of buildings and structures;
- monthly inspection of the territory to detect karst-suffosion manifestations in accordance with the regulatory documents and programs developed, and continuously cooperates with leading scientific organizations in the field of control of the geotechnical state of soils, geodesic control over the soil subsidence and deformations of buildings and structures, and safe operation of buildings and structures.

Annual reports are drawn up based on the works performed.

Within the frame of extension of operational lifetime of power units No. 1 and No. 2, SE Kyiv Institute of Engineering Surveys and Research "ENERGOPROEKT" performed a set of geotechnical surveys and geophysical soil studies in 2008. According to the results of the studies, Scientific and Technical Report on Geotechnical Survey (a comprehensive analysis of the soil conditions at the bases of buildings and structures) 14-349/07-08, 10-439.1 was issued with a positive conclusion on further safe operation of buildings and structures.

Within the frame of extension of operational lifetime of power unit No. 3, SE Kyiv Institute of Engineering Surveys and Research "ENERGOPROEKT" developed Scientific and Technical Report on Complex Geotechnical and Geophysical Survey 14-126-08, 10-726-1 in 2014. The results of the studies suggested that the engineering and geological situation within the structures of power units No. 1-3 are in line with the operational lifetime extension, namely:

- karst monitoring did not record any active karst processes;
- the observation data on subsidence of buildings did not exceed the permissible values;
- according to hydrogeological monitoring data, the hydrogeological situation is characterized as stable and controlled by all indicators;
- soil condition ensures reliable operation of structures.

Also, a survey and assessment of the technical condition of buildings and structures of power units were conducted at power units No. 1 and No. 2 in 2007-2010 and at power unit No. 3 in 2013-2016.

According to the results of the surveys, specialists of Prydniprovska State Academy of Civil Engineering and Architecture issued positive opinion on further extension of operation of power unit buildings and structures. Decisions on further operation of power unit buildings and structures were agreed with the SNRIU.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

6 TRANSBOUNDARY ENVIRONMENTAL IMPACT ASSESSMENT

In accordance with the requirements of the International Convention on Environmental Impact Assessment in a Transboundary Context, as ratified by the Law of Ukraine No. 534-XIV dated 19 March 1999, the radiation environmental impact of Rivne NPP in a transboundary context, i. e. its impact on the territories of the neighbouring states, has been assessed. The impact of RNPP has been assessed both during normal operation and during accidents.

The degree of environmental impact was assessed taking into account the amounts of radioactive releases, which were monitored daily or once a month.

The amounts of radioactive releases are monitored by IRG, LLN and iodine radionuclide groups in the following ventilation systems:

- VS of power units No. 1, 2;
- VS-1 at PR of power units No. 3, 4;
- VS-2 at PR of power units No. 3, 4 (during operation of 3TL-21, 4TL-21 systems);
- VS at SPB of power units No. 3, 4.

IRG release activity was measured on a continuous basis using PING-206S (units Nos. 1, 2, 3) and RKS-07P (unit No. 4) radiation detectors.

LLN and radioiodine samples were taken on a continuous basis using AFA-RMP-20 and AFAS-I-20 filters. Filters were sampled and checked using FHT-770S radio detectors on a daily basis for the purposes of in-process monitoring of LLN release (following 1 day exposure and not taking into account the activity at the time of filter installation). In-process monitoring of radioiodine was performed by γ-spectrometry at the Radiation Safety Laboratory.

For the purposes of radionuclide content monitoring, AFA-RMP-20 filters were kept for a month and then tested at the External Radiation Monitoring Laboratory by γ-spectrometry using GEM solid-state detectors and DSPEC PLUS multichannel pulse analysers by ORTEC (USA). Release activity calculation was in compliance with the requirements of MM-I.0.03.025-14 “Model procedure for gamma-spectrometry of gamma-emitting radionuclides activity in loads sampled from NPP process media”.

The acceptable gas-aerosol release (GAR) levels are calculated in accordance with NRBU-97 requirements taking into account the limit dose rate, and are not affected by NPP capacity. The acceptable and reference GAR and liquid discharge levels at RNPP were approved by the MoH of Ukraine.

Table 6.1. Calculated values of air radionuclide releases from SS RNPP facilities during normal operation

Radionuclide group	Radionuclide name	Release, Bq/year
IRG	^{88}Kr	2.35×10^{12}
	^{133}Xe	1.69×10^{13}
	^{135}Xe	4.23×10^{12}
Iodine	^{131}I	9.43×10^{7}
	^{133}I	5.04E$\times10^{7}$
	^{135}I	1.31×10^{7}
LLN	^{137}Cs	6.28×10^{6}
	^{134}Cs	9.66×10^{5}
	^{60}Co	7.27×10^{6}
	^{58}Co	1.09×10^{6}

Radionuclide group	Radionuclide name	Release, Bq/year
	^{54}Mn	1.22×10^{6}
	^{51}Cr	4.56×10^{6}
	^{90}Sr	2.60×10^{5}
	^{59}Fe	3.28×10^{5}
	^{95}Zr	5.80×10^{5}
	^{95}Nb	2.23×10^{6}
	^{110m}Ag	4.71×10^{6}
Tritium	^{3}H	1.01×10^{12}
Radiocarbon	^{14}C	1.99×10^{11}

The absolute distances and weather sectors indicated by arrows in Figure 6.1.

Figure 6.1. The distance to neighboring countries from the Rivne NPP

<u>The distance to neighboring countries from the Rivne NPP</u>

Belarus - 60 km
Poland - 130 km
Lithuania - 310 km
Slovakia - 340 km
Moldova - 360 km
Romania - 370 km
Hungary - 410 km
Czech Republic - 510 km
Austria - 700 km
Germany - 710 km

6.1 Doses at Borders With the Neighboring States During Normal Operation

The calculation of total expected individual doses from SS Rivne NPP in representatives of the population at borders with the neighbouring states, is given in Table 6.2 and in Figure 6.2. The distances in Figure 6.2. Dependences of the total dose on distances for two population categories — infants under 1 YOA and adults — have been shown. Expected annual doses were calculated after 50 years of releases. As seen from the table, the critical group in this case is represented by infants who are exposed to higher doses. Calculations for the critical group represented by children under 10 resulted in mean values between adult and infant doses. This data is omitted.

Table 6.2. Expected dose, nSv/year

Country	Infants	Adults
Belarus	1.5	1.3
Poland	0.82	0.7
Lithuania	0.3	0.26
Slovakia	0.35	0.3
Moldova	0.26	0.22
Romania	0.2	0.17
Hungary	0.29	0.25
Czech Republic	0.2	0.18
Austria	0.15	0.13
Germany	0.14	0.12

However, the expected doses are rather low. The maximum value is expected to occur at the border with Belarus, which is the nearest country to RNPP. These doses are within 1 nSv/year, which is well below the limit dose rate for NPP releases, which is equal to 40,000 nSv/year (see NRBU-97) and population radiation rates during normal NPP operation in Russia, which is equal to 200,000 nSv/year

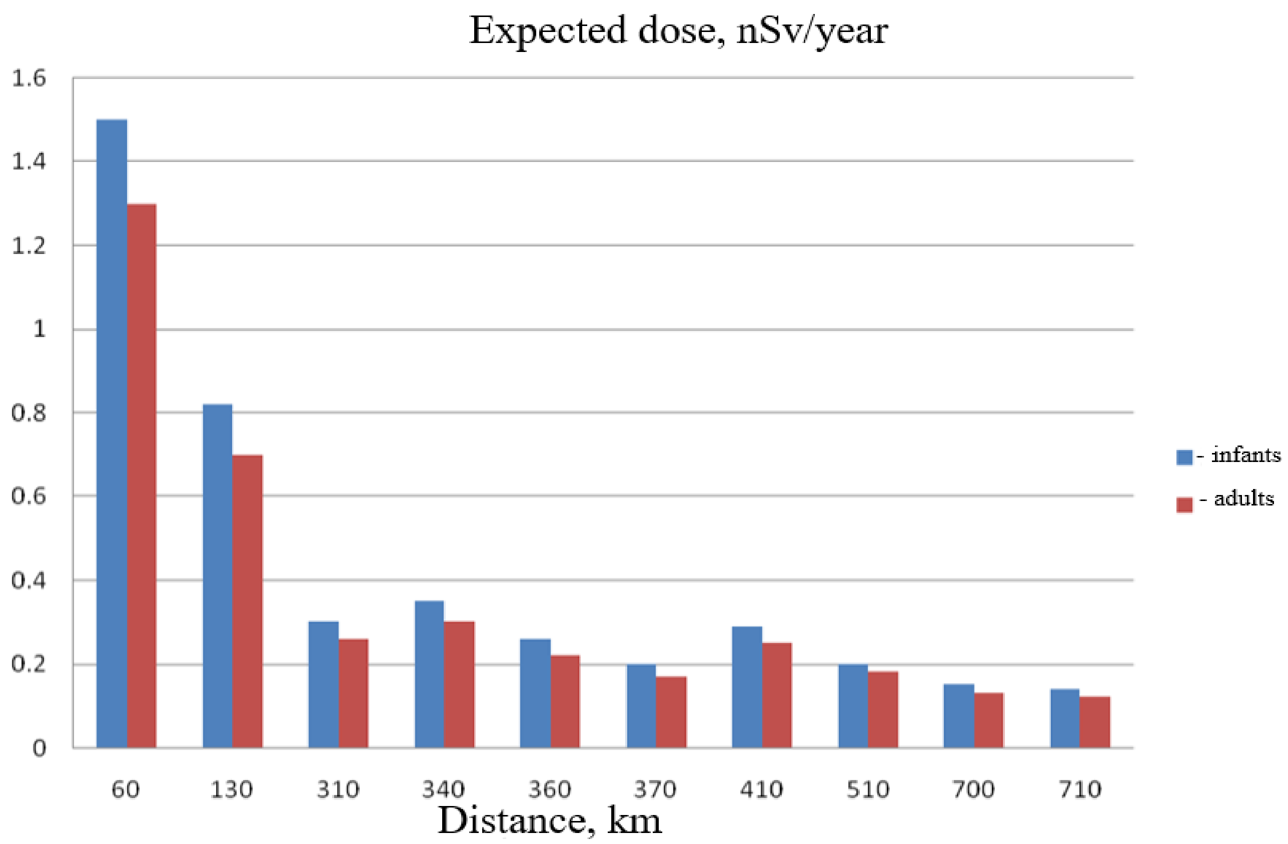

Figure 6.2. Total expected individual doses from the NPP in population
(the distances refer to countries in Figure 6.1)

So, the impact on the neighboring countries will be well below the established dose rates and limits for individual effective annual doses of 1 mSv (1,000,000 nSv) for the population.

Nonuniform reduction of doses based on the distance is due to the weather conditions, which are only measurable for 16 discrete sectors. Vectors from RNPP to the nearest borders of different countries (see Figure. 6.1) are located in different sectors, so, even though the doses reduce as the distance grows, the wind pattern may reverse this dependence. In Figure 6.2, this is true for Lithuania (310 km) and Slovakia (340 km), as well as for Romania (370 km) and Hungary (410 km).

Let's analyse partial shares in full doses for different radionuclides and radiation routes in infants at the border with Poland, as an example. The relative ratios of the above data are nearly the same for other countries, however their values are proportional to the full dose (Figure 6.3).

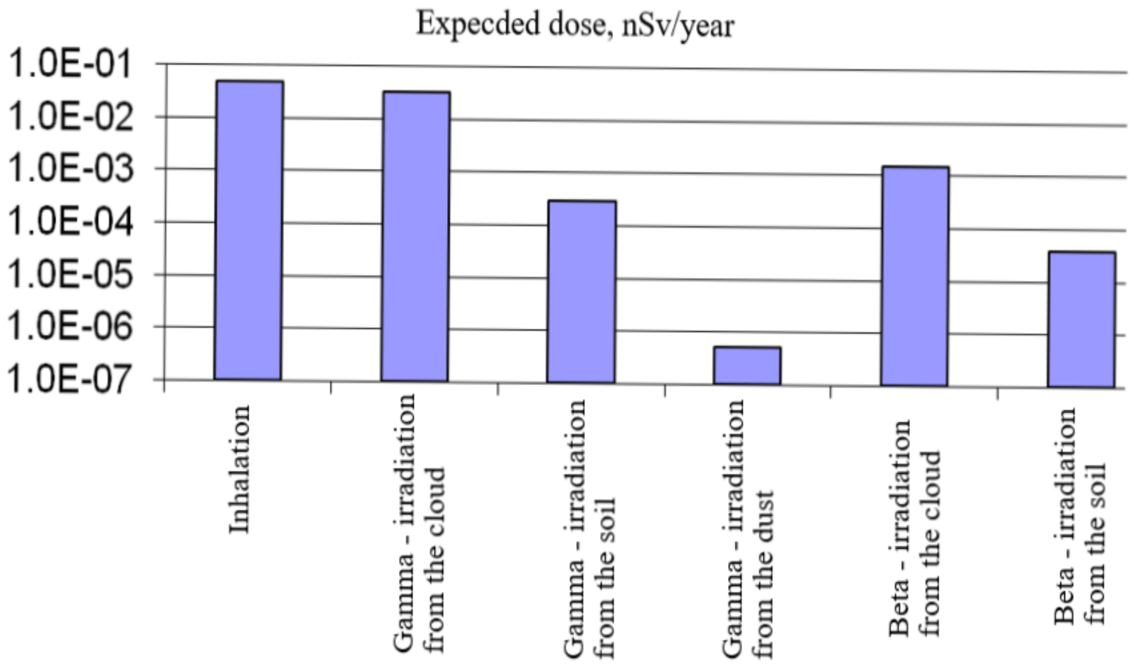

Figure 6.3. Relative share in expected individual doses for infants at the border with Poland

Figure 6.3 shows shares (for inhalation and external radiation) in the full expected dose over a year after 50 years of releases in infants within 130 km from RNPP (at the border with Poland). The maximum share of 0.05 nSv/year is due to inhalation intake. The value is practically the same for gamma-ray photon radiation from the release cloud. The share of gamma radiation from soil is lower by two orders of magnitude. With the full dose at this distance of 0.82 nSv/year, radiation from the above sources accounts for about 5.6 %, while the rest of the dose is obtained from food products.

The maximum share of 0.56 nSv/year is due to milk consumption. The share of cereals is lower; it makes 0.47 nSv/year.

The share of fruits and berries, which contain radionuclides that affect breast milk, is 2 times lower (0.27 nSv/year). Root crops and green vegetables account for a significant share, also absorbed through breast milk. Dairy products (cream, butter, cheese, etc.), similar to meat products, account for a negligible share. In general, food products provide a major share (94.4 %) in the total expected dose.

The major share in the total expected dose over a year after 50 years of releases of all radionuclides during normal operation is due to the following radionuclides: ^{14}C, ^{3}H, ^{131}I and ^{88}Kr, see data in Figure 6.4. This figure shows calculated shares of different radionuclides in expected individual doses in infants at the border with Poland.

It should be noted that the listed shares in the total dose reduce as the distance grows roughly the same as the total dose in Figure 6.2.

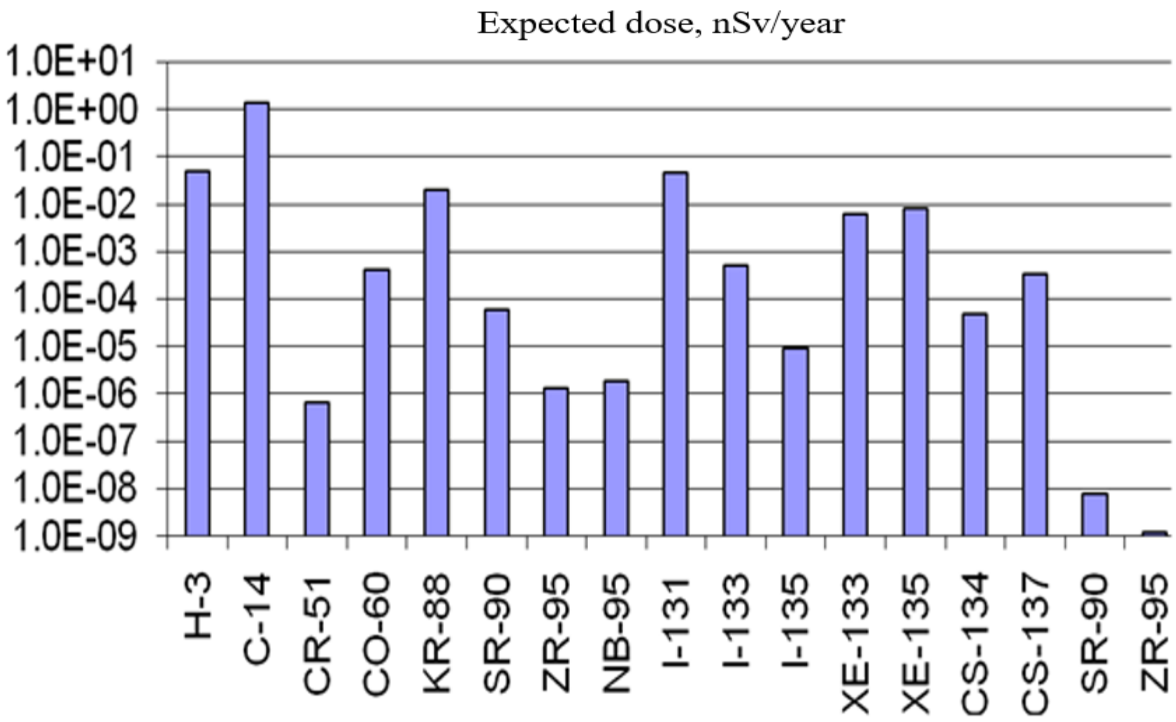

Figure 6.4 Relative shares of different radionuclides in expected individual doses in infants at the border with Poland

6.2 Transboarding Impact in Emergency Situation

The radiation impact of Rivne NPP was analysed based on the following maximum design basis accident (MDBA): an accident caused by double-ended rupture of the cooling system pipeline (loss-of-coolant nuclear reactor accident) at normal energy level.

Radionuclide intake during the beyond design basis accident (BDBA) was determined based on the limit value of environmental release of ^{137}Cs at the level of 30 TBq in accordance with the safety requirements of European operators for designs of nuclear power plants with light water reactors (LWR). ^{137}Cs isotope was chosen due to its prevalent value for long-term environmental pollution as well as its health impact.

Other isotopes in the form of aerosol (i. e. all radioactive decay products, except for inert gases and gaseous iodine isotopes) are released into the environment in proportion to this value, even if these isotopes are released into the atmospheric air.

The release activity of inert gases and gaseous iodine isotopes was calculated at 0.5 % of the total daily activity within the containment. The conservative value of the total release activity over the entire period of the release was established at the level of 7-fold release activity during day one.

The conservative release height is considered to be at the surface air level, which corresponds to the forecast release routes in case of major accidents due to containment leakage.

The total list of radionuclides that may be released in the environment, except for illustrative isotopes, includes other radioisotopes from the same group, which are present in the general member in proportion equal to that of the sum of decay products in the reactor core with respect to the illustrative isotope.

The dose of the proposed source member should be calculated taking into account the release of separate radioisotopes based on the time interval of linear duration of 0 to 24 hours following the accident - a conservative approach compared to the considered release duration of 7 days.

Table 6.3 shows radionuclide release parameters during the MDBA. The accident duration is taken to be 60 minutes. Other accidents that result in lower radionuclide releases are omitted.

Table 6.3 — Radionuclide release activities during the MDBA at RNPP, Bq

Radionuclide	Half-life	Release during MDBA
^{88}Kr	2.84 hours	2,00E+13
^{90}Sr	29.1 years	3,10E+11
^{103}Ru	39.6 days	4,50E+12
^{106}Ru	1.01 years	6,60E+11
^{131}I	8.04 days	4,98E+12
^{132}I	2.3 hours	2,70E+12
^{133}I	20.8 hours	4,00E+12
^{135}I	6.61 hours	2,30E+12
^{134}Cs	2.06 years	7,80E+11
^{137}Cs	30.0 years	5,00E+11
^{140}La	1.68 days	8,40E+12
^{141}Ce	35.2 days	1,40E+13
^{144}Ce	284 days	8,60E+12

Primary radionuclides and their respective releases in case of the BDBA are listed in Table 6.4.

Table 6.4 — Radionuclide release activities during the BDBA at RNPP, Bq

Radionuclide	Release amount, TBq	Radionuclide	Release amount, TBq
^{133}Xe	3,50E+05	^{136}Cs	1,50E+01
^{85}Kr	2,10E+03	^{131m}Te	2,00E+01
^{85m}Kr	5,30E+04	^{129m}Te	8,00E+00
^{87}Kr	1,10E+05	^{132}Te	2,00E+02
^{88}Kr	1,40E+05	^{127}Sb	1,60E+01
^{131m}Xe	2,10E+03	^{129}Sb	4,60E+01
^{133m}Xe	1,10E+04	^{90}Sr	5,00E+00
^{135}Xe	1,10E+05	^{89}Sr	6,00E+01
^{135m}Xe	7,70E+04	^{91}Sr	7,50E+01
^{138}Xe	3,20E+05	^{103}Ru	3,00E+00
^{131}I	1,00E+03	^{99}Mo	4,00E+00
^{132}I	1,50E+03	^{140}La	5,00E+00
^{133}I	2,10E+03	^{91}Y	4,00E+00
^{134}I	2,30E+03	^{141}Ce	4,00E+00
^{135}I	2,00E+03	^{144}Ce	3,00E+00
^{137}Cs	3,00E+01	^{239}Np	4,80E+01
^{134}Cs	6,00E+01	^{140}Ba	1,00E+02

Calculations of expected effective doses for 50 years at different distances from RNPP during the MDBA and BDBA are shown in Figure 6.5. The continuous curve in Figure 3.6 demonstrates the dependence of the effective dose for 50 years on the distance in case of a BDBA, while dashed curve indicates the same in case of a MDBA.

Based on the data in Figure 6.5, expected efficient doses reduce rapidly as the distance grows, and expected efficient doses during the BDBA are higher than the same during the MDBA by approx. two orders of magnitude.

The Radiation Safety Standards of Ukraine set the doses that require countermeasures to protect the population for radiation accidents.

The dose of 1 Gy for 2 days has not been exceeded since the total effective dose for 50 years is much below this value.

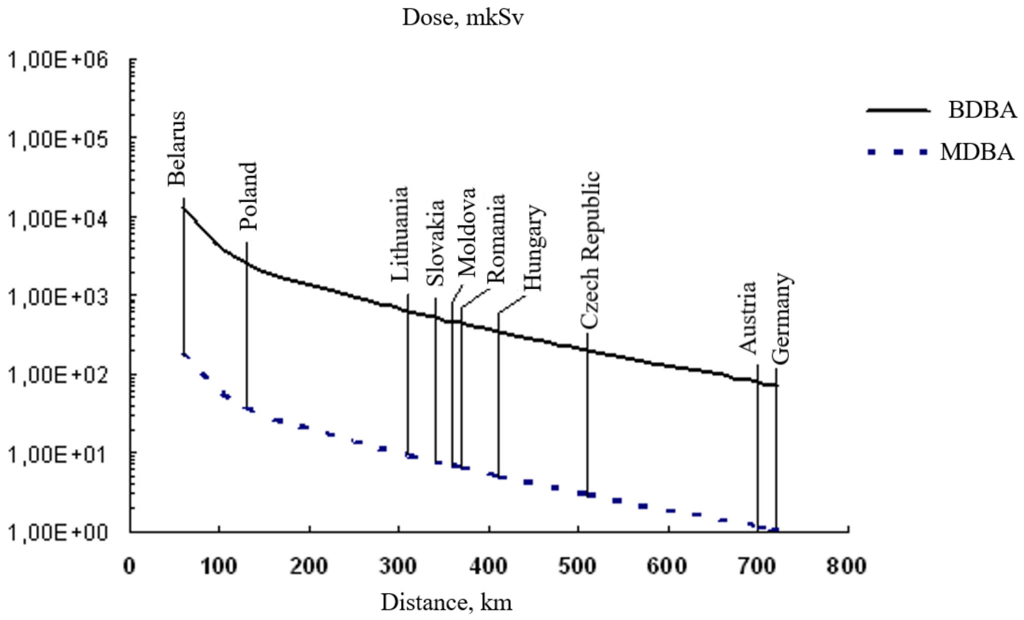

Figure 6.5. Dependence of the expected effective dose on distance during the MDBA and BDBA at RNPP

The dose of 5 mSv for the entire body for the first 2 weeks has not been exceeded since the calculation for the Republic of Belarus, which is the nearest country to RNPP, for the same period results in a value of 0.19 mSv for 2 weeks.

7 COMPREHENSIVE MEASURES TO ENSURE ENVIRONMENT CONDITION AND SAFETY COMPLIANCE

7.1 Protective Measures

SS Rivne NPP was designed in accordance with the requirements of the regulatory documents and the emergency response system is in operation, which is an interconnected set of technical means and resources, organizational, technical, radiation and hygienic measures implemented by SE NNEGC “Energoatom” to prevent or reduce radiation exposure to personnel, the population and the environment in the event of a nuclear or radiation accident at the NPP, as well as to provide civil defence.

According to the document, the emergency preparedness and response system (ERS) of SS Rivne NPP is defined as a component of the Preparedness and Response System of SE NNEGC “Energoatom” for the event of accidents and emergencies on NPPs of Ukraine, which is an interconnected set of technical means and resources, organizational, technical, radiation and hygienic measures implemented by the operating organization to prevent or reduce radiation exposure to personnel, population and the environment in the event of a nuclear or radiation accident at the NPP.

ERS has two interrelated levels:

- Level of SE NNEGC “Energoatom” Directorate (Company’s Management level ERS);
- NPP level (NPP ERS).

The main goals of SS Rivne NPP ERS are:

- maintenance of the required level of SS Rivne NPP emergency preparedness;
- response to accidents and emergency situations at SS Rivne NPP including implementation of measures to protect personnel, population and the environment.

The main SS Rivne NPP ERS measures to maintain the required level of emergency preparedness are:

- development and timely review of the emergency plan;
- outfitting and maintaining the technical support centre and internal and external crisis centres in good working condition;
- arrangement of interaction with the SE NNEGC “Energoatom” crisis centre, centre for organization of interaction and assistance to NPPs, Information Centre of the State Regulatory Authority for Nuclear and Radiation Safety, and regional and local authorities of the territorial and functional subsystems of the unified civil defence system;
- maintaining in good working condition and improving the system for collecting, processing, documenting, storing, displaying and transmitting data from SS Rivne NPP crisis centres, alarming and communication systems;
- timely creation and maintaining the preparedness state of the emergency system: control and measuring devices and equipment, personal protective equipment, decontamination and sanitation means, tools, devices and other emergency means;
- training of emergency personnel, emergency training, including plantwide emergency training, development of schedules and training programs;
- maintaining and updating regulative, organizational and process documentation for emergency preparedness and response;
- ensuring accident response readiness in case of commissioning of new radiation-hazardous objects at SS Rivne NPP.

The main accident and emergency response measures at SS Rivne NPP ERS are:

- identification and classification of accidents and other hazardous events at SS Rivne NPP;
- alarming for SS Rivne NPP management and personnel, the population of the neighbouring town, responsible persons of the operating organization, the state regulatory body for nuclear and

radiation safety, central and local executive authorities, local self-government bodies, other bodies, institutions and organizations participating in emergency response, informing them about the occurrence of an accident and initiated countermeasures;

- introduction of the emergency plan, cancellation of actions according to this plan;
- support of the main control room personnel, operational staff of SS Rivne NPP related to beyond design basis accident management;
- estimation and forecasting of accident scenarios, consequences, estimation of radioactive substances releases and discharges, monitoring and prediction of radiation condition changes, personnel exposure doses;
- implementation of works on the accident consequences elimination, including urgent emergency construction, repair and other works;
- logistic support of emergency measures;
- implementation of measures for the protection of SS Rivne NPP, radioactive contamination zones;
- interaction with the state regulatory body for nuclear and radiation safety;
- interaction with management bodies and forces of the “Nuclear power and fuel and energy complex” functional subsystem of the Ministry of Energy and Coal Industry of Ukraine, other territorial and functional subsystems of the unified civil defense system involved in emergency response;
- documenting the accident conditions and emergency response measures. The main ERS measures for personnel protection are:
- personnel radiation protection measures;
- delivery of health care.

The main ERS activities for the protection of population and the environment are:

- in-depth monitoring of radiation parameters for the environmental objects and population exposure doses within the OZ;
- prediction of population radiation exposure doses within the OZ;
- informing central and local executive authorities, as well as local self-government, about the results of monitoring and exposure dose prediction;
- providing recommendations to central and local executive authorities as well as local self-government bodies on countermeasures to protect the population.

Emergency response actions performed by the NPP with the exception of measures for the protection of the population and the environment are limited to the NPP site and the sanitary protection zone. The population and the environment protection measures performed at the NPP are limited to the observation zone.

7.2 Compensation Measures

7.2.1 Compensation for Environmental Damage

During the last years, the legal management of SS Rivne NPP has not received any materials that should be interpreted as claims requesting for compensation for environmental damage, or these claims were not acknowledged in the procedure established by law. Cases of penalty payment by the accounting department of SS Rivne NPP for violating the legislation on environmental protection. These amounts were deducted in full from the wages of employees in accordance with Article 132 of the Labour Code of Ukraine.

7.2.2 Social and Economic Management of Risk for Population Within the Observation Zone Around the NPP

SS Rivne NPP is not only an environmentally friendly site for the production of thermal and electric energy, it also has an annual social guarantee in the form of a state subvention, which adds to budgets of settlements within the nuclear facility observation zone.

In accordance with the current legislation of Ukraine, the population permanently residing within the 30-kilometre observation zone around NPP has the right to receive social and economic compensation for risks caused by operation of NPP, which particularly includes: development and maintenance of a special-purpose social infrastructure in good condition, preferential tariffs for the consumed electric energy set in accordance with the Law of Ukraine “On Electricity”

According to the Resolution of the Cabinet of Ministers of Ukraine, the distribution of state subventions between local budgets of settlement within the observation zones of nuclear power plants is as follows:

- 30 % - for regional budgets;
- 55 % - for district and regional subordination city budgets;
- 15 % - for budgets of satellite-towns of nuclear facilities.

These funds are used exclusively for the purposes and in the manner established by the Cabinet of Ministers of Ukraine.

Subventions are directed, first of all, for:

- construction, reconstruction, capital and current repair of facilities of special social infrastructure and protective structures of civil defence;
- purchase of respiratory protective equipment and stable iodine pills;
- population training on the use of protective equipment and civil defence facilities.

Control over the purposeful use of funds by local authorities and local self-government bodies is carried out in accordance with the current legislation.

Taking into account the subvention amounts for socio-economic compensation for risks to the population within the observation zone, Rivne NPP is the main budget-forming enterprise in the region contributing to its sustainable economic development.

In 2017, the government directed more than 32 million hryvnias (UAH) of state subsidies to finance social and economic compensation measures for the population living in the OZ of SS Rivne NPP.

Distribution of subventions to local budgets in 2017 was as follows:

- Rivne region (regional share) - UAH 7 million 18.3 thousand;
- Volyn region (regional share) - UAH 2 million 757.9 thousand;
- Manevitsky district (Volyn region) - UAH 7 million 227.6 thousand;
- Volodymyrets district (Rivne region) - UAH 9 million 895.9 thousand;
- Sarny district (Rivne region) - UAH 646 thousand;
- Kostopilsky district (Rivne region) - UAH 153.6 thousand;

Town of Varash (Rivne region) - UAH 4 million 888.1 thousand.

7.3 Protection Measures

7.3.1 Radioactive Fallout Protection Measures

Warning or mitigation of radioactive emissions is ensured by the following technical solutions:

- cleaning of air containing radioactive substances by means of filters;
- using closed loops to prevent leaks of liquid substances containing radioactive components;
- arrangement of a special system for collecting and storing LRW and SRW;
- establishment of SPZ and OZ;

ongoing monitoring of emissions into the air, as well as levels of radioactive contamination of soils, flora and water in the SPZ and OZ.

7.3.2 Non-radiation Impact Protection Measures

Appropriate organizational measures taken to ensure stable operation of SS Rivne NPP power units are as follows:

- hydrological station has been put into operation on the Styr River in Varash (downstream of the water intake and discharge of Rivne NPP);
- power units regime schedule based on condition of the Styr River has been developed; the Styr River.
- purification of one hundred percent of added water for feeding water circulation systems at the make-up water treatment facilities;
- minimum sanitary water consumption from the Styr River during the low-water months of the year;
- the following instrumental measurements are carried out by a certified laboratory: industrial emissions into the atmosphere from stationary sources; circulation and surface waters; soils, underground waters and atmospheric air in the areas of waste disposal sites. The results are recorded in the primary accounting documents;
- hazardous waste is removed, as well as secondary raw materials are sold;
- civil liability insurance to cover environmental accidents at SS Rivne NPP and insurance for hazardous goods transportation;
- subdivisions carry out primary accounting of emissions, water use, wastes, develop and submit environmental protection reports to the management of SS Rivne NPP, SE NNEGC "Energoatom", tax inspectorate, as well as state statistics, management and supervision bodies;
- maintenance, repair and reconstruction of production assets related to environmental protection is carried out;
- in-house supervision, including instrumental and laboratory supervision, is ensured as well as inspections of the environmental protection legislation compliance at SS Rivne NPP by state supervisory bodies;
- environmental tax and rent payments for the use of natural resources (water) are calculated and paid.

Scheduled environment protection measures are carried out in due time; work progress monitoring system is established and operating. The industrial activity of SS Rivne NPP does result in any adverse changes in the environment.

7.4 Radiation Monitoring of the Environment

In 1978, two years prior to commissioning of the power unit of Rivne NPP, the external radiation monitoring laboratory was established at the plant with the main function of identification of radiation impact from plant operation on the population and environment. In 2001, the laboratory of automated radiation monitoring system (ARMS) was established.

Radiation monitoring is implemented in accordance with "Technical Specification on Radiation Monitoring" 132-1-Р-ЦРБ, agreed with the Main State sanitary doctor of the facility and State Nuclear Regulatory Inspectorate of Ukraine. According to the Technical Specification, about 2500 environmental samples in the territory of Rivne NPP location are taken and measured.

The monitoring process comprises monitoring of radioactive releases into the atmosphere, monitoring of atmospheric air, precipitations, flora, pine-needle, soil, agricultural products, dose rates, liquid effluents, water, bottom deposits, fish and weeds of the Styr River. In general, the radiation monitoring covers 43 out of 110 settlements of OZ of Rivne NPP.

The normative document NRBU-97 specifies the dose limits for the personnel that works with the sources of ionizing radiation (Category A for exposed persons) and population (Category C).

A dose limit is the main radiation and health-related standard, which aims at limitation of radiation influence on the personnel and population from all industrial ionizing radiation sources (IRS) in the situations of practical activity. The dose limit for industrial IRS is 1 mZv/year for the population, whish is several times less than radiation dose from the natural sources. The quota of 8% was set for NPP from this limit to fulfill operation of all power units, independent from their number.

Regulation and monitoring of the Category B exposure is conducted upon calculations of the annual radiation effective dose for the critical groups. The critical group is a population group, which can obtain the highest levels of radiation from the source based on their age and gender, social and professional conditions, place of living and other indicators.

Limitation of the Category B exposure is accomplished through regulation and control of the activity of environmental objects (water, air), gas and aerosol releases and liquid effluents during plant operation. For gaseous and aerosol releases and liquid effluents, the allowed radiation levels are established. At these levels, the total annual effective dose of a critical group representative, with regard to all radionuclides present in the releases and effluents, does not exceed the quota for the dose limit. The established levels are reviewed and agreed on a regular basis with the Ministry of Health Protection of Ukraine.

In order to reduce the personnel and population exposure limit below the dose limits, based on the actual achieved radiation adequacy level, the plant introduced the radiation monitoring levels. The monitoring levels are defined based on the analysis of actual releases and effluents for the last five years.

For the prompt response to the changed release and effluent activity, the operator NNEGC "Energoatom" introduced the additional indicators – administrative technological release levels. The release levels are defined for each power unit during at-power operation and during maintenance activities.

During operation, the plant conducts continuous monitoring of non-exceedance of administrative technological, reference and allowed levels of releases and effluents from Rivne NPP, as well as analysis of the manmade radionuclides activity in comparison with the values of "zero" background.

From 2000, the laboratory of external radiation monitoring was certified to conduct activities in the field of radiation monitoring of the environment. The next certification was performed in 2015. The certification covered verification of legitimacy and adequacy of equipment and methodological support; amount and qualification of the personnel, equipping of the working places, their compliance with the sanitary norms. The laboratory is equipped with the state-of-the-art measuring equipment by the advanced world manufactures. The work of the laboratory is subject to the regular inspections with participation of the representatives of the State Inspectorate for Technical Regulation and Consumer Policy (Derzhspozhivstandard) of Ukraine, State Oblast Administration for Ecology.

In addition to monitoring of the environmental radiation impact from Rivne NPP, the continuous monitoring is performed from April 2007 using automated radiation monitoring system (ARMS).

ARMS includes:

- 16 control and monitoring stations on the territory of Rivne NPP site:

✓ 6 stations of gas and aerosol release monitoring, conduct measurements of the dose rate in the ventilation stacks; concentration of radioactive inert gases, iodine, aerosols; conduct sampling to determine tritium concentration in the releases;

✓ 2 stations on the territory of the plant site, conduct measurement of the dose rate, iodine and aerosol concentration in the atmospheric air;

✓ 7 stations located on the roofs of main buildings of the site, conduct measurement of the dose rate.

- 13 stations of the territory of SPZ and OZ, conduct measurements of:

- ✓ dose rate;
- ✓ iodine and aerosol concentration in the atmospheric air during an emergency situation;
- ✓ sampling of aerosols and atmospheric air, precipitations for lab monitoring;
- ✓ ^{137}Cs, ^{60}Co activity in the stormwater sewage system, volume of discharged water, sampling of water to determine tritium concentration.

The ARMS system also includes two mobile monitoring stations, which conduct a complex of measurements similar to the scope of stationary monitoring stations. The stations are equipped with the additional equipment for identification of locations, carrying out of γ-spectrometry measurements, identification of meteorological parameters, sampling of the environment.

The mobile stations are equipped with the devices for information transfer via the satellite communication channels and mobile operator networks.

With the help of four meteorological complexes, more than 50 meteorological parameters are defined in the near-surface layer of the atmosphere, and meterological parameters are identified at the elevation up to 3000 m.

Radiation and meteorological information is used in the program complexes for calculation of the population doses from the actual releases and effluents (RNPP Doses) and doses for all settlements of Observation Zone in case of emergency situations. The program complexes are developed by "Institute of Radiation Protection" of the Academy of Technological Sciences of Ukraine.

The calculation methods are agreed with the Ministry of Health Protection of Ukraine. From 2017, the European system for forecasting of the radiation accident consequences RODOS is in place.

Information on the radiation and meteorological situation, in the real-time mode, is available for the personnel of Rivne NPP. It is also provided together with the technological parameters of Rivne NPP into the Crisis Centre of NNEGC "Energoatom", Crisis Centre of State Nuclear Regulatory Inspectorate of Ukraine, Rivne State Administration, Oblast Administration of the State Emergencies Service.

The systematic measurements of radioactive material concentration in the atmospheric air, soil, flora and food in the Sanitary protection zone and Observation Zone, confirm absence of significant impact of Rivne NPP on the population and environment.

During the entire period of NPP operation, the content of radionuclides in the air of Rivne NPP's Observation Zone was at the level of annual average concentration, peculiar for the pre-commissioning period.

The indications of γ-radiation level in the surrounding settlements did not change after commissioning of Rivne NPP. And, it is not possible to point out the radiation impact of Rivne NPP, in comparison to the natural background, even with the help of state-of-the-art measuring equipment.

Information on correlation of release activity and allowed values, established by the Ministry of Health Protection of Ukraine is presented in the diagram below (Figure 7.1)

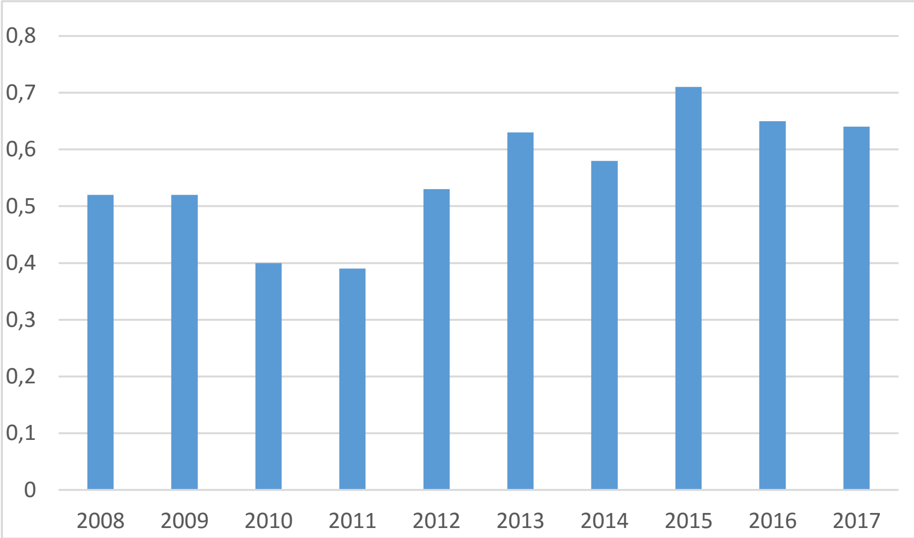

Figure 7.1. Index of gaseous and aerosol releases of Rivne NPP as related to the allowed release.

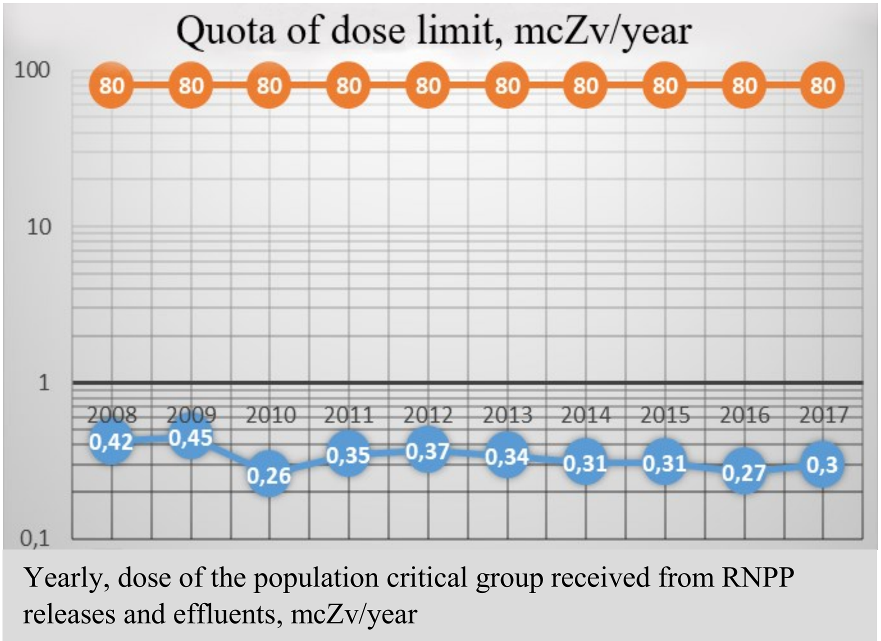

Figure 7.2. Comparative characteristics of the quota of dose limit and dose of the population critical group from the releases and effluents of Rivne NPP, mcZv/year

The main indicator, which characterizes the plant impact on the population of the Observation Zone is a maximum possible dose on the border of SPZ (dose for the population critical group). The normative document NRBU-97 specifies the quota at the level of 80 mcZv/year – a limit of the yearly population radiation dose from the NPP release and effluents.

From January 2006, the plant applies a program on dose monitoring complex for the population critical groups, which is intended for calculation of the radiation dose, formed by actual gaseous and aerosol releases and liquid effluents on the CA border during a calendar year.

The calculation methodology is agreed with the Ministry of Health Protection of Ukraine. The calculation results, presented in the diagram (Figure 7.2), show that the actual radiation impact of RNPP on the population for the last ten years did not exceed 0.5% from the quota of the dose limit, specified in NRBU-97, and is hundred of times less than the radiation from the natural sources.

7.5 Informing the Public About the Assessment of the Environmental Impact of the SS Rivne NPP Site

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

Information Center of SS Rivne NPP is located at:

5 Nezalezhnocti Square, Varash, 34400, Rivne oblast,

e-mail:informsentr@mail.ua, official site of SS Rivne NPP: www.rnpp.rv.ua.

Tel.: 2-14-43, 2-11-96, Facebook page: rnpp.polissia.

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

Information Center operates in four main areas:

- excursion activities;
- exhibition activities;
- work with the public of SS Rivne NPP Observation Zone;
- educational activity.

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

Work with the public from the Observation Zone of SS “Rivne NPP” and co-operation with public organizations.

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

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

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

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

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

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

Given that the main succession pool of our enterprise is the young people from the town and adjacent areas, Rivne NPP pays much attention to vocational-oriented education.

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

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

The department employees meet with the public of the Observation Zone, students of higher educational establishments.

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

The newspaper "Energia" is published weekly in a printing form with an average circulation of 2000 copies and in an electronic form on SS Rivne NPP website. The information content of the newspaper is constantly improved. Hourly radio broadcasts go on air twice a week (Tuesday and Friday). The editors of television and radio broadcasting, in addition to their own programs, create programs "Pulse of RNPP", which are broadcast on the regional television in Rivne and Lutsk.

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

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

The information on the electronic board is updated daily.

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

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

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

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

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

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

CONCLUSIONS ON SS RIVNE NPP SITE ENVIRONMENTAL IMPACT ASSESSMENT

Rivne NPP produces heat and electricity. Electricity production is accomplished at four power units with VVER-440 reactor and VVER-1000 reactor, with total installed capacity of 2835 MWt. The capacity factor is 74.2%.

SS Rivne NPP power units meet the current nuclear and radiation safety requirements as confirmed by inspections by IAEA (1988, 1996, 2003, 2005, 2008) and World Association of Nuclear Operators (WANO) (1988, 1989, 1993, 1995, 1997, 2001, 2003, 2005, 2012, 2014, 2015, 2016, 2018 years).

SS Rivne NPP power units are designed according to a multilevel protection concept, which is based on the levels of protection and contains a number of successive barriers to eliminate release of radioactive substances into the environment. The inbuilt safety systems provide emergency protection and emergency cooling of the reactor units:

- protection safety systems;
- localizing safety systems;
- auxiliary safety systems;
- control safety systems.

Each power unit is equipped with all systems providing radiation and nuclear safety, as well as emergency shutdown, shutdown cooling, and residual heat dissipation regardless of the mode of operation of other power units.

The process of economic operations, including all environmental impact factors and technical solutions, is intended to eliminate or reduce harmful releases, discharges, leaks and radiation in the environment.

VVER-440 and VVER-1000 reactors operate based on the controlled fission chain reaction for ^{235}U nuclei contained in nuclear fuel.

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

- decontamination of air which is removed and which contains radioactive isotopes using aerosol and iodine filters;
- decontamination of process vent on filters-absorbers, where gas is held up in order to reduce relative activity (radioactive decay of the major part of inert noble gases isotopes (xenon (Xe), Krypton (Kr);
- air releases from the premises of reactor compartment controlled access area and auxiliary building through vent stacks of 150 m high, that provides necessary dispersion of radioactive substances in atmosphere;
- establishment of barriers to prevent propagation of radioactive substances by way of the reactor compartment containment, lining of the premises with LWR sources by corrosion resistant steel;
- implementation of closed process and component cooling systems to prevent discharges of liquid substances containing radioactivity;
- implementation of special system for SRW collecting, as well as SRW and LRW storage;
- prevention of non-controlled releases and discharges;
- arrangement of NPP SPZ;
- organization of continuous technological dosimetry monitoring of discharges and releases, air, soil, vegetation, water contamination monitoring in the SPZ and OZ.

Production of the electricity at the nuclear power plants comes along with generation of radioactive waste in the course of the main technological process, as well as during routine and maintenance operations. The stable development of the nuclear energy field in the country requires safe management of the radioactive waste at all phases of waste formation and existence. The RW management system is an important component in the entire safety systems while using nuclear energy.

The main principles of the RW management at the NPP is minimization of waste formation and interaction between all phases – from formation to disposal.

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

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

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

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

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

- thermal impact on the air environment associated with operation of NPP process equipment cooling systems (spray cooling ponds and cooling towers);
- increased humidity due to the evaporation of water into the atmosphere from spray cooling ponds and cooling towers;
- thermal impact on the water environment associated with the discharge of blowdown water from the main cooling system;
- impact on the water environment (the Styr river) associated with the irretrievable water consumption;
- impact of the electric field of 330/750 kVt transmission lines;
- noise during equipment operation and traffic.

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

The existing regulatory documents do not have requirements to the allowed limits of heat releases. Monitoring of heat releases is performed by measuring the consumed water, which is collected from the River Styr for service needs and consumed water that returns to the river.

Taking into account that impact of the plant cooling systems is quite insignificant on the climate parameters, and that impact of the cooling towers and spray ponds is practically implicit on the microclimate and environment outside the sanitary protection zone within the radius of 2.5 km, no special activities are foreseen with regard to limitation of these influences during NPP operation.

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

The size of SS Rivne NPP SPZ is 2.5 km, and OZ area is 30 km.

The size of SPZ and OZ are officially introduced in accordance with SS Rivne NPP document, namely the "Decision on the size and boundaries of Sanitary protection zone and Observation Zone of Rivne NPP" No. 132-1-Р-11-ЦРБ.

To control non-spreading of the radioactive materials into the ground waters, the radiation monitoring of underground waters is conducted on the territory of Rivne NPP site. To control the underground water supply sources, the content of radionuclides is measured in the artesian wellholes.

There are 35 check-wellholes, and water is sampled from the bottom layer at a depth of 10÷14 meters from the surface. The frequency of water sampling from the check and artesian wellholes is once per quarter. Each sample is measured in terms of Σβ-activity using α/β radiometer MPC-9604 and specific activity of tritium is measured using liquid scintillational radiometer Tri-Carb 3170 TR/SL. The samples of check-wellholes are averaged and are subject to γ-spectrometeric analysis. The activity of man-made isotopes in the groundwaters is thousand times less than the level of allowed concentration in the portable water.

The network of artesian well-holes consists of nine wells, organized on the territory of the water withdrawal point "Ostriv". The samples of water are taken from the special collector, and go through γ-spectrometry and measurement of tritium activity. The water of artesian wellholes has no isotopes of manmade nature.

The ecological and chemical laboratory of environmental protection service (EPS) performs analysis of the surface and sewerage (discharge) waters three times a week using 25 indicators. The analysis of monitored indicators prove that the values of the maximum allowed effluents (in tons) were not exceeded, the sewerage water is within the purity limits, and contains the same natural impurities like the source river water, and operation of Rivne NPP does not input the significant changes into the quality of surface waters.

SS Rivne NPP has little influenced on the change of water-physical properties of adjacent soils due to changes in the level of groundwater during its construction. It is possible to talk about the joint influence of SS Rivne NPP and land-use only in case of overshooting of SS Rivne NPP emissions to agricultural soils, when, as a result of agrochemical treatment, pollutants penetrate down the soil profile to the depth of plow sole and evenly mix. In fact, there is an acceleration of the migration process of those small amounts of pollutants which can settle on soil due to the emissions from a nuclear power plant.

During the reporting period, the maximum contribution to the specific activity of the soil is due to the presence of ^{137}Cs isotope that over all reporting years exceeds the "zero background", but this contamination is explained by the consequences of Chernobyl accident.

The main foodstuffs of the local population were monitored in the zone of placement of the SS Rivne NPP - milk, vegetables, and grain crops. Samples were selected during maturation.

The samples were examined using γ-spectrometric analysis to determine the possible presence of radionuclides of technogenic origin, especially ^{131}I.

^{131}I was not registered in agricultural products in 2017. The presence of other man-made radionuclides, except ^{137}Cs of "Chornobyl" origin was not registered, too. The high content of this radionuclide in food is due to the higher value of transition coefficient of "soil-solution-plant" chain.

The maximum content of ^{137}Cs was recorded in Manevychi checkpoint - 4.95 Bq/l. Permissible content of ^{137}Cs in milk is 100 Bq/l. Exceeding the upper bound of values of "zero background" by ^{137}Cs has not been fixed.

For most objects of the environment, the activity of radionuclides is within the range of "zero background" measurements.

The analysis of subsidence and core samples from buildings and structures over a long period of time demonstrates the stability of structures and a stable state of soils at the bases of their foundations.

The analysis of control characteristics shows that the work of the Rivne NPP NP does not significantly change the quality of underground water. Radiation state of groundwater is satisfactory, content of ^{226}Ra, ^{137}Cs, ^{90}Sr is much lower than the values that are standardized in the Radiation Safety Standards of Ukraine.

The assessments have shown that the major share of gas-aerosol release within the dose during operation of power units of SS Rivne NPP will be by inert gases through irradiation from the cloud. The maximum annual average concentrations of these radionuclides in the air were obtained in the east direction at a distance of about 1.5 km from the plant. They made: 1.351×10^{-11} Ci/m^3

(0.5 Bq/m^3) for ^{133}Xe; 2.703×10^{-13} Ci/m^3 (0.01 Bq/m^3) for ^{85}Kr; 5.406×10^{-14} Ci/m^3 (0.002 Bq/m^3) for ^{41}Ar.

Non-exceedance of the effective dose of 100 mrem/year (1 mSv/year) per population (Category B) is possible when maximum air concentrations of these radionuclides are as follows: 26.489×10^{-8} Ci/m^3 (9.8 kBq/m^3) for ^{133}Xe; 54.06×10^{-8} Ci/m^3 (20 kBq/m^3) for ^{85}Kr; 0.973×10^{-8} Ci/m^3 (0.36 kBq/m^3) for ^{41}Ar, which is 10^3-10^6 times higher than the maximum design concentrations of radioactive noble gases during normal operation of the power units.

On the whole, based on the analysis of changes in the background concentration of radionuclides with increase of distance from the power units of SS Rivne NPP, it can be concluded that the radiation regime of the plant during its normal operation does not affect the vegetation and does not cause any changes in the radiation level of individual plant species.

Technical design solution on cooling of process water in cooling towers and spray pools (instead of a cooling pond) allowed minimizing adverse impact of the plant on the ecosystem and preserving the valuable floodplain of the Styr River with its meadow, shrub, and forest animal complexes.

During normal operation of SS Rivne NPP, the radiation conditions and population doses in the region are defined by the existing natural background radiation. SS Rivne NPP radiation impact on the population and the environment does not exceed 0.05 % of the dose level produced by natural radiation sources, and does not change the natural radiation level in the area around the NPP.

Hazardous radiation levels exist only for personnel performing radiation hazardous works, however these risks are brought to a minimum if radiation safety rules are followed. No hazardous radiation risks are present for other works and beyond working hours during normal operation of SS Rivne NPP.

As a result, it can be said that Rivne NPP has no adverse effect on the population health within the SS Rivne NPP OZ.

The radiation impact of Rivne NPP was analysed based on the following MDBA: an accident caused by double-ended rupture of the cooling system pipeline (loss-of-coolant nuclear reactor accident) at normal energy level.

Radionuclide intake during the BDBA was determined based on the limit value of environmental release of ^{137}Cs at the level of 30 TBq in accordance with the safety requirements of European operators for designs of nuclear power plants with light water reactors (LWR). ^{137}Cs isotope was chosen due to its prevalent value for long-term environmental pollution as well as its health impact.

Other isotopes in the form of aerosol (i. e. all radioactive decay products, except for inert gases and gaseous iodine isotopes) are released into the environment in proportion to this value, even if these isotopes are released into the atmospheric air.

The main indicator, which characterizes the plant impact on the population of the Observation Zone is a maximum possible dose on the border of SPZ (dose for the population critical group). The normative document NRBU-97 specifies the quota at the level of 80 mcZv/year – a limit of the yearly population radiation dose from the NPP release and effluents.

In case of radiation accidentals, the existing radiation protection and control systems take into account only the radioactive influence of the Rivne NPP, which is also limited to the NPP monitoring area. The expected exposure doses of the population living in the observation zone and the neighboring states do not exceed the established dose rates and the individual effective annual dose of 1 mSv, indicating that there is no significant negative transboundary impact.