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REPORT

DEVELOPMENT OF THE MATERIALS FOR ASSESSMENT OF ENVIRONMENTAL IMPACT IN THE COURSE OF ZAPOROZHYE NPP OPERATION
(Final)

Book 7
Transboundary environmental impact of industrial activities

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2015

Content of the report **«Development of the materials of environmental impact assessment in the course of Zaporozhye NPP operation»**

Book number	Part number	Name	Note
1		Basis for Environmental Impact Assessment implementation. Physiographic characteristics of Zaporozhye NPP location area	
2		General characteristics of Zaporozhye NPP. Industrial wastes.	
3		Environmental impact assessment of Zaporozhye NPP operation	
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5		Complex measures for ensuring normative state of the environment and its safety	
6		Declaration of ecological consequences of economic activity	
7		Transboundary environmental impact of industrial activity	

ABSTRACT

There are calculations and justified radiation impact of the consequences of Zaporozhye NPP radioactive substances releases on environment and population in normal operation and emergencies in a transboundary context provided in this document.

All calculations have been performed for conservative conditions of additive extension and irradiation doses formation (maximum doses).

It is demonstrated that the maximum admissible values of radiation criteria of equivalent and absorbed doses in organs and for whole body on the border with other countries, specified by the normative documents, are met in normal operation conditions of power units or in a design emergency case occurrence.

It is justified that there is no any significant transboundary impact of planned activity, and in accordance with the International Convention on Environmental Impact Assessment in a Transboundary Context any aggrieved party does not exist. In order to implement p.8, Article 3, of the Convention on the Provision of Society with Information, its is sufficient to place the materials about impact assessment of planned environmental activity in a transboundary context on public resources in Internet, for instance, on the sites of state organs: Ministry of Nature and Ministry of Coal.

This report contains 73 pages, including 14 Figures, 16 Tables.

Key words: NPP, irradiation doses, volume activity in atmospheric air, precipitation on soil surface, radiation accident, transboundary impact.

CONTENTS

LIST OF ACRONYMS

FA	-	fuel assembly
IAEA	-	International Atomic Energy Agency
IRG	-	inert radioactive gases
ND	-	normative documents
NPP	-	Nuclear Power Plant
RCP	-	reactor coolant pump
RP	-	reactor plant
RW	-	radioactive waste
SE	-	Separated Entity
SE NNEGC «Energoatom»	-	State Enterprise «National Nuclear Energy Generating Company «Energoatom»
SG	-	steam generator
WWER	-	Water Water-Energetic Reactor
ZNPP	-	Zaporozhye Nuclear Power Plant

INTRODUCTION

In accordance with the requirements of the International Convention on Environmental Impact Assessment in a Transboundary Context ratified by the Law of Ukraine No.534-XIV of 19/03/99, the assessment of Zaporozhye NPP environmental radiation impact in a transboundary context, i.e. the assessment of impact on the territories of neighboring states was performed. ZNPP impact assessment was considered for normal operation conditions and emergency cases.

1 DESCRIPTION OF THE OBJECT OF ENVIRONMENTAL IMPACT AND PURPOSE OF ITS OPERATION

The object of study – SE ZNPP – is a separated entity (structural unit) of the State Enterprise National Nuclear Energy Generating Company «Energoatom». SE NNEGC Energoatom implements its activities in compliance with its statute and is subordinated to the Ministry of Energy and Coil Industry of Ukraine.

SE NNEGC «Energoatom» is assigned functions of the Operating Company responsible for safety of all Ukrainian NPPs.

Zaporozhye NPP is located in Zaporizhzhya region, on the left bank of the central part of the Kakhovka water reservoir, 70 km downstream Zaporozhye city and 160 km upstream from Kakhovka hydroelectric plant dam. It is situated in Kamyanka-Dniprovska distruict. Its district center, Kamyanka-Dniprovska is located at a distance of 12 km to the south-west from the NPP. The regional center, Zaporozhye city, is at a distance of 55 km to the north-east of the NPP.

The plant satellite town is Energodar. In the 30 km monitoring area beside Energodar, the following towns are located: Kamyanka-Dniprovska, Marganets, Nikopol. There are also villages. In total, there are 59 settlements located in the 30km monitoring area: 27 - in Zaporizhzhya region, 30 - in Dniepropetrivsk region and 2 - in Kherson region.

SE ZNPP site location and boundaries of its monitoring area are shown in Figure 1.1.

In the period of 1984 to 1987, first four units were commissioned into operation. Unit 5 was commissioned in 1989, and Unit 6 - in 1995. Total installed electric capacity of the nuclear power plant is 6000 MW. Currently there are six power units in operation at Zaporozhye NPP, installed electric capacity of each power unit is 1000 MW (Table 1.1).

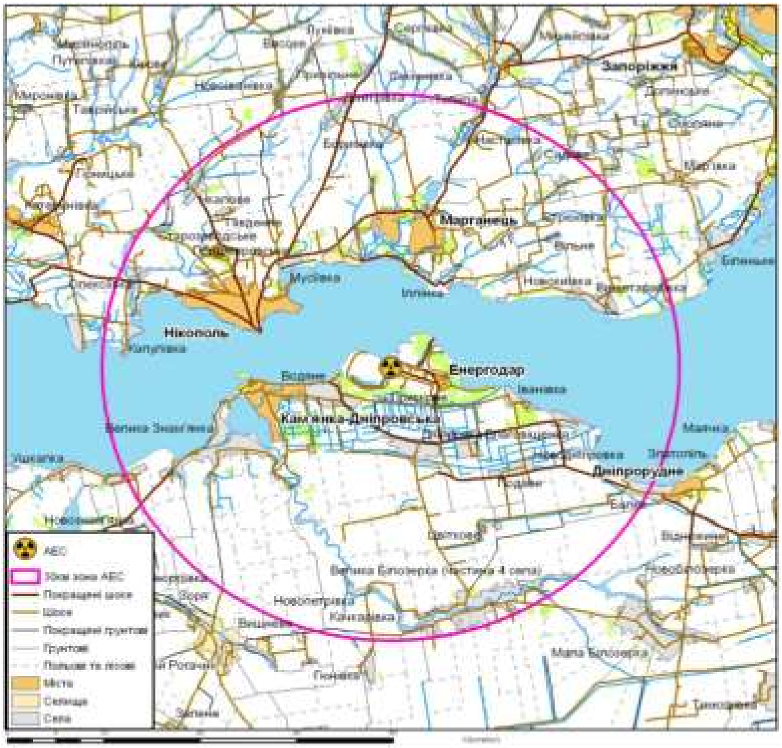

Figure 1.1 – Zaporozhye NPP location area

Table 1.1 — Information on Zaporozhye NPP power units

Unit No.	Power unit type	Reactor facility type	Date of commissioning to operation	Design operation period, years	Design operation expiration	Expected period of operation extension, years
ZNPP1	WWER-1000	V-320	10/12/1984	30	23/12/2015	15
ZNPP2	WWER-1000	V-320	22/07/1985	30	19/02/2016	15
ZNPP3	WWER-1000	V-320	10/12/1986	30	05/03/2017	15
ZNPP4	WWER-1000	V-320	18/12/1987	30	04/04/2018	15
ZNPP5	WWER-1000	V-320	14/08/1989	30	27/05/2020	15
ZNPP6	WWER-1000	V-320	19/10/1995	30	21/10/2026	15

Annually the plant generates 40-42 billion KWh, which is the fifth part of the average annual electricity generation of Ukraine and about 47% of the electricity generated by the NPPs of Ukraine.

The NPP is also a heat source for the plant site, Energodar town and other consumers around. Total installed heat capacity is 1200 Gkal/hour (200 Gkal/hour per each unit).

1.1 Brief description of the power units and technological processes

General diagram (layout) of Zaporozhye NPP is given in Figure 1.2.

The unified monoblock unit is located on a separate main building of NPP and consists of the reactor compartment, turbine compartment, deaerator stack with the rooms of electrical devices. Main buildings of the power units are oriented to the water cooling pond – a source of NPP circulating water supply. There are unit pumping plants and industrial water pipelines between the water cooling pond and main buildings of the power units.

The connection of Zaporozhye NPP with the unified power grid of Ukraine is provided by means of three 750 kV transmission lines and one 330 kV transmission line.

Each of six power units of ZNPP includes the following equipment:

- WWER-1000 reactor;
- K-1000-60/1500-2 type turbine;
- TVV-1000-4 type electric generator.

WWER-1000 water-water energetic reactor on thermal neutrons serves for generation of thermal power (rated heat capacity is 3000 MW). The reactor operation is based on controlled chain nuclear fission reaction of ^{235}U nuclei that are contained in nuclear fuel. Reactor core comprises fuel assemblies located in the hexagonal grid nodes and manufactured from reduced enrichment uranium dioxide, located inside zirconium cladding.

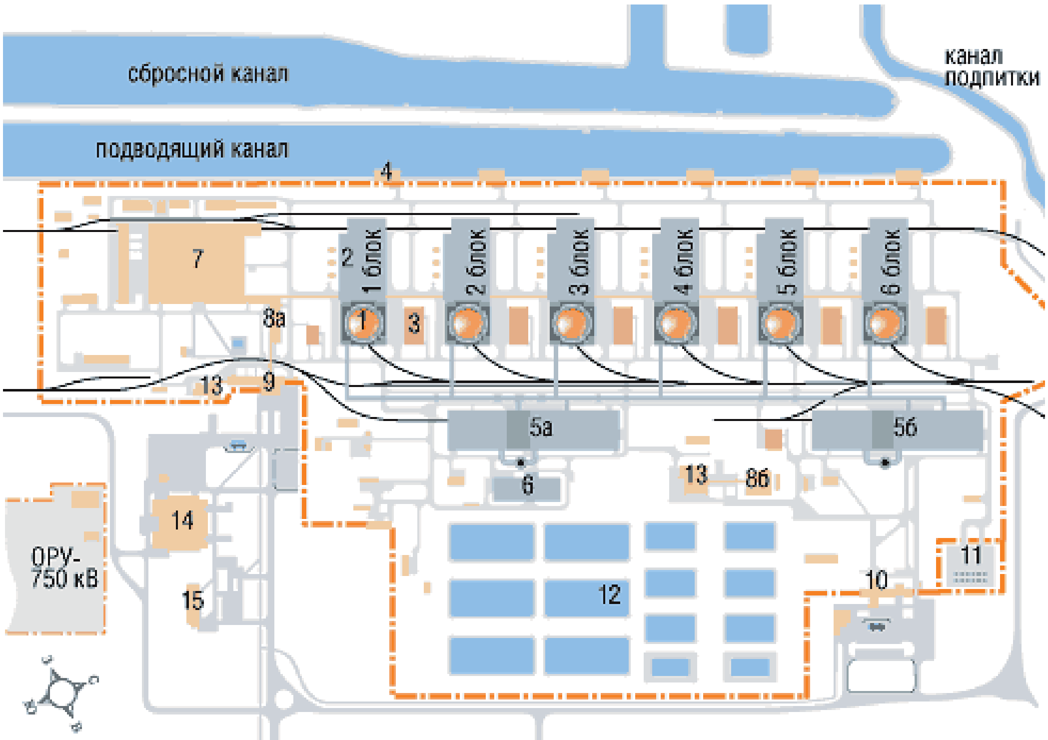

Figure 1.2 – Zaporozhye NPP layout

1. reactor vessel; 2. turbine building; 3. diesel generator; 4. unit pumping plant; 5. radwaste treatment buildings a and б; 6. solid radwaste storage; 7. additional buildings; 8. laboratory and service structures a and б; 9 administration buildings and Check Gate 1; 10. Check Gate 2; 11 dry spent fuel storage facility; 12. spray ponds; 13.canteen; 14. Full Scope Simulator; 15.Training Center.

WWER-1000 power unit operates based on two-circuit diagram: primary circuit (radioactive) is a water circuit which takes directly heat from the reactor; secondary circuit (non-radioactive) is a steam circuit that receives heat from the primary circuit and utilizes it in the turbine generator.

Primary (main) circulation circuit consists of:

- reactor;
- four circulation loops, each of them contains:
  - steam generator (SG);
  - main coolant pump (MCP);
  - reactor coolant pipes (RCP), connecting the equipment of loops with reactor.

Energy from nuclear fuel fission in the reactor core is removed by the coolant that is pumped through it by main coolant pumps. From the reactor, via reactor coolant pipes, «hot» coolant is fed to the SG, where heat is conveyed to the secondary circuit water; and the coolant is returned to the reactor by main circulation pump. Dry saturated steam is produced on the secondary side of the steam generators, is fed to the turbines of the turbine generator equipped with 1000 MW capacity electrical generator.

As moderator and coolant, WWER-100 reactor utilizes boron water under a pressure of 160 kgf/cm^2. Total flow rate of the coolant through the reactor is 84800m^3/year. Water temperature at the reactor inlet during operation on nominal power equals 290ºC, at the output it equals 320ºC. Drop of low-grade steam power that left the turbines is done via the water cooling system.

2 POTENTIAL RADIOACTIVE IMPACT

In the process of NPP operation, generation of gaseous, solid and liquid material containing radioactive chemical isotopes is indispensable. Radiation impact of a power unit is related to their release to the environment [1-3].

In normal operation conditions, any release of elements from fuel cladding or partial damage of this cladding leads to ingress of certain amount of fission products to primary coolant. Small amounts of radioactive products can also get to the primary coolant as a result of neutron activation of the structural materials. The processes of erosion and corrosion of activation products facilitate the transfer of these materials to primary coolant.

Tritium which is in primary coolant is one of the components of these activation products.

Tritium release from the primary coolant is possible during the following:

- controlled leakages;
- draining of the primary coolant to the primary coolant drain tanks.

Tritium ^{3}H is radioactive isotope with half-decay period equal 12.34 years. In WWER reactors tritium is generated:

- directly during the fuel nuclei fission as a triple fission product;
- as a result of interaction of neurons with deuterium nuclei contained in the primary coolant as D_2O;
- as a result of different reactions of fast neutrons with structural materials of the reactor core;
- as a result of boric acid activation in the primary coolant.

Besides, the processes of air activation in close proximity to the RPV lead to generation of insignificant amounts of gaseous radioactive particles including evaporation of tritium water and inert gases.

Radioactive products of fission and activation are removed from coolant due to the ion exchange processes leading to contaminated ion exchange resins of special water treatment facilities. As a result of periodic replacement of these resins, both liquid and solid radwaste are generated. The process of radioactive environment treatment on special water treatment facilities located at the special building leads to generation of the radwaste: solid, liquid and gaseous.

Primary to secondary leaks acceptable in the steam generator lead to generation of radioactively contaminated water of the secondary circuit.

Gases accumulated in the primary circuit during operation are removed from it. This leads to generation of gaseous releases flow. Releases to the atmosphere can also be generated due to ventilation of flying emissions from the primary coolant generated due to small leaks, both collected and non-collected. Such releases usually contain tritium water steam, inert gases, aerosols and other gaseous particles.

During annual reactor shutdown pressure in the cooling systems is decreased, the reactor lid is removed and one third of the fuel assemblies is removed and placed in the spent fuel pond for storage. Other two thirds are relocated for maintaining optimum integrity of neutron flux, and fresh fuel is loaded to the core. Besides the spent fuel, the fuel reloading procedures can lead to increase of liquid radwaste generation and releases to the atmosphere from the spent fuel pond, reactor inspection pit and protection tube bank inspection pit. These radwaste in its nature are similar to the waste released from the primary coolant.

Besides, the maintenance and repair procedures conducted during the RPV shutdown are also sources of different radwaste generated in the process of opening and maintenance of the equipment. Independent components of the primary circuit contaminated in the process of neutron irradiation, as well as reactor compartment equipment and special building components subjected to radioactive contamination can be replaced, which fact causes additional generation of solid radwaste.

Liquid and solid radwaste treatment, their storage is implemented in compliance with the requirements of «Sanitary rules of NPP design and operation». Release of these types of radwaste to the environment in normal operation conditions, design-basis accidents and most credible beyond-design basis accident is practically excluded.

3 ASSESSMENT OF THE ENVIRONMENTAL IMPACT SCOPE

Assessment of the environmental impact scope was conducted by the values of radioactive substances releases controlled daily or once a month.

3.1 Methods and instruments of monitoring

Gas and aerosol releases to atmosphere during daily monitoring [1-3] were determined by the results of:

- continuous monitoring of inert radioactive gases with RKS-2-02, UDGB-08, UDG-1AB radiometers;
- radiometric monitoring of long-life nuclides by the method of selection for AFA-RMP-20 filters under 1 day exposition and measurement in 1 day after sampling with the use of KRK1-01 combined radiometer;
- gamma-spectrometry monitoring of gas and aerosol fractions of radioactive iodine by the method of sedimentation on analytic filters (AFA-RMP-20 and AFAS-I-20) with the use of SEG-002 two-channel gamma-spectrometry complex with DGDK-80 and BDEG-10176 semiconductor detectors.

Monitoring of gas and aerosol releases to atmosphere was conducted in accordance with the following documents:

- GND 95.1.10.13.046-99 «Measurements of radionuclide activity in gas and aerosol releases from ventilation tubes of nuclear power plants. Instruction notes»;
- MI12-04-99 «Activity, specific activity and volume activity of gamma-emitting radionuclides in counting samples of the technological and natural media objects. Methods of measurement with the use of SEG-002 gamma-irradiation energy spectrometer of semiconductor type».

Minimum measured activities under determination of gas and aerosol release are as follows:

- volume activity of long-lived nuclides – 3.7E-02 Bq/l;
- volume activity of iodine radionuclides -131 – 6.9E-06 Bq/l

Radionuclide releases during monthly monitoring were determined by the results of:

- gamma-spectrometry measurements with AFA-RMP-20 daily monitoring filters, unified for each monitoring point for a month, on SEG-002 «A KP-P» gamma-irradiation spectrometer with BDEG-10180 detection unit based on high-purity germanium;
- radiochemical emission of strontium-89, 90 by classic oxalit method from combined sample for each monitoring point for a quarter with subsequent measurement with UMF-1500M.

Tritium releases are not measured because of instrumentation stock non-existence.

3.2 Average parameters of radioactive substances releases

Table 3.1 – Values of gas and aerosol radionuclide releases to atmosphere by ZNPP facilities

Nuclide groups	Year 2011, Bq/year	Year 2012, Bq/year	Year 2013, Bq/year	Average, Bq/year
Inert radioactive gases	3.3E+13	3.2E+13	3.2E+13	3.2E+13
Long-lived nuclides	2.6E+08	2.2E+08	2.5E+08	2.4E+08
Iodines	9.2E+07	8.5E+07	1.4E+08	1.0E+08

In accordance with [4] for calculations it is accepted that relative contribution of specific radionuclides from inert radioactive gases is as follows:

- ^{88}Kr – 0.1;
- ^{133}Xe – 0.72;

- ^{135}Xe – 0.18.

In accordance with [5] for calculations it is accepted that relative contribution of specific radionuclides to iodine group is as follows:

- ^{131}I – 0.598;
- ^{133}I – 0.319;
- ^{135}I – 0.083.

From all the radionuclides of long-lived nuclide group Table 3.2 contains only those ones monitored at ZNPP.

Table 3.2 – Values of the releases of average and long-lived nuclides to the atmosphere by ZNPP facilities, Bq/year

Year	Radionuclide designation				
	Cs-137	**Cs-134**	**Co-60**	**Co-58**	**Mn-54**
2011	4.90E+06	3.90E+06	9.10E+06	2.70E+06	2.10E+06
2012	3.30E+06	2.10E+06	4.40E+06	1.90E+06	1.70E+06
2013	4.30E+06	2.00E+06	4.90E+06	2.20E+06	1.80E+06
2014	8.7E+06	2.5E+06	5.8E+06	2.5E+06	2.2E+06
Average	5.3E+06	2.6E+06	6.0E+06	2.3E+06	2.0E+06
	Cr-51	**Zr-95**	**Nb-95**	**Sr-90**	
2011	2.00E+07			5.70E+05	
2012	1.90E+07			5.40E+05	
2013	1.70E+07	6.80E+05	4.30E+05	7.30E+05	
2014	1.9E+07			1.1E+06	
Average	1.9E+07	6.8E+05	4.3E+05	7.3E+05	

Radionuclide ^{14}C releases are not monitored at ZNPP. Based on the conservative approach, the maximum value from this radionuclide release range for WWER reactor type [5] is $6.9 \cdot 10^{7}$ Bq/(MW(el.)·year).

Besides, ^{3}H radionuclide releases are not monitored at ZNPP. Actual values of tritium releases for WWER reactor type [5] is $0.74 \cdot 10^{10}$ Bq/(MW(el.)·year).

All the radionuclides with their annual average releases used in calculations are given in Table 3.3.

Table 3.3 – Calculated values of radionuclide releases to atmosphere by ZNPP facilities in normal operation conditions

Radionuclide groups	**Radionuclide**	**Acceptable release**	**Release, Bq/year**
Inert radioactive gases	^{88}Kr	69000 GBq/day	$3.2 \cdot 10^{12}$
	^{133}Xe		$2.3 \cdot 10^{13}$
	^{135}Xe		$5.8 \cdot 10^{12}$
Iodines	^{131}I	6 GBq/day	$6.2 \cdot 10^{7}$
	^{133}I		$3.3 \cdot 10^{7}$
	^{135}I		$8.7 \cdot 10^{6}$
Long-lived nuclides	^{137}Cs	2,2 ГБк/сут	$5.3 \cdot 10^{6}$
	^{134}Cs		$2.6 \cdot 10^{6}$
	^{60}Co		$6.0 \cdot 10^{6}$
	^{58}Co		$2.3 \cdot 10^{6}$
	^{54}Mn		$2.0 \cdot 10^{6}$
	^{51}Cr		$1.9 \cdot 10^{7}$
	^{95}Zr		$6.8 \cdot 10^{5}$
	^{95}Nb		$4.3 \cdot 10^{5}$
	^{90}Sr		$7.3 \cdot 10^{5}$

Radionuclide groups	Radionuclide	Acceptable release	Release, Bq/year
Tritium	^{3}H		$4.4 \cdot 10^{13}$
Radiocarbon	^{14}C		$4.1 \cdot 10^{11}$

3.3 Distances to contiguous countries

The nearest distances to contiguous countries, see Figure 3.1:

250 km – Russia;
360 km – Moldova;
450 km – Romania;
510 km – Byelorussia;
840 km – Poland;
880 km – Hungary;
910 km – Slovakia.

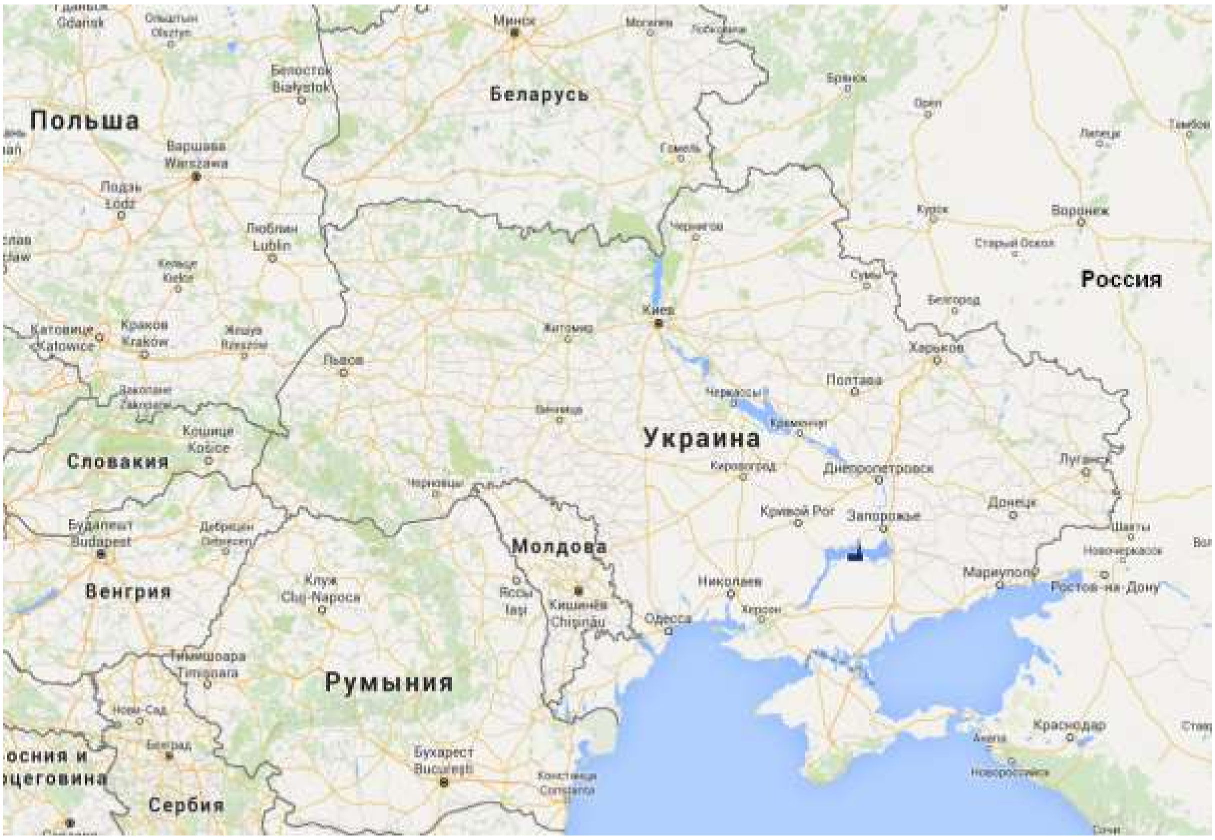

Figure 3.1 – ZNPP location on the territory of the country

- ZNPP

3.4 Doses on the boundaries of contiguous countries in normal operation conditions

The selection of meteorological conditions for normal operation condition was made based on the calculations of population irradiation doses, i.e. the most unfavorable meteorological conditions were selected, under which the doses were maximum (the conservative approach).

Calculation of committed accumulated individual doses got by the representatives of population at a distance of 200 – 1000 km from ZNPP, is given in Figure 3.2. The dependencies of accumulated dose on the distance for two population categories: babies under 1 year and adults. The committed doses are calculated after 50 years. It is evident that in this case the critical groups are the babies that will get the high doses. For the critical group – the children of 10 years old – the calculation provided the average values between the doses of adults and babies. The figure does not reflect that.

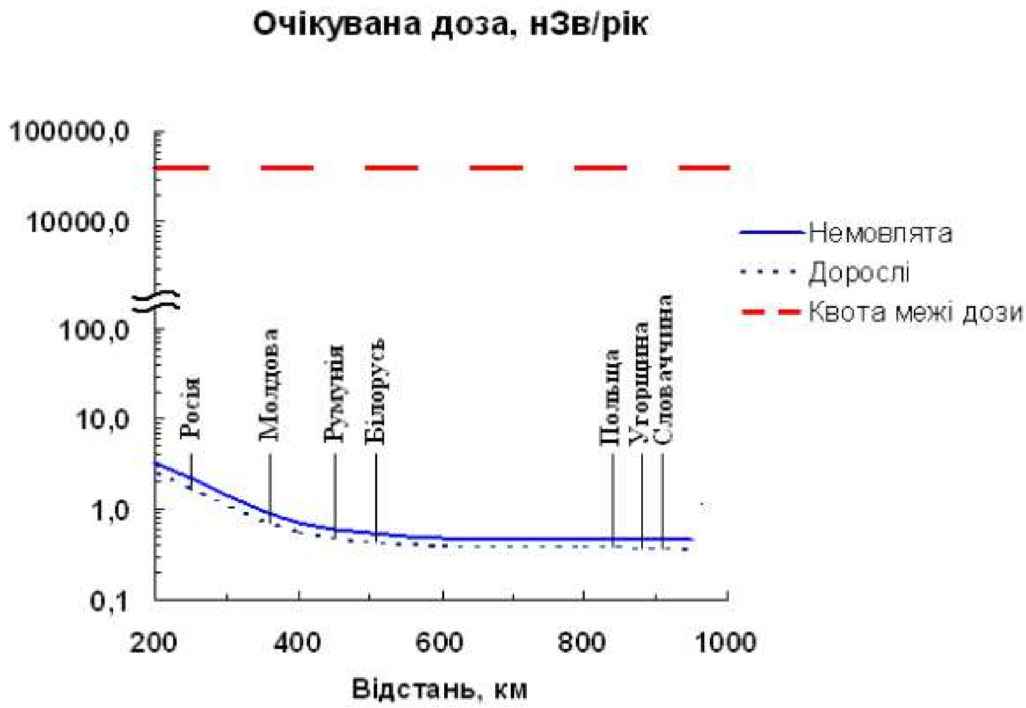

Figure 3.2 - Calculation of committed accumulated individual doses got by the representatives of population at a distance of 200 – 1000 km from ZNPP

The committed doses are very low. The maximum value can be expected at the border with Russia which is the nearest to ZNPP by distance. These doses are at a level of several nSv/year, that is significantly less than the quota of dose limit due to NPP releases, equal 40000 nSv/year in accordance with NRBU-97 [7] and the quota for population irradiation due to releases of the Russian NPPs in normal operation conditions, such releases are equal to 200000 nSv/year for an operating NPP and 50000 nSv/year for a projectable NPP [8].

Therefore, the impact on contiguous countries will be significantly lower than the established dose quotas and the limit of effective individual annual dose of 1 mSv (1 000 000 nSv).

Figure 3.3 reflects the contributions (breathing and external irradiation) to full committed dose for one year after 50 years of releases for babies at 200 km distance from ZNPP. Maximum contribution provides the inhalation ingress of radionuclides – 0.2 mSv/year. Irradiation by gamma-ray quantum from release cloud provides the ingress approximately by an order of magnitude. If the total dose at this distance is 3.3 nSv/year, irradiation by listed ways is about 6%, remaining contribution is provided by food.

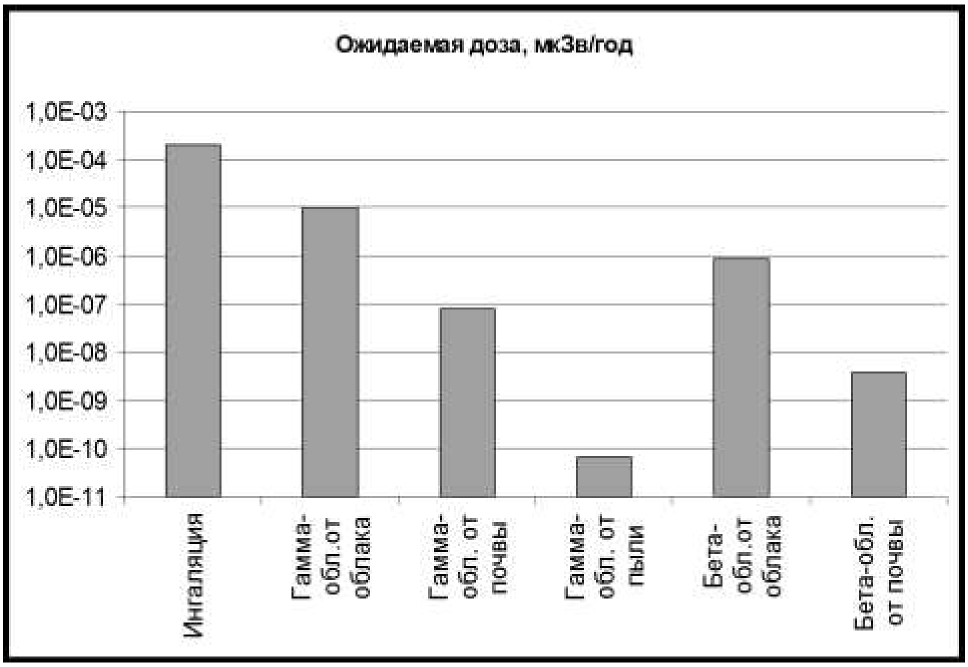

Figure 3.3 – Relative contribution to committed individual doses for babies by different irradiation ways at the distance of 200 km from ZNPP

Figure 3.4 reflects the contributions to full committed dose for one year after 50 years or releases, starting from food stuff for babies, at the distance of 200 km from ZNPP.

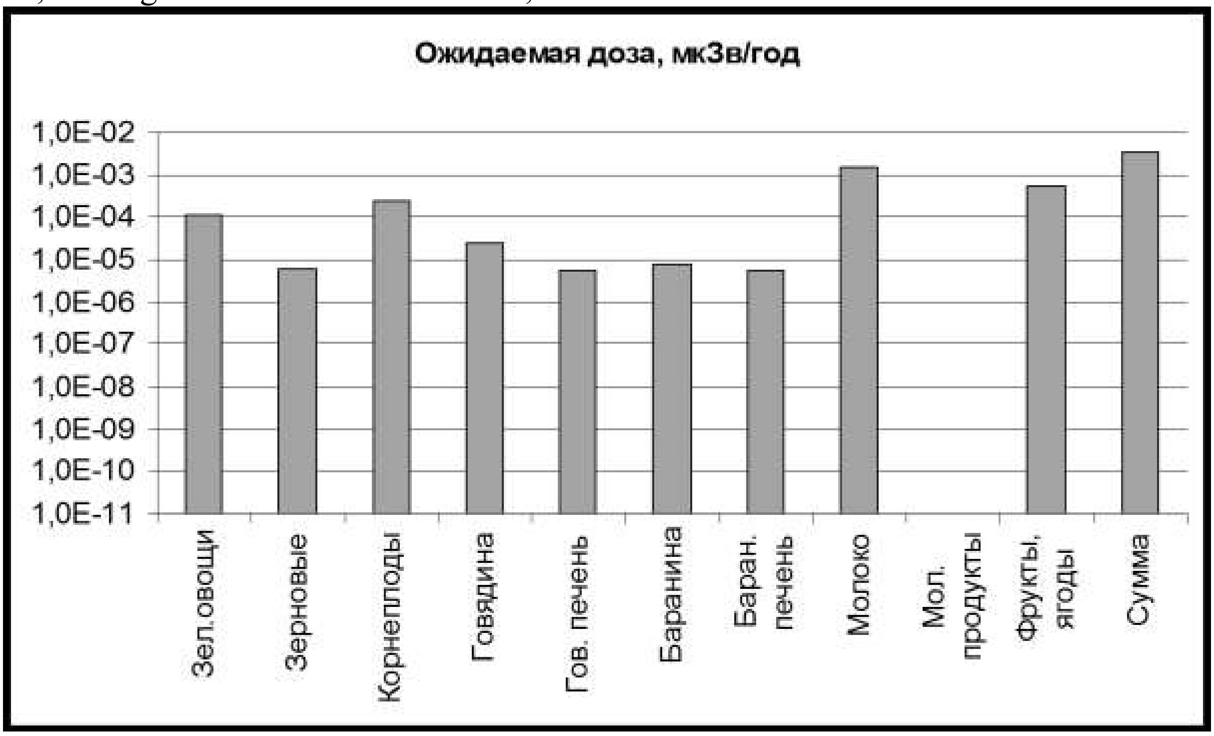

Figure 3.4 - Relative contribution to committed individual doses for children from different food at the distance of 200 km from ZNPP

Maximum contribution provides milk consumption is 1.5 nSv/year.

Approximately 3 times less value (0.55 nSv/year) is contributed by consumption of fruit and vegetables containing radionuclides that make impact on mother's milk. A notable contribution is also provided by root-crops and green vegetables via mother's milk (see data in Figure 3.4). Milk products like cream, butter, curd, etc. make a very small contribution. In total, food contributes mainly (94 %) to committed accumulated dose.

From all listed radionuclides in the release in normal conditions (Table 3.3), main contribution to full accumulated committed dose one year after 50 years of the releases is made by radionuclides: ^{3}H and ^{14}C (see data provided in Figure 3.5).

Figure 3.5 - Relative contribution of different radionuclides to committed individual doses for babies at the distance of 200 km from ZPPP

This Figure provides the calculated contribution of different radionuclides to committed individual doses for babies at the distance of 200 km from ZNPP. Besides two already mentioned radionuclides, a significant contribution is made by ^{88}Kr, ^{131}I, ^{133}Xe и ^{135}Xe.

It is worth to mention that all the listed contributions to accumulated dose are decreased about the same with distance increase, as the accumulated dose shown in Figure 3.2.

3.5 Description of emergencies and parameters of radioactive substances release to environment

3.5.1 List of potential accidents in the course of ZNPP Units operation

For the analysis of Zaporozhye NPP radiation consequences the following design-basis accidents were studied:

- ultimate design-basis accident is the accident caused by the unilateral rupture of cooling system (nuclear reactor accident with loss of coolant) at nominal power;
- accidents caused by steam-generator collector cover lift-up;
- accidents caused by spent fuel pond leaks (accidents during transportation or process operations with fuel);
- accidents caused by fuel assembly drop into spent fuel pond (accidents in the course of transportation or technological operations with fuel);
- accidents caused by water siphon drop into spent fuel pond (accidents in the course of transportation or technological operations with fuel).

Table 3.4 provides the parameters of radionuclide release under ultimate design-basis accident (accident 1) and two more accidents (steam-generator collector cover lift-up for two scenarios – accidents 2, 3), which are inferior to it in the release value. Duration of mentioned accidents is accepted equal to 60 minutes. All the rest of accidents causing less radionuclide releases are not considered.

Table 3.4 – Activity of radionuclide releases in emergencies at ZNPP, Bq

Radionuclide	Ultimate design-basis accident (accident 1)	Steam-generator collector cover lift-up – accidental spike (accident 2)	Steam-generator collector cover lift-up – pre-accidental spike (accident 3)
Kr-87		6.50E+13	
Kr-88	2.00E+13	2.00E+14	2.00E+13
Sr-90	3.10E+11		
Ru-103	4.50E+12		
Ru-106	6.60E+11		
I-131	4.98E+12	2.53E+13	4.50E+12
I-132	2.70E+12	9.20E+13	1.60E+13
I-133	4.00E+12	8.44E+13	1.54E+13
I-134		1.00E+14	1.70E+13
I-135	2.30E+12	7.90E+13	1.30E+13
Cs-134	7.80E+11	2.10E+11	2.10E+11
Cs-137	5.00E+11	5.30E+11	5.30E+11
La-140	8.40E+12	2.60E+12	2.60E+12
Ce-141	1.40E+13		
Ce-144	8.60E+12		
Xe-133		2.00E+15	

For ultimate design-basis accident (accident 1) the calculations of committed effective dose at the distance of 200 km, made at different precipitations level demonstrated that the maximum effective dose for 50 years is achieved at 1mm/h level of precipitations (see the calculation data provided in Figure 3.6).

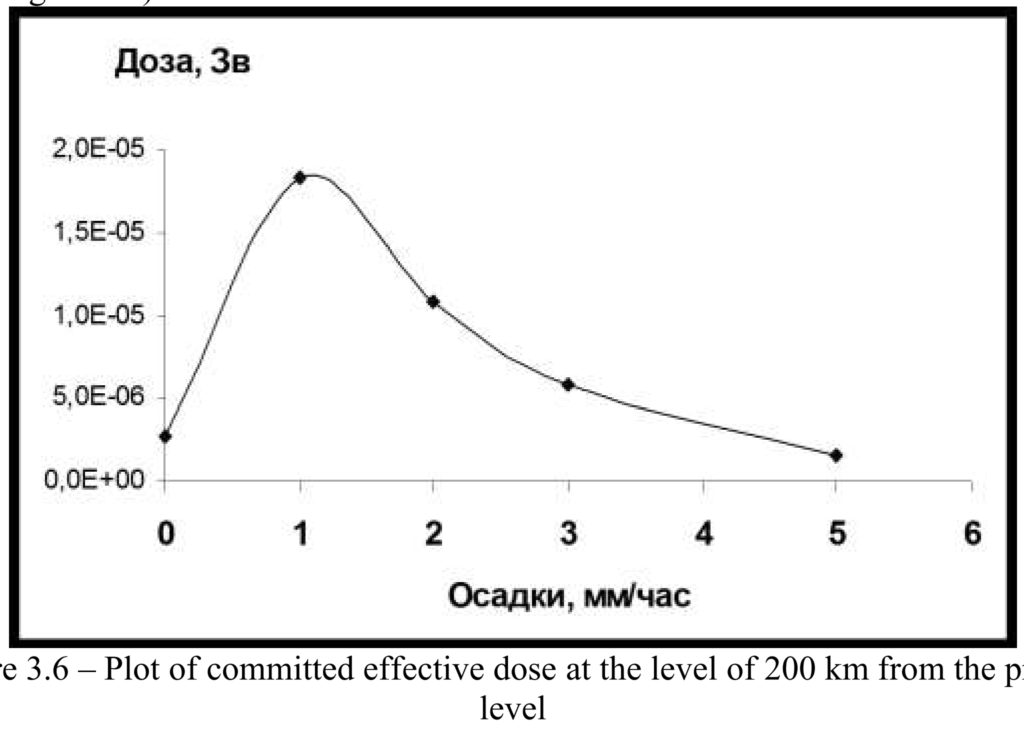

Figure 3.6 – Plot of committed effective dose at the level of 200 km from the precipitations level

If small precipitations levels cause radionuclide washing out of a cloud, thereby increasing the dose value, great precipitation levels remove efficiently the radionuclides in the cloud's way to the calculation point. Therefore the maximum dose is achieved within the range from zero to maximum precipitation levels. Based on the conservative approach, further calculations shall be made with 1 mm/hour precipitation level.

Depending on weather conditions, the dose at the calculation point can be changed. There are six weather categories by Pasquille: A, B, C, D, E, F. The Pasquille's approach supposes the distribution of all weather conditions by six categories: from very unstable «A» to the stable «F» category. There is one very stable «G» category – calm – to be described additionally. If the unstable «A» category dominates during a release, there are great variations observed in the direction of wind velocity, there is a great layer of the release cloud dislocation, and small amount of the radionuclide release arrives at great distances.

If the stable «F» category dominates for the releases, even if the layer of cloud mixture is small, the wind velocity is also small, and small radionuclide activity also gets to the calculation by means of «dry» and «wet» radionuclide washing out. These qualitative arguments prove the qualitative calculations, the results of which are provided in Figure 3.7. This Figure demonstrates the dependence of committed effective dose at the distance of 200 km from the weather category in case of accident 1.

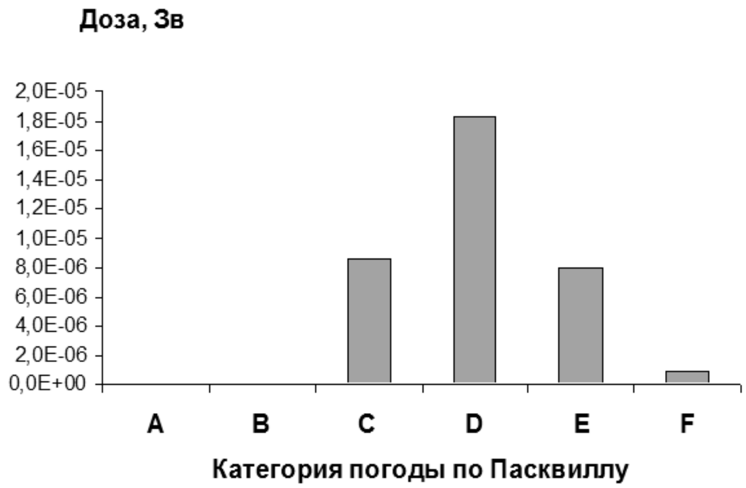

Figure 3.7 – Dependence of committed effective dose at the distance of 200 km on weather category

Based on the calculation data provided in Figure 3.7, maximum committed effective dose is reached in case of an emergency release during the weather conditions corresponding to «D» category.

Based on the conservative approach, further calculations shall be made for the weather conditions corresponding to «D» category.

3.6 Doses on the boundaries of contiguous countries in design-basis accidents at the NPP

The performed calculations of expected effective individual doses at different distances from ZNPP are given in Figure 3.8. All distances to contiguous countries are within the limits of calculation distances.

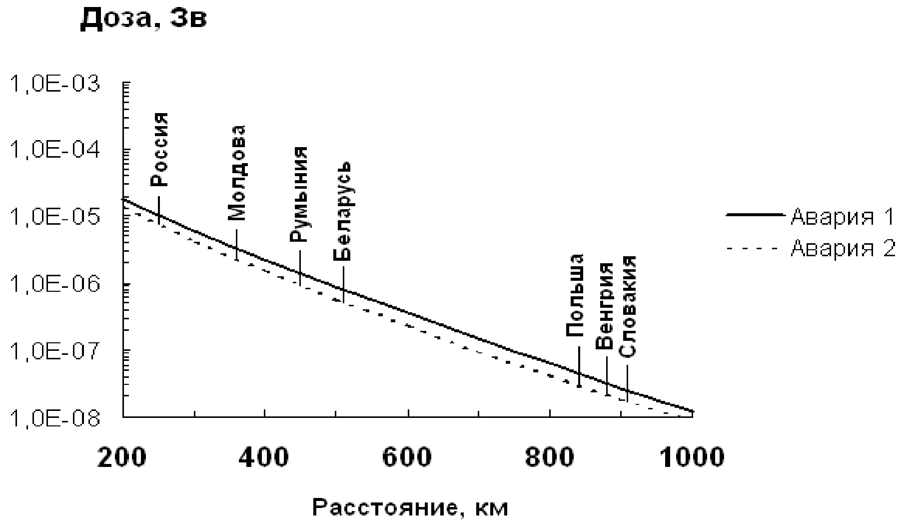

Figure 3.8 – Dependence of the expected effective dose on the distance in case of accident 1 and accident 2

Based on the data given in Figure 3.8, the expected effective doses decrease as the distance increases, at that the expected effective doses in case of ultimate design-basis accident (accident 1) is approximately 50 % greater than in case of accident 2 - SG collector cover lift-up – accidental spike. Comparison of radionuclides and their activity released in the course of accident 2 and accident 3 demonstrate that in the course of accident 3 the committed effective doses will be even less. Therefore accident 1 and accident 2 are analyzed. But the value of committed effective dose is very low – it is at the level of 18 mcSv for 50 years at the distance of 200 km, at greater distances it will be even less.

In the Radiation Safety Norms [7] for radiation accident the dose rates at which the implementation of countermeasures for population protection is required are specified, see Table 3.9.

Table 3.9 - Levels of intervention in radiation accidents

No.	Countermeasures	Dose levels
1	Emergency intervention is certainly justified in case of acute irradiation	1 **Gy** for 2 days for overall body (marrow)
2	The lower justifiability limit for urgent countermeasures	5 **mSv** for overall body for first 2 weeks after accident
3	The lower justifiability limit for taking decision on resettlement	**0.2 Sv** for resettlement period
4	The lower justifiability limit for taking decision on resettlement	**0.05 Sv** for first 12 months after accident
5	The lower justifiability limit for taking decision on temporal resettlement	**0.1 Sv** for temporal resettlement period

All the values of these doses are much greater than the doses got by the population in case of accident 1 at a distance of 200 km. No intervention is required.

The committed effective doses for the population after accident 1 are low in comparison with natural radiation background. In accordance with the UNO Scientific Committee Report to the UNO General Meeting on nuclear radiation impact for 1993 [9] the annual effective dose caused by natural radiation sources within the areas with normal radiation background is equal to 2.4 mSv.

And in case of accident 1 the effective dose for 50 years will be less than 20 mcSv even at a distance of 200 km. Therefore at the boundary with Russia (250 km), Moldova (360 km), Romania (450 km), Byelorussia (510 km), Poland (840 km), Hungary (880 km), Slovakia (910 km) the expected effective dose for 50 years will be even less.

For 50 years the population gets from natural background the effective dose approximately equal to 120 mSv, that is 6 700 times greater than the accident 1 dose for 50 years. Therefore, the dose got by the population of contiguous countries for 50 years will be less than 18 mcSv that is very low in comparison with the natural radiation background.

The relative contribution of different nuclides in the committed effective dose at the distance of 200 km from ZNPP in accident 1 is given in Figure 3.9.

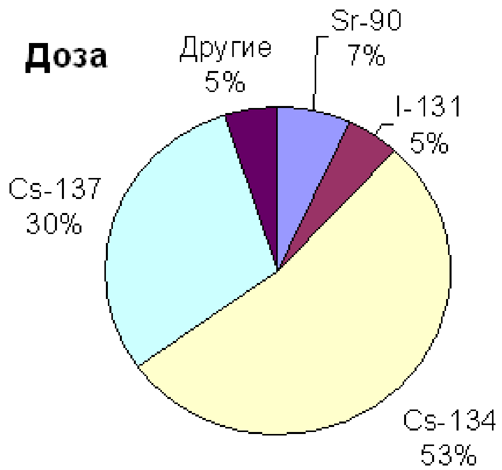

Figure 3.9 - Relative contribution of different nuclides in the committed effective dose at the distance of 200 km in accident 1.

Based on the data provided in Figure 3.9, main contributions are made by cesium isotopes: ^{134}Cs – 53% and ^{137}Cs – 30%. A notable contribution to accumulatedeffective dose is also made by the nuclides ^{90}Sr and ^{131}I. A contribution of each of the rest of nuclides is less than 1 %.

The calculations demonstrate that a determinative contribution to accumulated effective dose among various irradiation ways is made by food consumption – 94 % (see the data provided in Figure 3.10). Irradiation from soil makes a contribution at the level of 5 %, and irradiation due to inhalation is 1 %. Other irradiation ways can be negligible.

Figure 3.10 – Relative contribution of different irradiation ways to committed effective dose at the distance of 200 km in case of accident 1.

From all the food staff, a notable contribution to accumulated effective dose is made by cereal products, milk and meat (see the data in Figure 3.11).

Figure 3.11 – Relative contribution of the food staff to committed effective dose at the distance of 200 km in case of accident 1 (other products - 4 %)

4 MEASURES ON REDUCING ENVIRONMENTAL IMPACT

Reduction of the releases to environment is accomplished due to consequent implementation of the defense-in depth strategy [10], based on the use of:

- the system of physical barriers in the path of ionizing radiation and radioactive substances to the environment

- the system of technical and organizational measures on the protection of physical barriers and their effectiveness maintenance, with the purpose of the protection of population and environment

The system of consequent physical barriers consists of:

- fuel matrix;
- fuel cladding;
- the boundary of the reactor plant coolant circuit;
- reactor plant sealed enclosure;
- biological protection.

In normal operation all the barriers listed above and the required technical methods for their monitoring and protection should be operable and in the conditions facilitating their assigned functions. If this condition is violated, a power unit must be transferred to a safe condition in accordance with the operating documents.

Main objectives of the implementation of the defense-in depth strategy are timely detection and elimination of the factors leading to abnormal operation, occurrence of emergency operating conditions, and their development into accidents, as well as limitation and elimination of accident consequences.

5 DESCRIPTION OF THE METHODS ON ENVIRONMENTAL IMPACT ASSESSMENT

In order to simulate the extension of the radionuclides released to the long distances up to 1000 km in normal operation conditions, PC CREAM (Consequences of Releases to the Environment: Assessment Methodology) software package developed for EC NRPB (National Radiological Protection Board) of the Great Britain in cooperation with a number of EC scientific organizations was used.

5.1 PC CREAM

5.1.1 Brief description of the software package

The descriptions of PC CREAM software package and its individual models are given in the work [11]. This system is intended for radiation impact calculation of long-term (accident-free) releases to atmosphere and discharges of radioactive substances into the rivers and seas. Some of the main features of the software package are given below:

- ✓ assessment of individual and collective doses caused by the releases to atmosphere and discharges into the sea, as well as individual doses caused by the discharges into the rivers;
- ✓ effective doses (specified in accordance with the Publication of International Radiological Protection Committee No. 60 [12]) shall be calculated with the use of dose coefficient specified in the Publication of International Radiological Protection Committee No.72 [13] (the recommendations of International Radiological Protection Committee are also used in Ukraine during the development of the Radiation Safety Norms and Rules);
- ✓ three age groups – children under 1 year, children under 10 years and adults;
- ✓ initial data - average releases and releases per year;
- ✓ a selection possibility for five time periods of integration (1, 50, 500, 1000 years and discontinuity) for collective doses and three periods of integration (1, 5 and 50 years) for individual doses;
- ✓ time periods of integration after radionuclide ingress into the human body is accepted as equal to 50 years for adults and 70 years for children;
- ✓ the dose integrated since n years for one year of release and/or discharge is numerically equal to the average dose in the n-th year for continuous release and/or discharge;

- ✓ for the releases to atmosphere all irradiation paths are considered, and in the models describing the discharges into the water objects any possibility of using water from reservoirs for agricultural irrigation is not considered.

In PC CREAM the atmospheric dispersion is assessed with Gaussian model, the dry deposition – with the model of source depletion, wet deposition – with the use of washout rates. The used model of atmospheric dispersion allows taking into account the run periods of one daughter product in the course of spot dislocation. After deposition the transportation of radionuclides is presented by means of individual compartment models of soil and food stuff [14].

In PC CREAM the external irradiation from radionuclides in the air is calculated with the use of finite and infinite models of the cloud for gamma- and beta-irradiation respectively.

5.1.2 Mathematic models of plume dispersal

Plume dispersal is simulated by means of the modified Gauss's equation [14]:

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

where $\overline{A}$ is an average activity in the air in the point (x, z), Bq/m^3

Q is a velocity of radionuclide release from the tube, Bq/s;

x is a distance from the leeward side, m;

μ is an average wind velocity, m/s;

σ_z is a vertical dispersion factor, m;

$h_{эфф}$ - is an effective height of the tube, m;

L is a height of the moving air, m;

s – 0, 1, 2, 3, etc.

PC CREAM uses the fixed values of wind velocity and height of displacement air for each atmosphere stability category from those provided in Table 5.1.

Table 5.1 – Wind velocity and displacement air height used in PC CREAM

Pascal stability class	**Wind velocity at the height of 10 m, m / s**	**Height of the moving air, 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 factor of dispersion σ_z, used for calculation of dispersion:

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

$F(z_0, x)$ is a site error:

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

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

z_0 is a ground roughness, m; the values of a, b, c and d factors in the equation (5.2), f, g, h and j in the equations (5.3) and (5.4) are given in Table 5.2.

Table 5.2 – Factors for calculation of the vertical dispersion factor and the site error factors

Pascal 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

Ground roughness, 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 dispersal*

c. *Dry deposition*

Dry deposition is simulated as follows: $R_{сух} = V_г \cdot A$, where $R_{сух}$ is the factor of radionuclide deposition per one unit area (Bq/(m²·s)); $V_г$ is a deposition velocity (m/s); A is a radionuclide concentration in the air surface layer (Bq/m³).

d. *Wet deposition*

A ratio of the particles deposited from the plume by rain or snow shall be simulated by the equation:

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

where: $R_{вл}$ is a velocity of deposition on the surface (Bq/(m²·s)); Φ is a washout factor (c⁻¹); $Q'_{вл}$ is a radionuclide activity, stayed in the plume upon the achievement of an interesting point (x (m) from the release point) for overall time period (t) (Bq/m³):

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

$$2m_1 = -(\Phi + P_{сух} + P_{вл}) - \sqrt{(\Phi + P_{сух} + P_{вл})^2 - 4\Phi P_{сух}},$$

$$2m_2 = -(\Phi + P_{сух} + P_{вл}) + \sqrt{(\Phi + P_{сух} + P_{вл})^2 - 4\Phi P_{сух}},$$

$$f_{вл} = P_{сух}/(P_{сух}+P_{вл}),$$

$P_{сух}$ and $P_{вл}$ are the probabilities of dry and wet weather respectively; α is an angular width of the sector, rad; μ is an average wind velocity.

e. *Depletion factor*

Fraction of the radionuclides removed from the plume:

$$F = F_{вл} \cdot F_{сух} \cdot F_{рас}$$

Fraction of radionuclide removal by means of precipitation:

$$F_{вл} = \frac{f_{вл}}{m_1 - m_2}\left[(m_1 + \Phi)e^{m_2 t} - (m_2 + \Phi)e^{m_1 t}\right],$$

Where the designations are similar to those from formula (5.5).

Fraction of radionuclides removed from the radionuclide plume due to dry deposition:

$$F_{сух} = \left[\exp F_{0сух}(x)\right]^{V_г/\mu},$$

where $F_{0сух}(x) = -\sqrt{\frac{2}{\pi}}\int_0^x \frac{1}{\sigma_z}\left\{\exp\left[-\frac{h_{эфф}^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(h_{эфф}+2L)^2}{2\sigma_z^2}\right]\right\}dx$ at $\sigma_z(x) < L$, and $F_{0dry}(x) = F_{0dry}(x_L)-(x-x_L)/L$ at $\sigma_z(x) \geq L$. Here x_L is such as $\sigma_z(x_A) = L$.

Fraction of radionuclide amount reduction in the plume due to radioactive decay is:

$F_{dec} = \exp(-\lambda x/\mu)$. Concentrations of daughter products shall be calculated by the replacement of Q with $QR_д$ in equation (5.1), where:

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

here $\lambda_д$, $\lambda_м$ are constant decay values of daughter and parent radionuclide respectively.

5.1.3 Compartment exponential models

Dynamics of admixture exchange in the systems simulating by differential equations of the first order [14]:

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

where A_i is a content of these radionuclides in i link;

$\dot{A}_{0,i}$ is a velocity of radionuclide ingress into *i* link from the outside of the system;

k_{ij} is a constant value of these nuclides transfer from *i* link to *j* link.

Positive members of the sum in (5.6) are the intensiveness of admixture ingress to *I* link from other links, and the negative ones are the intensiveness of admixture discharge from it due to carry-over to other links and radioactive decay. The members of k_{ij} A_i type is the velocity of admixture transfer from *i* link to *j* link. The solution of the equation system (5.6) has a type of polynomial, each summand of which with a precision up to the factor is a product of the line: exp $(-a_i t)$, a_i — these are several constants. Main disadvantage of this model is an assumption of independence on the time of constants of k_{ij} transfer. Actually, the migration of radionuclides in the environment has frequently a more complicated character.

5.1.4 Migration model for agricultural plants

The migration diagram is provided in Figure 5.1. Link 1 is an agricultural ground layer with a n evenly distributed activity. 2 - the above-ground plant parts directly contaminated with the fallout, 3 — the above-ground plant parts contaminated with the soil particles fallen on them in the course of harvesting, 4 — the root system of the plants, 5 — the ground layer beyond the root-inhabitant horizon. k_{ij} (c^{-1}) constants correspond to the transients between the links as the results of the following processes: k_{12} — secondary dust generation; k_{21} – wind-overblown and rain-washed-out; k_{13} — contamination of the above-ground plant parts with the soil particles in the course of harvesting; k_{14} — ingress as a consequence of root taking; k_{22}, k_{33}, k_{44} - periodic harvesting; k_{31}, k_{41} — formal transfer constants providing proportionality of the nuclide content in Links 1, 3, 4.

The values of transfer constants are provided in Table 5.3 and Table 5.4.

Table 5.3 – Transfer constants for agricultural plants (common for all chemical elements), c^{-1}

Transfer constant	**Cereals**	**Other agricultural plants**	**Transfer constant**	**Cereals**	**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

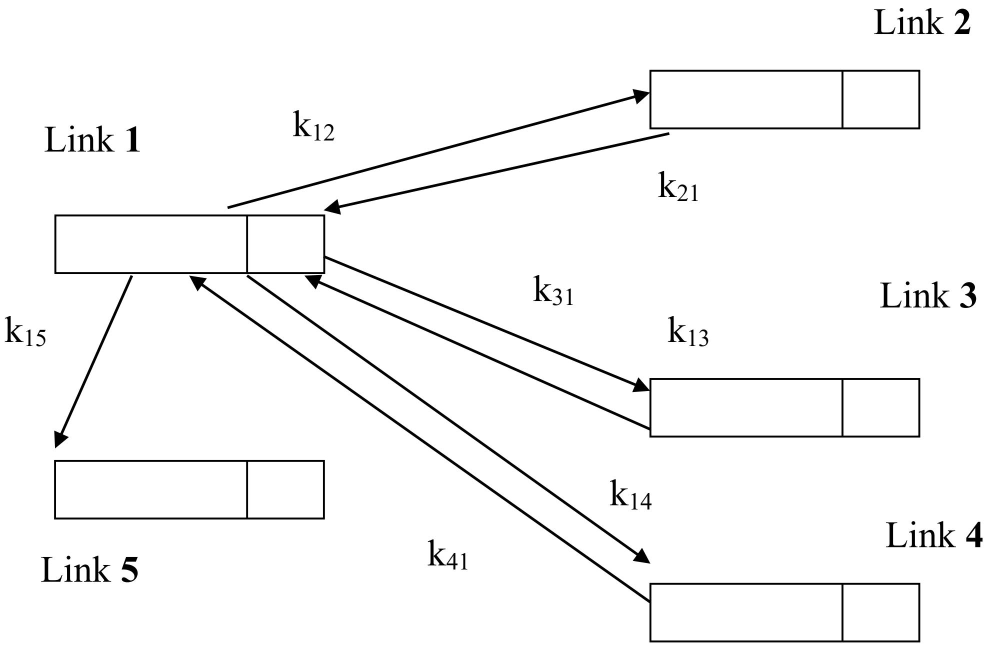

Figure 5.1 – Diagram of nuclide migration for agricultural plants

Таблица 5.4 – Transfer constants for agricultural plants (dependant on a chemical element) k_{14}, c^{-1}

Element	**Cereals**	**Other agricultural plants**		**Cereals**	**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. Mathematic models for dose calculation

5.1.5.1 Individual dose calculation by food chains

Individual doses by radionuclide ingestion shall be calculated with an assumption that only local food stuff is consumed. Such an assessment provides the maximum allowable irradiation levels in these conditions. They are practically higher than the real doses, because a part of the ratio is normally not produced locally. For some of them, for example, milk, leaf vegetables, fruit from private grounds such assessments can be close enough to the real ones. With consideration of mentioned supposition, the average rate of annual individual effective dose $\dot{H}$, Sv/s, caused by uniform fallout $\dot{A}_S$, Bq/(m^2·s), under established balance of the processes of radionuclide accumulation-removal in the environment:

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

where B_{ig} is a dose factor of internal irradiation in case of radionuclide ingestion with water or food, Sv/Bq; K_{fi}^{ind} is a factor combining the fallout level with the ingestion of radionuclide with food for one individual, m^2:

$$K_{fi}^{ind} = K_{fi}\overline{S}, \qquad (5.7)$$

where K_{fi} is a dimensionless factor, characterizing the radionuclide loss during migration by the food chain, in the process of cooking and storage; $\overline{S}$ is the area of agricultural grounds required for production of the food of this type, consumed by one individual, m^2. In PC CREAM this parameter is calculated by the below formulas:

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

where P_y is an annual productivity of the plant type under consideration, kg/m^2; I_m - an annual consumption of this type by one individual, kg;

for the products of animal origin:

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

here I_m is an annual consumption of meat or milk by one individual (l); P_a - an annual productivity of one animal weight increment (average meat per one animal), kg (l); $\overline{S}_{a,i}$ – an area of the i-th feed crop per one animal. This parameter shall be calculated by formula:

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

$P_{y,i}$ – is an annual harvesting capacity of the i-th feed crop, kg/m^2; $I_{a,i}$ – its annual consumption by one animal, kg. $\overline{S}$ values can be different for the population not only of different republics, areas and regions, but also of one village. As there are no precise data for the villages located near Ukrainian NPPs and TPPs, and taking into account the fact that it is useful to use the maximum identical parameters (without any loss to the assessments), for the assessments provided in this work the average value of this parameter has been taken from static data, dividing the surfaces taken for this culture by the number of consumers in country.

K_{fi} value in (5.7) is a dimensionless factor characterizing the radionuclide loss during their migration by food chain, in the process of cooking and storage. When considering the areas of agricultural grounds, required for production of the food from one type plants, this factor is a fraction of total amount of radionuclides fallen on this surface; this fraction will be maintained in the food stuff by the moment of their ingestion. K_{fi} factor values are different for various radionuclides, food stuff, local climate conditions, soil types, fallout conditions (short-term duration or continuous).

5.1.5.2 Individual radiation doses in case of direct impact

Direct radiation way is an external way from photons and β-particles of the radionuclides contained in atmosphere and deposited on soil, as well as internal irradiation caused by the radionuclides ingested with the inhaled air (inhalation way). In these cases the individual doses are formed directly in the area of release source location.

Photon irradiation dose caused by radioactive cloud

The radionuclides dissipated in the atmosphere can be the sources of photon irradiation. At that, the dose caused by radioactive gases and aerosols depends significantly on physical and chemical form of radionuclides and, certainly, on irradiation type and energy. [14].

Source in the form of semi-infinite space

In case of a long-term release with a changing wind dose and other meteorological parameters, the radioactive cloud shall be simulated by the source in a form of semi-infinite space with A_V activity, Bq/m^3, evenly distributed in space. Therefore, $\dot{H}$ effective dose rate, Sv/s, shall be calculated by formula:

$$\dot{H} = A_V B_{a\gamma}, \tag{5.8}$$

where $B_{a\gamma}$ is a dose factor of external irradiation with photons, $Sv \cdot m^3/(s \cdot Bq)$. For 2π- irradiation geometry:

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

where $E = \sum_i n_i E_i$ is a power release of photons, MeB/decay. (n_i — absolute release in decay scheme, photon/decay; E_i – i-th photon energy, MeB/photon); $1{,}602 \cdot 10^{-13}$ – energy equivalent, J/MeB; r = 1,09 – a factor of transfer from absorbed dose in the air to equivalent dose in biological tissue, Sv/Gy; ρ = 1,293 – air density in normal conditions, kg/m^3. 2 – a factor considering 2π-geometry of a human, w is a Gray energy equivalent referred to 1 kg mass of the irradiated medium (air in this case), w = 1 J/(Gy·kg).

Depending on a selected option, the dose factor (5.9) shall be presented as follows:

$$B_{a\gamma} = 2{,}13 \cdot E \text{ mkSv} \cdot m^3/(\text{year} \cdot Bq)$$

Photon irradiation dose caused by the radionuclides deposited on the ground

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

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

where τ_{ef} is an effective period which considers the radioactive decay and radionuclide removal from soil, it shall be calculated by formula $\tau_{ef} = \left[(T_{1/2}\, T_b)/(T_{1/2} + T_b) \right] / 0{,}693$, $T_{1/2}$ and T_b – the periods of radioactive semi-decay and biological semi-removal; $\dot{A}_S$ – contamination intensiveness, $Bq/(s \cdot m^2)$; $B_{S\gamma}$ - dose factor, $Sv \cdot m^2/(s \cdot Bq)$ characterizes the effective dose rate from contaminated soil, it depends on the type of soil contamination and the type of photon contamination distribution.

Dose from external radionuclide β-irradiation

The generalized term «β-irradiation» is electrons irradiation by radioactive nucleous. In case of their negative charge, they are called β-particles, in case of their positive charge – β^+-particles or positrons. The energy spectrum of β-particles is consistent from very low values to 10 MeV), but the main practically significant range is within 10 keV - 5 MeV. Within the above mentioned range the energy of electrons, in case of interrelation with the substance, losses its energy as a result of braking processes. The braking capability equal to average energy loss per one path length due to Coulomb collisions with the medium bound electrons $S_C[-dE/dx]$, meV/cm. This process leads to atom ionization and excitation. The second energy loss accomplished due to braking (photon) irradiation in the electric field of atomic nuclei and electrons is called S_r radiation braking capability, MeV/cm. In practice S = S/ρ mass braking capability is used, where ρ is a medium density.

The source is contaminated air

In this case the dose calculation is performed by the «immersion method», simulating the source in a form of semi-infinite space. For β-irradiation 2π irradiation geometry is always met. $\dot{H}$ equivalent dose rate for biological tissue not protected with clothe, Sv/s:

$$\dot{H} = A_V B_{a\beta}, \tag{5.11}$$

where A_V is a volumetric activity, Bq/m³; $B_{a\beta}$– a dose factor of external β- irradiation, Sv·m³/(s·Bq),), $B_{a\beta}$ values are given in Table 5.5.

Table 5.5 – Dose factors in the skin basal layer, produced by β-particles and electrons of conversion of the radionuclides contained in semi-infinite cloud, $B_{a\beta}$, Sv·m³/(year·Bq)

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

Nuclide	$B_{a\beta}$	Nuclide	$B_{a\beta}$	Nuclide	$B_{a\beta}$
^{99}Tc	$1.14 \cdot 10^{-7}$	^{135}Xe	$5.99 \cdot 10^{-7}$	^{242}Cm	$1.01 \cdot 10^{-14}$

The source is contaminated skin surface

The values of $B_{S\beta}$ transient dose factor, Sv·cm²/(year·Bq), depending on the thickness of epidermis layer are given in Table 5.6.

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

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

Internal irradiation dose caused by inhalation of radioactive gases

Annual effective doses of internal irradiation due to inhalation of the air contaminated with radioactive substances shall be calculated by the formula:

$$\dot{H} = QGVB \qquad (5.12)$$

In this formula $\dot{H}$ is an annual effective dose, Sv, Q – a release, Bq/year. G – an average factor of meteorological dilution, s/m³, V – inhalation velocity, m³/s. B transfer dose factor, Sv/Bq, characterizes the committed effective dose in case of inhalation of 1Bq nuclide.

5.1.5.3 Collective dose calculation

Assessment of the collective dose is required in case of selection of a place for construction of radiation hazardous factories, comparison of the efficiency of different activities for population protection, calculation of radiation risk from individual links of nuclear fuel cycle, selection of the type of radiation technology, etc. S collective dose, persons·Sv, shall be made by the formula:

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

where N_I is a number of individuals who received H_i individual dose.

5.2 Meteorological parameters

In the course of calculation of the transboundary impact in the conditions of normal operation the PC CREAM program is used, it facilitates calculating the impact of radionuclide releases at the distance of up to 3000 km.

The development of the meteofile required for operation of PC CREAM program shall be performed based on the data measured at ZNPP.

In 2011 the ZNPP Group of Meteorological Parameters Monitoring was certified for the Hydrometeorological Measurements.

Meteorological parameters monitoring was performed by the Sevastopol automated meteocomplex, Lambrecht precipitation gauge and the instruments located at stationary meteosite. The Sevastopol meteocomplex sensors (of temperature, atmospheric pressure, temperature gradient) monitor the data at the height of 40 m. There is psychometric box, glaze bench, Tretyakov precipitation gauge on the meteorological site.

The visual observations for cloudiness (form, height, quantity), glaze and hoarfrost phenomena, atmospheric visibility range, atmospheric phenomena were conducted. The calculation of the category of atmosphere stability by Pesquill method was performed.

Velocity, direction and maximum gust of wind were measured with M63-MP anemorumbograph, which sensors are located at the distance of 10 m.

5.2.1 Meteorological parameters in the year 2013

The average temperature of the air is 12.3 ºC. The maximum value of 36.2ºC was detected on the 26th of June. The minimum value was minus -10.4ºC on the 11th of January.

The average wind velocity was 2.9 m/s. The distribution of the average monthly and annual wind velocity is given in Table 5.8. The repeatability of wind directions and calms are given in Table 5.7.

The average amount of precipitations was 384.6 mm. The maximum amount of precipitations 69.6 mm was in March. The average maximum was detected on the 13th of July, it was 26.8 mm. The number of days with fog was 30. A great repeatability and duration of smokes was detected in the cold period of the year. In 2013 during 1017 hours the atmospheric precipitations (including smoke) were observed. The repeatability of precipitations by wind velocity and direction is specified in Table 5.9. A neutral category of atmosphere stability is a dominant one for the year 2013.

In 2013 20 days with thunderstorm were fixed. The average thunderstorm duration was detected on the 14th of June – 4 hours 20 min.

In 2013 7 cases of glaze and hoarfrost phenomena were detected.

Based on the annual report data the following conclusions can be made:

- Winter was warm, with little snow. For overall winter period a stable snow layer was observed on the 9th, 10th and 16th of January. The maximum height of snow cover was 17 cm. In January frequent thaws were observed. In February the average daily temperature was below zero – on the 17th, 18th and 19th. The first and the second decades were moderately cold, the third decade was warm. The number of the days of fair with some cloud was 8. During that winter period the winds of «E» direction were dominant;

- Spring was moderately warm. Since the 6th of March the air temperature started to increase gradually, and on the 15th of March the maximum temperature reached 17 ºC. On the 22nd of March a potential cyclone caused the abrupt fall of temperature. On the 23rd of March the temperature dropped from 8.5 ºC to minus 5.8 ºC during a day. It was raining all the day long, and on the 24th of March the rain turned into snow, the wind gust reached 17 m/s, the icing was observed in the night. Since the 30th of the air temperature started to increase, and it was not decreased below zero. April and may were warm. The number of days of fair with some clouds and clear days was 31. In spring the East-direction wind was dominant.

- Summer was moderately hot, without any temperature variations. The number of days of fair with some clouds and clear days was 58. In summer the East-direction wind was dominant.

- Autumn was moderately warm. On the 28th of November the air temperature below zero was detected. The number of days of fair with some clouds and clear days was 18. In autumn the South-West direction winds were dominant.

In total, the warm winter and moderately hot summer were specific for the year 2013. The East-direction wind was noted as dominant for that year.

Table 5.7 – Repeatability of wind duration and calms %

Month	**N**	**N NE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**W SW**	**W**	**W NW**	**NW**	**NNW**	**calm**
December	4.2	1.5	3.0	1.9	5.7	6.8	3.4	2.6	4.5	10.6	15.9	14.0	6.4	7.9	4.2	7.6	8.6
January	5.4	4.6	5.4	5.5	6.3	2,6	6.2	10.2	9.0	10.0	7.1	3.5	5.8	3.9	9.3	5.7	2.0
February	5.0	4.6	8.9	14.1	21.1	8.5	8.1	6.0	3.2	5.9	4.0	1.8	2.8	0.5	2.2	3.4	0.0
average	4.9	3.6	5.8	7.2	11.0	6.0	5.9	6.3	5.6	8.7	8.9	6.4	5.0	4.1	5.2	5.6	3.5
March	2.9	3.7	7.0	6.0	10.6	6.2	9.6	5.4	4.8	7.0	5.1	3.6	8.9	6.6	9.7	3.2	4.1
April	10.0	8.9	9.6	10.7	9.2	4.4	2.6	1.9	7.4	8.5	5.2	7.4	3.0	3.3	4.1	4.1	5.3
May	5.3	5.9	5.7	7.9	14.7	5.6	10.5	11.1	6.4	7.4	7.0	2.9	1.3	1.8	2.9	3.7	13.9
average	6.1	6.2	7.4	8.2	11.5	5.4	7.4	6.1	6.2	7.6	5.8	4.6	4.4	3.9	5.6	3.6	7.8
June	8.1	8.5	10.5	11.6	16.3	2.3	3.5	2.7	3.5	2.3	7.0	3.5	4.7	3.9	7.0	4.7	11.5
July	18.3	12.3	8.3	2.0	9.1	0.8	0.8	0.8	2.0	0.0	4.8	4.0	6.0	9.9	9.1	11.9	5.7
August	12.1	14.1	14.8	10.6	13.7	1.2	0.4	0.0	2.0	0.4	0.0	0.8	4.3	10.6	5.9	9.4	5.7
average	12.8	11.6	11.2	8,1	13.0	1.4	1.6	1.2	2.5	0.9	3.9	2.8	5.0	8.1	7.3	8.7	7.6
September	2,4	1,7	1,4	0,3	4,4	2,0	3,4	3,7	10,8	5,1	9,8	9,8	10,1	15,2	15,9	4,1	6,0
October	17,6	8,4	8,0	4,4	4,8	1,6	5,2	6,0	5,6	10,8	12,0	6,4	0,8	1,2	3,2	4,0	13,8
November	5,8	4,6	1,9	3,5	10,4	10,0	5,0	10,8	8,1	8,5	7,3	5,8	2,3	6,2	5,0	5,0	3,0
average	8,6	4,9	3,8	2,7	6,5	4,5	4,5	6,8	8,2	8,1	9,7	7,3	4,4	7,5	8,0	4,4	7,6
average for the year	8,1	6,6	7,0	6,5	10,5	4,3	4,9	5,1	5,6	6,3	7,1	5,3	4,7	5,9	6,5	5,6	6,6

Table 5.8 – Average monthly and annual wind velocity by directions, m/s

Month	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**W SW**	**W**	**W NW**	**NW**	**N NW**	**NNE**
December	4.4	2.1	2.4	3.2	2.8	2.6	2.7	2.3	2.9	2.8	2.7	3.7	3.5	4.3	3.9	5.5
January	2.7	2.3	4.1	4.2	2.5	2.6	3.0	2.8	2.5	2.6	2.4	2.7	3.2	3.0	2.8	2.3
February	2.6	3.0	3.1	3.5	3.1	3.2	3.8	3.6	3.1	3.1	2.5	3.5	4.1	2.2	2.1	2.2
average	3.2	2.5	3.2	3.6	2.8	2.8	3.2	2.9	2.8	2.8	2.5	3.3	3.6	3.2	2.9	3.3
March	2.2	2.5	3.2	2.8	2.7	3.9	4.2	3.8	4.3	4.7	3.0	3.9	5.5	5.7	3.9	3.7
April	3.7	3.0	3.0	3.6	3.1	2.6	3.0	2.4	2.7	3.4	3.2	3.0	4.0	2.5	3.9	2.8
May	3.0	2.7	2.4	2.9	2.8	3.3	4.0	3.6	3.0	2.1	2.9	3.0	3.3	0.0	2.7	3.5
average	3.0	2.7	2.9	3.1	2.9	3.3	3.7	3.3	3.3	3.4	3.0	3.3	4.3	2.7	3.5	3.3
June	3.1	2.7	2.5	2.9	2.4	2.8	2.3	2.0	2.7	2.7	3.5	3.3	2.5	3.8	2.6	3.3
July	2.5	2.5	2.2	2.7	3.1	2.3	1.8	2.4	2.3	0.0	1.9	3.8	3.6	3.6	3.2	2.7
August	2.9	2.8	2.3	2.6	2.6	2.7	1.6	0.0	1.7	1.3	0.0	3.4	3.6	3.1	4.2	3.5
average	2.8	2.7	2.3	2.7	2.7	2.6	1.9	1.5	2.2	1.3	1.8	3.5	3.2	3.5	3.3	3.2
September	3.0	2.4	1.4	1.0	2.7	2.2	2.1	4.0	4.3	2.8	3.6	3.7	4.7	4.2	3.7	3.2
October	3.7	4.9	3.9	3.6	2.2	1.9	1.9	2.3	2.4	2.5	2.5	2.1	2.5	2.1	3.6	3.0
November	2.5	2.8	2.4	3.0	2.8	3.1	3.4	3.6	3.4	3.3	3.5	3.6	4.3	4.2	3.2	3.3
average	3.1	3.4	2.6	2.5	2.6	2.4	2.5	3.3	3.4	2.9	3.2	3.1	3.8	3.5	3.5	3.2
average for the year	3.0	2.8	2.7	3.0	2.7	2.8	2.8	2.7	2.9	2.6	2.6	3.3	3.7	3.2	3.3	3.3

Table 5.9 – Repeatability of precipitations by wind velocity and direction

Rain — Total 5.586 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.671	0.097	0.101	0.157	0.201	0.121	0.005	0.114	0.048	0.056	0.114	0.016	0.026	0.025	0.006	0.005
2<U<3	0.039	0.024	0.449	0.091	0.051	0.032	0.072	0.049	0.070	0.048	0.025	0.017	0.012	0.017	0.011	0.015
3<U<4	0.040	0.000	0.101	0.059	0.098	0.038	0.002	0.046	0.079	0.007	0.071	0.104	0.015	0.066	0.023	0.061
4<U<5	0.000	0.000	0.140	0.055	0.053	0.080	0.110	0.001	0.070	0.043	0.045	0.043	0.043	0.045	0.008	0.000
5<U<7	0.318	0.163	0.080	0.080	0.009	0.041	0.015	0.026	0.035	0.025	0.001	0.099	0.008	0.131	0.021	0.000
7<U<10	0.040	0.080	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.000	0.000
U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	1.108	0.364	0.911	0.443	0.412	0.312	0.206	0.236	0.301	0.179	0.257	0.279	0.143	0.285	0.068	0.081

Shower — Total 0.596 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.207	0.010	0.000	0.000	0.000	0.000	0.000	0.000
2<U<3	0.000	0.007	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.000
3<U<4	0.000	0.005	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.003	0.002	0.000	0.004	0.000	0.000
4<U<5	0.000	0.000	0.000	0.000	0.000	0.000	0.318	0.006	0.000	0.000	0.004	0.000	0.004	0.000	0.000	0.000
5<U<7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000
7<U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	0.000	0.012	0.000	0.000	0.006	0.004	0.318	0.006	0.207	0.010	0.019	0.002	0.004	0.004	0.003	0.000

Shower with thunderstorm — Total 0.600 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.344	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2<U<3	0.000	0.000	0.000	0.049	0.006	0.000	0.001	0.000	0.025	0.000	0.001	0.000	0.000	0.008	0.000	0.000
3<U<4	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.012	0.000	0.025	0.000	0.000	0.036	0.003	0.000
4<U<5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.009	0.005	0.000	0.007	0.000	0.000	0.000
5<U<7	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.001	0.042	0.000	0.005	0.000	0.000	0.000	0.000	0.000
7<U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	0.344	0.007	0.000	0.049	0.010	0.000	0.001	0.001	0.090	0.009	0.036	0.000	0.007	0.043	0.003	0.000

Snow Total 1.558 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.008	0.017	0.004	0.001	0.002	0.000	0.000	0.002	0.002	0.042	0.002	0.001	0.001	0.000	0.004	0.002
2<U<3	0.001	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.013	0.000	0.029	0.001	0.006	0.003
3<U<4	0.007	0.003	0.006	0.332	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.021	0.007	0.003
4<U<5	0.003	0.009	0.054	0.002	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.040	0.003	0.007	0.082	0.025
5<U<7	0.024	0.000	0.043	0.005	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.008	0.113	0.288	0.032
7<U<10	0.000	0.000	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.103	0.000	0.002
U>10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	0.043	0.030	0.118	0.342	0.041	0.000	0.001	0.005	0.015	0.043	0.015	0.041	0.163	0.245	0.387	0.068

Snow with rain Total 0.501 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.002	0.001	0.002	0.004	0.001	0.000	0.001	0.003	0.003
2<U<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.001	0.003	0.002	0.002	0.002
3<U<4	0.002	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.001
4<U<5	0.003	0.003	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.041	0.000	0.000	0.000	0.000	0.000
5<U<7	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.040	0.000	0.000	0.000	0.308	0.000	0.000
7<U<10	0.000	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
U>10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	0.005	0.047	0.001	0.001	0.000	0.001	0.001	0.006	0.003	0.043	0.047	0.002	0.020	0.312	0.006	0.006

Drizzle Total 0.935 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.105	0.040	0.000	0.006	0.045	0.004	0.041	0.000	0.000	0.027	0.040	0.001	0.000	0.000	0.001	0.000
2<U<3	0.041	0.057	0.136	0.001	0.002	0.044	0.000	0.038	0.012	0.021	0.048	0.013	0.002	0.000	0.001	0.011
3<U<4	0.000	0.000	0.000	0.022	0.001	0.039	0.040	0.000	0.010	0.000	0.006	0.000	0.000	0.011	0.000	0.004
4<U<5	0.000	0.000	0.000	0.000	0.000	0.001	0.018	0.012	0.001	0.005	0.001	0.000	0.000	0.000	0.015	0.000
5<U<7	0.002	0.000	0.000	0.003	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
7<U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
U>10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	0.148	0.098	0.137	0.033	0.047	0.087	0.100	0.055	0.022	0.052	0.095	0.014	0.002	0.013	0.016	0.016

Fog Total 1.832 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<U<2	0.115	0.007	0.006	0.060	0.048	0.003	0.119	0.082	0.004	0.184	0.132	0.009	0.000	0.000	0.002	0.005
2<U<3	0.001	0.002	0.000	0.041	0.183	0.021	0.094	0.027	0.000	0.094	0.159	0.058	0.000	0.000	0.020	0.000
3<U<4	0.000	0.000	0.000	0.080	0.063	0.042	0.035	0.000	0.001	0.002	0.001	0.061	0.001	0.009	0.000	0.000
4<U<5	0.000	0.000	0.000	0.000	0.018	0.000	0.013	0.027	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000
5<U<7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7<U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
U>10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
сума	0.116	0.008	0.006	0.181	0.311	0.066	0.261	0.137	0.006	0.280	0.293	0.129	0.002	0.009	0.022	0.005

Table 5.10 – Repeatability of stability categories by velocity and direction

A stability category Total 0.956 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<=U<2	0.064	0.021	0.106	0.021	0.149	0.000	0.000	0.000	0.021	0.043	0.000	0.021	0.021	0.128	0.043	0.021
2<=U<3	0.021	0.043	0.043	0.021	0.064	0.021	0.000	0.000	0.021	0.000	0.000	0.000	0.021	0.000	0.021	0.021
3<=U<4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4<=U<5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5<=U<7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7<=U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10<=U	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

B stability category Total 10.333 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<=U<2	0.489	0.490	0.747	0.153	0.501	0.043	0.171	0.043	0.107	0.213	0.298	0.320	0.234	0.171	0.172	0.236
2<=U<3	0.106	0.255	0.510	0.479	0.871	0.149	0.048	0.000	0.021	0.000	0.127	0.085	0.109	0.171	0.064	0.276
3<=U<4	0.064	0.106	0.106	0.425	0.531	0.064	0.000	0.021	0.000	0.000	0.000	0.064	0.043	0.149	0.191	0.191
4<=U<5	0.064	0.042	0.021	0.021	0.064	0.000	0.000	0.000	0.000	0.016	0.000	0.085	0.106	0.170	0.106	0.021
5<=U<7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7<=U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

10<=U	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

C stability category Total 15.610 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<=U<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2<=U<3	0.808	0.172	0.429	0.426	1.106	0.255	0.171	0.044	0.087	0.219	0.343	0.129	0.170	0.170	0.088	0.256
3<=U<4	0.621	0.492	0.283	0.653	1.073	0.191	0.128	0.107	0.215	0.130	0.088	0.490	0.344	0.532	0.789	0.489
4<=U<5	0.446	0.255	0.150	0.285	0.207	0.128	0.090	0.130	0.212	0.150	0.219	0.246	0.276	0.382	0.191	0.361
5<=U<7	0.021	0.043	0.000	0.021	0.000	0.000	0.021	0.000	0.043	0.064	0.000	0.043	0.000	0.043	0.021	0.064
7<=U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10<=U	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

D stability category Total 44.823 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<=U<2	0.574	0.277	0.358	0.404	0.945	0.314	0.363	0.617	0.964	0.620	0.666	0.557	0.091	0.091	0.277	0.242
2<=U<3	0.529	0.716	0.683	0.689	0.817	0.637	0.734	0.537	0.801	0.749	0.929	0.555	0.429	0.512	0.524	0.347
3<=U<4	0.654	0.141	0.529	0.783	1.292	0.392	0.186	0.545	0.553	0.829	1.038	0.722	0.623	0.591	0.790	0.370
4<=U<5	0.516	0.387	0.407	0.194	0.411	0.144	0.828	0.607	0.346	0.262	0.364	0.555	0.269	0.666	0.563	0.174
5<=U<7	1.148	0.460	0.220	0.223	0.141	0.135	0.287	0.275	0.472	0.540	0.598	0.756	0.857	1.638	1.309	0.545
7<=U<10	0.085	0.000	0.001	0.001	0.000	0.001	0.046	0.000	0.042	0.042	0.000	0.044	0.299	0.128	0.128	0.125
10<=U	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

E stability category Total 15.069 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<=U<2	0.091	0.174	0.005	0.174	0.209	0.093	0.092	0.047	0.005	0.122	0.139	0.007	0.044	0.001	0.008	0.047
2<=U<3	0.216	0.188	0.999	0.227	0.177	0.238	0.045	0.098	0.251	0.013	0.321	0.185	0.100	0.091	0.136	0.188
3<=U<4	0.349	0.349	0.430	0.839	0.234	0.397	0.216	0.202	0.278	0.134	0.318	0.258	0.161	0.358	0.350	0.411
4<=U<5	0.135	0.055	0.300	0.137	0.050	0.177	0.383	0.111	0.218	0.061	0.273	0.225	0.045	0.276	0.342	0.341
5<=U<7	0.424	0.134	0.096	0.091	0.000	0.043	0.051	0.046	0.142	0.043	0.006	0.097	0.000	0.244	0.000	0.028
7<=U<10	0.043	0.085	0.048	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.127	0.000	0.002
10<=U	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

F stability category Total 13.209 %

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0<=U<2	1.108	0.767	0.639	0.214	0.342	0.255	0.301	0.434	0.431	0.475	0.846	0.425	0.171	0.170	0.256	0.385
2<=U<3	0.982	0.510	0.683	0.220	0.342	0.128	0.301	0.260	0.510	0.300	0.618	0.284	0.043	0.086	0.300	0.385
3<=U<4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4<=U<5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5<=U<7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.000	0.000	0.000
7<=U<10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10<=U	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

A – extremely instable
B - moderately instable
C - slightly instable
D - neutral
E - slightly stable
F - moderately stable

5.3 PC COSYMA

PC COSYMA software system was designed in National Radiological Protection Board (England) and was applied to simulate consequences of radioactive substances propagation into the atmosphere, set radiation doses caused by releases under emergency conditions. Publication № 103 issued by International Commission on Radiological Protection where some principles related to the assessment of radiation effects were reviewed in comparison with the previous publication № 60 and № 72, which are fundamentals for the applied software and effective Ukrainian normative documents such as NRBU-97 and OSPORBU, uses two approaches for the assessment of effective radiation doses. Further when comparing calculated values with the standards accepted in Ukraine one uses the approach which gives higher priority to doses. Therefore, conservatism of assessments is reserved.

PC COSYMA (Code System for MARIA) – is a software package to simulate the consequences of accidental releases of radioactive materials into the atmosphere. PC COSYMA was co-designed by National Radiological Protection Board (Great Brirtain) and Forschungszentrum Karlsruhe (Germany) as a part of MARIA project (Methods for Accidental Radiation Impact Assessment) by European Commission.

The description of PC COSYMA software system and its separate modules is presented in the document [15]. The system is designed for the calculation of radiation effects of accidental (short-term) releases of radioactive materials into the atmosphere.

The system allows assessing the following parameters and consequences:

- integrated volumetric radionuclide activity in the lowest atmospheric layer and activity accumulated on the ground surface at the specific points of the ground;
- anticipated individual and collective doses for the selected period of time;
- the number of people involved in the implementation of countermeasures (shelter, pills with stable iodine, resettlement, decontamination, restriction on the use of agricultural products) and the area where the countermeasures are to be implemented;
- the number of agricultural products forbidden for use;
- the number of lethal and non-lethal diseases;
- economic cost of countermeasures and treatment.

The system may be used for deterministic and probabilistic assessments. The deterministic assessments allow to calculate the consequences for a set of meteorological conditions and probabilistic ones take into account a probable combination of meteorological conditions which may occur in case of an accident.

Transfer of impurities in the atmosphere is simulated in MUSEMET module. This module uses a model of segmental Gaussian spot which takes into account the change of speed and wind direction by the hour, categories of the atmosphere stability and amount of precipitation having an impact on the released substances. The model assumes that meteorological conditions are the same in the region of interest. Only probabilistic assessment takes into account the change in the meteorological conditions by the hour. When performing deterministic assessment it is admitted that meteorological conditions (speed and direction of the wind, atmosphere stability category) are not changed within the period of interest. MUSEMET uses the height of intermixing atmospheric layer, horizontal and vertical dispersion coefficients which are the functions of the atmosphere stability. Dispersion coefficients have two parameter values ─ for flat (agricultural regions) and uneven (towns) surfaces.

6 PROGRAMME FOR MONITORING AND CONTROL OF ENVIRONMENTAL EFFECTS

The monitoring programme includes two large sections:

- Control of safety barriers condition;
- Control of NPP impact on the population and the environment.

6.1 Monitoring of safety barriers condition

6.1.1 Control of the primary coolant

Integrity of the first and second safety barriers at ZNPP is controlled in compliance with «Rules for radiological monitoring during operation of ZNPP facilities» 00.РБ.XQ.Pr.01.A by sampling and gamma-spectrometric analysis on the following parameters:

- specific activity of iodine radionuclides in the primary coolant;
- isotopic composition and specific activity of radionuclides in the primary circuit.

«Technical Specifications for Safe Operation of ZNPP power units» specifies the following limits:

- operational limits for fuel failures – 1 % of fuel elements due to microcracking with gas-leak imperfections of fuel cladding and 0,1 % of fuel elements with direct contact of the reactor fuel with the coolant;

- operational limits for fuel failures – 0.2 % of fuel elements due to microcracking with gas-leak imperfections of fuel cladding and 0.02 % of fuel elements with direct contact of the reactor fuel with the coolant

6.1.2 Control of iodine radionuclides concentration in the primary coolant

The specific activity of iodine radionuclide concentration is controlled in the primary coolant at ZNPP power units.

6.1.3 Average monthly specific activity of reference radionuclides

Isotopic composition of the primary coolant is presented by fission products, radioactive corrosion products and its own radioactivity. The following radionuclides : ^{134}Cs; ^{137}Cs; ^{60}Co; ^{58}Co; ^{54}Mn; ^{59}Fe are under control.

6.1.4 Index of conventional release of the primary coolant into the atmosphere

Index of conventional release of the coolant into the atmosphere is controlled in relation of average specific activity of ^{131}**I** in reactor water to the release value of this radionuclide into the atmosphere.

6.1.5 Control of NPP process media

The integrity of the third safety barrier at ZNPP is controlled in compliance with «Rules for radiological monitoring during operation of ZNPP facilities» 00.РБ.XQ.Pг.01.A by sampling and its analysis on the following parameters:

- specific activity of essential service water;
- specific activity of intermediate circuit water;
- specific activity of SG blowdown water.

6.1.6 Control of operational efficiency of ventilation system, active gas purification system and special water treatment system of ZNPP

Ventilation systems are controlled according to airflow rate.

Operational efficiency of ventilation filters TL-21,22,23,28 of power units 1-6 and TL-52,53,54,57 Special Building-1, Special Building -2 is controlled by remote continual control of volumetric activity of inert radioactive gases, radioactive aerosols and iodine through the channels of Automated Radiation Monitoring System «Vulkan» of power units №№1-4 and channels of Radiation Safety Control Equipment -03, Radiation Control System of power units №№ 5-6, Special Building-1,2 and by means of laboratory method before and after filters in compliance with «Rules for radiological monitoring during operation of ZNPP facilities» 00.РБ.XQ.Pг.01.A.

The efficiency of active gas purification system of ZNPP power units 1-6 is controlled by the remote control of volumetric activity of inert radioactive gases by means of the channels of Automated Radiation Monitoring System «Vulkan» of power units №№1-4 and the channels of Radiation Safety Control Equipment -03, Radiation Control System of power units №№ 5 and 6, before and after filters of active gas purification system.

The efficiency of special water treatment system -1 and 2 of ZNPP is controlled by remote continual control of volumetric activity of water through the channels of Radiation Safety Control Equipment -03, Radiation Control System before and after filters of special water treatment system.

6.2 Monitoring of NPP impact on the population and environment

Extensive monitoring programme includes the following items:

1) setting of control, administrative, process and allowable release levels of radioactive releases and discharges;

2) control of gas-aerosol releases into the atmosphere:
   a) daily control of radionuclide releases;
   b) monthly control of radionuclide releases;
   c) an analysis of releases as compared to control levels;
   d) an analysis of releases as compared to administrative and process levels;
   e) an analysis of releases as compared to the allowable level;

3) control of radionuclide discharge into the cooling pond;
   a) control of ZNPP discharge water characteristics;
   b) control of discharge as compared to control levels;
   c) control of discharge as compared to administrative and process levels;
   d) control of discharge as compared to the allowable level;

4) control of radioactive materials in natural environment locations:
   a) the atmosphere;
   b) atmospheric precipitation;
   c) soil;
   d) vegetation;
   e) agricultural products;
   f) water bodies;

5) monitoring of dose rate intensity:
   a) dose rate intensity of gamma radiation in situ;
   b) annual dose of gamma radiation along the perimeter of ZNPP site;
   c) annual dose of gamma radiation in situ;
   d) continual control of dose rate intensity of gamma radiation assisted by information and measurement system «Koltso» 86;

6) control of meteorological parameters;

7) setting of radiation doses caused by releases and discharges:
   a) annual radiation dose caused by gas-aerosol releases into the atmosphere;
   b) annual radiation dose caused by liquid discharges of radioactive materials;
   c) an analysis of radiation doses of critical population group in comparison with the allowable level.

6.3 Control of the impact on the environment

The strategy related to the control of the emergency situation is implemented through the five levels [10].

Level 1. Prevention of operational occurrences.

The main means for reaching of the mentioned goals are as follows:

- selection of a site for NPP location in compliance with the normative documents;

- development of a design on the basis of the conservative approach with maximum use of the reactor facility safeguard features;
- ensure the required quality of systems, structures and components of NPP, activities related to its construction, operation and upgrading;
- availability of hardware preventing operational occurrences;
- operation of power units in compliance with the requirements of normative documents, Technical Specifications for Safe Operation and Operating Procedures;
- maintain systems, structures and components important to safety by means of timely failure detection and taking preventive measures, replacement of equipment with exhausted service life , arrangement of efficient system for monitoring of systems, structures and components, their maintenance and upgrading, record keeping of the mentioned work results;
- personnel recruitment, training and maintaining of the required level of personnel qualification;
- development of safety culture.

Level 2. Safety assurance in case of operational occurrences to prevent emergency situations.

Main means to achieve the specified goal are as follows:

- timely detection and correction of deviations from normal operation;
- availability of automatic operational safeguards and interlocks that prevent operational occurrences under emergency conditions;
- personnel actions shall be in compliance with the requirements of procedures and technical specifications for safe operation, their constant improvement with account of accumulated experience and new scientific and technical data;
- drills for personnel in case of operating occurrences.

Level 3. Prevention and elimination of accidents.

Main means to achieve the specified goal are as follows:

- availability of safety systems (protective, confining, supporting and control ones) that are intended to prevent emergency situations and design-basis accidents, to eliminate their consequences and to prevent their transformation into beyond design-basis accidents;
- use of normal operation systems to prevent emergency situations and design-basis accidents as well as to limit their consequences;
- availability and use of emergency operating procedures and ensure personnel actions in compliance with their requirements;
- personnel training in case of accidents at the full scope simulator.

Level 4. Management of design-basis accidents.

Main means to achieve the specified goal are as follows:

- use of normal operation systems and safety systems to prevent evolution of beyond design-basis accidents, to limit their consequences and to return the reactor facility into controllable state;
- availability and use of procedures for beyond design-basis accident management intended to stop fission chain reaction, to cool effectively nuclear fuel, to hold radioactive materials within the prescribed limits, and to limit severe accident consequences including protection of the containment against destruction;

- availability and use of severe accident management procedures aimed to prevent core melt escape from the reactor pressure vessel and loss of the containment integrity, to limit radiation effect on personnel, population and the environment as well to set conditions for timely implementation of plans on personnel and population protection;
- personnel actions shall be in compliance with the requirements of design-basis accident management procedures;
- personnel training in beyond design-basis accident management.

Level 5. Emergency preparedness and response.
At this level it is necessary:
- to determine buffer area and surveillance area around the NPP;
- to ensure availability of emergency plans and emergency response plans, their effectiveness and implementation preparedness must be periodically tested during emergency response drills and exercises;
- to build radiation shelters and crisis centers.

CONCLUSION

Radiation effect of gas and aerosol releases during normal operation of ZNPP is significantly lower than the set dose limits for population in contiguous countries (this limit for different countries is within the range 0.2-0.3 mSv/year). At the frontier of the nearest country – Russia as well as of the adjacent European countries the value of annual individual effective dose does not exceed 3.3nSv/year ($3.3 \cdot 10^{-6}$ mSv/year).

The main criterion of population exposure limitation in Europe due to anthropogenic sources is the limit of individual effective dose (for all kinds of exposure) which is set at the level of 1 mSv/year. The assessment has shown that in the event of one of the considered accidents at the border of the nearest European states and Russia, the committed total effective dose for 50 years will not exceed 18 mcSv (0.018 mSv).

Under normal conditions of ZNPP operation and in the event of accidents there is no environmental impact in a transboundary context, i.e. in the territory of contiguous countries, because the regulatory requirements to atmosphere pollution are met and dose limits for population are not exceeded and at the distance of 200 km from ZNPP they are at the level that is significantly below the limit.

Gas and aerosol releases of chemical contaminants do not impact the environment under normal operating conditions and in the event of accidents in a transboundary context, i.e. in the territory of adjacent countries (the nearest one is Russia, 250km). According to analysis of documents that substantiate the volume of chemical contaminant releases [16÷29] the main volume of these contaminants is generated from the sources of ZNPP1. Chemical effect of gas and aerosol releases under normal operating conditions does not go beyond the regulatory requirements to atmosphere pollution in the territory of Ukraine. Maximum contribution to the environmental contamination from ZNPP1 does not exceed standard indicators and at the distance of 100 m (ZNPP1 standard buffer area for chemical factor as per DSP 173-96 [30]) is 0.56 parts of maximum permissible concentration $_{mcR}$ [16]. It is 1.8 time lower than the maximum permissible limits. The area of ZNPP1 chemical impact is 2 km [16], total contaminants concentration of all sources of emissions from ZNPP1 in the atmosphere outside this area does not exceed 0.05 of maximum permissible concentration $_{mcR}$ [31], which is 20 times lower than maximum permissible limits.

As can be seen from the above no substantial transboundary impact is observed and according to the Convention on Environmental Impact Assessment in a Transboundary Context there is no affected party. To fulfill Paragraph 8, Article 3 of the Convention on Public Access to Information it is sufficient to post materials about assessment of planned activity impact on the environment on the Internet common access resources, e.g. on websites of the state authorities: Ministry of Nature and Ministry of Fuel and Energy.

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