ANNEX D. Description of the forecasting methods and the reference data to apply these methods, as well as the environmental data, which was used for the calculations

1. DESCRIPTION OF THE FORECASTING METHODS OF THE ENVIRONMENTAL INDICATORS DINAMICS AND JUSTFICATION OF THE RATED FORECAST PERIODS

To forecast and evaluate parameters of the radiological situation in the KNPP location zone the program complex “PRO NPP” is used. It enables, with the consideration of specific soil and climate conditions of the power plant location area during normal operation and emergencies, to assess a number of parameters of radiological situation: specific activity of 82 radionuclides in the air, in the soil, in the agricultural products and in other environmental objects; radiation dose for the population with the consideration of the main impact routes. The Gaussian model of impurity dispersion in the air, recommended by IAEA, is used for the assessment of the radioactive substances concentration in the air and the density of the territory contamination with them. The assessments of the radioactive contamination of agricultural species and food are made with the use of developed and approved recommendations.

All dose estimates will be received using the radionuclides concentration fields in the air and contamination density of the surface grounds from gas-aerosol discharge from the plant. During calculations the secondary wind rise of radionuclides, accumulated on the ground surface, are not taken into account. The reason is a small contribution of the secondary wind rise into the surface volumetric activity of radionuclides in the air. According to the report data [1], the dose of the secondary rise in the first 2 years after the precipitations is 10% less than the dose conditioned by the initial precipitations (in most cases less than 1%).

1.1 Photon irradiation from the cloud

Power of the dose, formed in the unprotected layer of a human body, in an open area shall be calculated according to the formula:

$$H[Sv/sec]= A_{\Box}\,[Bq/m^3] \cdot B_{\alpha\gamma}[(Sv/sec)/(Bq/m^3)], \qquad (1)$$

Where

$A_{\Box}$ is a volumetric activity of radionuclides in the air;

$B_{\alpha\gamma}$ is the dose power per radionuclide concentration unit in the air.

Coefficients $B_{\alpha\gamma}$ are calculated for 2π geometry with the accuracy to edge effect in an open area according to the formula [2]:

$$B_{\alpha\gamma} = \frac{\sum_i n_i \cdot E_i \cdot 1.602 \cdot 10^{-13} \cdot r}{2 \cdot w \cdot \rho}, \qquad (2)$$

Where

n_i is an absolute yield in the decay scheme, photon/decay;

E_i is the energy of the photon ^{i}, MeV/decay;

$1.602 \cdot 10^{-13}$ is the energy equivalent, J/ MeV;

$r = 1{,}09$ is the transition coefficient from the absorbed dose in the air to the equivalent dose in the biological tissue, Sv/Gy;

ρ is the air density under normal conditions, kg/m^3;

w is an energy equivalent of Gray, relative to a mass of 1 kg of the irradiated medium.

1.2. Photon irradiation from the ground surface

$$H[Sv/sec]= A_s[Bq/m^2] \cdot B_{s\gamma}[(Sv/sec)/(Bq/m^2)], \tag{3}$$

Where

A_s is a surface ground contamination;

$B_{s\gamma}$ is a dose coefficient of the external irradiation from the ground [2].

1.3. Internal irradiation during inhaling

$$H[Sv/sec]= A_{\square}[Bq/m^3] \cdot B_{ih}[(Sv/sec)/(Bq/m^3)] \tag{4}$$

Where

$A_{\square}$ is a volumetric activity of radionuclides in the air;

$B_{ih} = DL/PC^{th}_{B}$

DL is the effective dose limit for the category B, 1 mSv/year;

PC^{th}_{B} is the permissible concentration of radionuclide in the air [3].

1.4. The expected annual dose from the peroral route of radionuclides

Individual dose of radionuclides, received with the food intake shall be calculated in assumption of the food consumption of local production. The doses shall be calculated for 45 years of a power unit service life. Root and aerial route of radionuclides into the agricultural products are taken into account. The model of the radionuclides migration is used [2], based on the maximum coefficients of the radionuclide transfer into the agricultural products and average ration of a rural resident. The dose coefficients, given in the paper [4], were used for the calculations.

$$H[Sv]= A_s[Bq/m^2] \cdot B_{ign}[(Sv/Bq)\cdot K^{ind}[m^2)] \tag{5}$$

Where

A_s is a surface ground contamination;

B_{ign} is an effective dose per radionuclide peroral route unit [4];

K^{ind} is a coefficient, connecting the contamination level with the radionuclide route into the body of an individual [2].

For the assessment of consequences of radionuclide discharge during hypothetical emergencies, the set of programs COSYMA will be used, which is widely used for such purposes in Europe. The set of programs gives a possibility to evaluate such parameters as radionuclide concentration in the air, fallout density, individual and collective doses for the population. Assessments of the radiation doses and assessments of risks of diseases shall be made based on the dose coefficients and dose-effect relation, which are specified in the International Commission on Radiological Protection (ICRP) publications. Besides, a set of programs RaDEnvir 3.1 will be used, elaborated for the assessment of the radiation dose for the population jointly by IAEA and Scientific and Research Institute of the Radiological Protection of the Academy of Technological Sciences of Ukraine.

2. TRANSBOUNDARY TRANSFER

2.1 Transboundary transfer during KNPP normal operation

In order to calculate correctly the transboundary transfer of the radionuclide of the KNPP emission, the average annual meteorological information at the whole territory of interest is required (profiles of the air temperature, speed and direction of wind at different altitudes, change of these characteristics in space). Such information is absent. Even with the availability of such information the calculation itself is very complicated and tedious.

For the assessment of the radiological significance of the transboundary transfer during normal operation of the power plant it is suggested to use the results of the calculation of the dispersion of the gas and aerosol discharge for KNPP Supervised Area (SA), received within the frames of the Gaussian dispersion model [5]. These calculations are made taking into account the actual meteorological data in the area of the power unit location (frequency of the stability categories, average speeds of wind for these categories and the wind rose extent) with the actual reserve of persistence. As far as the distance from the source of releases, the contamination of the territory with radionuclide decreases rapidly, which leads to the reduction of the radiation dose for population (figure 2.1). Besides, even in the control area the radiation dose does not exceed the limits of the radiation dose for the population. It means that even if the plant is located directly on the border, in this case the limit quota of the radiation dose for the population of the neighboring countries will not be exceeded (for most European countries it is higher than for Ukraine and is 200 μSv/h^{-1})

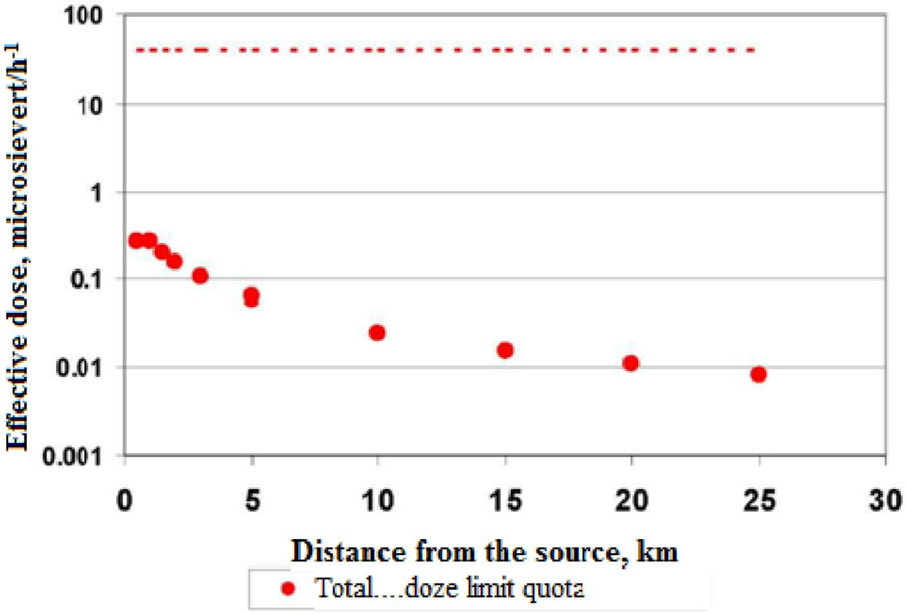

Figure 2.1– **Dependence of the radiation dose for the reference group of population on gas and aerosol discharge from the source (normal operation)**

Radioactive contamination due to gas and aerosol discharge at long distances outside the KNPP SA cannot exceed such at the border of the SA according to the following physical reasons:

- Gas and aerosol discharge occurs regularly and the impact of the short-term weather conditions, which are favorable for the transfer to long distances, is not significant in terms of average annual transfer;
- There is no reverse diffusion in the nature (the process of the impurity dilution is irreversible as long as there is a concentration gradient);
- Activity of radionuclide decreases in course of time as the result of the radioactive decay. The closest borders of the neighboring countries are at about 150 km distance from KNPP and by the wind speed of 3 m/sec^{-1} and its linear trajectory (which is never the case in the nature), the time for the cloud to approach the border is around 14 hours. During this time the activity of the radionuclide with the period of the half-decay of 1,4 hour will reduce 1000 times;
- During the movement of the radioactive cloud its depletion occurs due to gravitational settling of radionuclide and wash-out whereof through precipitations.

Taking into account the above stated one can assert that the radiation impact on the neighboring countries during normal operation of KNPP will be significantly less than the established dose quotas, and consequently less than the limit of the individual effective annual dose of 1 μSv.

2.2. Transboundary transfer during accidents

2.2.1 Substantiation of the choice of the mathematical model of the radionuclide spread in the air

Mathematical models of the spread of accidental radionuclide discharge in the air can be classified according to two principle criteria [6]:

a) Spatial scale of the problem, which is defined by an accident class;

b) Detail of the description of physical processes of the nuclide transfer and the related level of complexity of the applied mathematical algorithms.

A wide range of approaches is used for the calculation of the spread of radioactive discharge in the air: from the simplest methods to calculate the trajectories of the radioactive cloud transfer, which enable evaluating the direction of the discharge spread and making a semi-quantitative assessment of the impact [7], up to the calculations of numerical three-dimensional models of the turbulent diffusion [8].

In the nearest zone of the discharge source (local scale), the assessments of the surface air and underlying surface contamination are carried out mainly with the help of the method of IAEA Gaussian jet [9]. Herewith it should be noted, that in the IAEA recommendations it is stated, that the model can be used at the distance up to 10 km from the source (depending on the relief complexity). The margins of its applicability are limited in distance, because the model assumes stationarity and horizontal homogeneity of meteorological conditions, stationarity of the emission source (continuous or finite duration), horizontal homogeneity of the underlying surface. The extension of the margins of the model applicability in this region (of the distances from 20 to 30 km) requires special additional researches, which would confirm such possibility, and validation with regulatory authorities. Thus, in case of big radiation accidents, potentially able to lead to radioactive contamination of the territory beyond the NPP SA, the use of the IAEA model is not proper.

For the description of the distant transfer of the contamination (for distances of about thousand and more kilometers) mainly the simplified methods are use, with the use whereof one can get the averaged characteristics of the air contamination in the area.

In the area under study, the interim and the most complicated for the modeling are the processes of the contaminant diffusion at the distance of about hundreds and thousands kilometers, i.e. the space scales, where air-synoptic measurements are not carried out, but at the same time all special meteorological phenomena can be observed.

This is related to the fact that the mesogrid model shall take into account the diurnal variation of turbulence in the boundary layer, orographic and thermal heterogeneity of the underlying surface etc. Its peculiarity is, on one hand, the necessity to have a detailed and proper description of the main physical processes, which define the spread and deposition of the contaminant in such areas; and on the other hand the necessity to achieve a reasonable compromise with computational capabilities.

Taking into account, that KNPP is located at the distance of 160 km from the border with Belorussia and of about 190 km from the border with Poland, for the solution of the transboundary transfer of the radioactive discharge from KNPP the most optimal is the choice of the mesogrid model of the atmospheric transfer. Thus, the relative assessments were carried out, using the mesogrid model of the Lagrangian-Eulerian diffusion model LEDI of the contaminant transfer in the atmosphere [10]. The model was developed for calculations of the contaminant transfer to the distances up to 1000 km from the gas and aerosol "point" source with the effective altitude of the emission from 0 to 1500 m. The model was used for the reconstruction of the dynamics of the radioactive contamination with radionuclide ^{137}Cs [9] and ^{131}I [10] of the territory of Ukraine in the initial period after the Chernobyl accident.

The model takes into account the following information:

- Nonstationarity (as the result of the diurnal way of characteristics of the boundary layer and weather changes);
- Spatial inhomogeneity of the meteorological characteristics of the atmosphere;
- Different types of the source according to the duration of emission (volley, of the limited period, continuous), according to the phase composition (gas, aerosol), according to the isotopic composition;
- Horizontal inhomogeneity of the underlying surface.

The source of discharge into the air is modeled in the form of the sequence of emissions ("puffs"), taking into account the variability of the substance quantity or activity in them. The combination of the Lagrangian and Eulerian methods is used for the description of the contaminant transfer in the boundary layer. Such approach allows with relatively small investment of time for computer calculations to physically correctly take into account main factors, which define the contaminant transfer. The three-dimensional task of calculation of the contaminant transfer in the atmosphere boundary layer is divided into three stages:

- Calculations of the horizontal trajectory of the contaminant spread based on the Lagrangian method of the particle;
- Calculations of the vertical profile of the contaminant concentration in the nodes of the horizontal trajectory, carried out with the help of the one-dimensional semi empirical equation of the turbulent diffusion;
- Distribution of the contaminant in the cross direction is considered normal with the dispersion, parameterized as a function, which appears as a sum of contributions of

the horizontal turbulent diffusion and the expansion of the contaminant jet taking into account the interaction of the wind turn with the turbulence in the boundary layer.

The model enables calculating the transfer and the deposition of the radioactive contaminant for the horizontal underlying surface as well as in the conditions of heterogeneity of the underlying surface, in particular taking into account the moderately broken ground relief and heterogeneous plant cover on it.

The model calculates the dependence of the immediate concentration of the contaminant in the air on the time, time-integrated concentration in the air and the density of the contaminant deposition on the underlying surface during the radioactive cloud or trail passing above the given point.

2.2.2 Choice of typical meteorological scenarios of radioactive discharge transfer in the air

Meteorological conditions of the discharge transfer in the air play a decisive role in the formation of the fields of radioactive contamination of the air and of the underlying surface. Since for this task the period for the discharge from KNPP to reach the borders with Poland and Belorussia is about half a day, then for such periods of time the temporal dynamics of the meteorological parameters play an important role, conditioned by the diurnal characteristics of the atmosphere boundary layer as well as by the change of the weather of the synoptic scale. Thus, the most reasonable approach to the choice of the meteorological scenarios of the radioactive emission transfer in the air is not the design of the artificial “extremely conservative” scenarios (for example, a fortiori unrealistic assumption about the wind permanency during the whole period of the transfer), but the use of the realistic data of the atmosphere characteristics measurement. Taking into account that for the modeling of the transfer to mesoscale distances the information on the atmosphere characteristics in the layer up to the altitude of 2 to 3 km is required, the data of the radio sounding of the atmosphere was used, carried out by the Hydro-Meteorological Service of Ukraine. Three typical meteorological situations were chosen, where there may be an intensive transboundary carry-over of the activity in the direction of Poland and Belorussia.

Meteorological scenario 1. The data of the atmosphere radio sounding was used (vertical profiles of the wind speed and direction, as well as the air temperature in the layer up to 3 km), which were carried out on 10-12 of February 1984 by the nearest upper-air station in the town Shepetovka (located at the distance of 35 km, south-east from KNPP). At that time the east wind was observed with the speed from 5 to 6 m/sec^{-1} at the altitude of 1km, conditioned by the periphery of the southern cyclone. There are no atmospheric precipitations on the whole territory of the emission spread in this scenario.

Meteorological scenario 1A. The same actual data of the atmosphere radio sounding was used like in the scenario 1. However in this scenario the availability of precipitations (snow) with the intensity 0,5 mm/h is assumed. The precipitations of such intensity were in fact observed in the specified period at several meteorological stations of the area under review. For this meteorological scenario the assumption was made, that the area of the atmospheric precipitations of such intensity exists on the territory of Belorussia directly behind the border with Ukraine in the period of passing of the radioactive discharge from KNPP there, i.e. in the period, when the activity reach the territory of Belorussia. Such meteorological scenario was chosen, taking into account significant contribution of the radioactivity washout from the atmosphere by atmospheric precipitations and, respectively, their role in the formation of the density field of the radioactive fallouts. In this scenario the atmospheric precipitations are absent on the whole territory of Ukraine, which ensures the highest density value of precipitations on the territory of Belorussia under the given scenario of the emission.

Meteorological scenario 2. The data of the atmosphere radio sounding of 26-27th of November 1982 was used. The weather conditions were formed, influenced by the anticyclone with the center in the east, which conditioned the southern wind with the speed 3-5 m/sec^{-1} close to the ground surface and 7-9 m/sec^{-1} at the 1 km altitude. Atmospheric precipitations are absent on the whole territory of the discharge spread.

Meteorological scenario 2A. The same data of the atmosphere radio sounding was used like in the scenario 2. Herewith it was assumed that in that period when the radioactive discharge reached the territory of Poland, it would start snowing with the intensity of 0,5 mm/h.

Meteorological scenario 3. As opposed to the previous scenarios, typical for a cold season, meteorological scenario 3 characterizes weather conditions with the high turbulence in the daytime atmosphere boundary layer (data of the radio sounding of the atmosphere during May 6-9, 1986). East light wind (from 2 to 5 m/sec^{-1} in the layer up to 1 km) during the spread of the hypothetical discharge changes to south-eastern and then to north-eastern. Atmospheric precipitations are absent on the whole territory of the discharge spread.

Meteorological scenario 3A. The same data of the atmosphere radio sounding was used like in the scenario 3. Herewith it was assumed that in that period when the radioactive discharge reached the territory of Poland, it would start raining with the intensity of 0,5 mm/h. The duration of rainfall was assumed to be equal to 4 hours.

2.2.3 Methodology of the radiation dose assessment for the population

The assessment of individual radiation doses for the population is an important part of the radiation protection system. Information on the doses is the criteria for decisions making in performing certain protective measures. In the report the annual individual effective doses are evaluated, received in different ways: inhalation, radiation from a radioactive cloud, radiation from radionuclides, deposited on the ground and radiation from radionuclides, coming with food. As a reference group of population, rural residents were chosen which consume mainly food of their own production (farmers). The assessment of the dose was made for two age groups – adults and 1-2 year old children. Calculations were made using the set of application programs ***RadEnvir3.1***, which was developed jointly by IAEA and Scientific and Research Institute of the Radiation Protection of the Academy of Technical Science of Ukraine.

During the calculations the approaches were used, contained in the papers [5, 13]. The radionuclide route into the human body was evaluated using the average daily ration of residents of Poland [14] and Belorussia [15]. The children's ration was received using recommendations, specified in the direction [13]. Only the food was used, which give the maximum contribution to the dose. The ration is given below in the table 2.1

Table 2.1 – **Ration for the assessment of the radiation dose for the reference group of the population**

Food	Poland (2007)		Belorussia (2005)	
	Adults, kg/year^{-1}	Children (1-2 y.o.) kg/year^{-1}	Adults, kg/year^{-1}	Children (1-2 y.o.) kg/year^{-1}
Milk	73[1]	95	192[2]	250
Potato	121	36	182	55
Veal	4	0,8	21	4,2
Pork	43,6	4,4	26	2,6
Poultry	24	2,4	13	1,3

Remark:
1 Includes drinks, based on milk
2 Includes all milk products, except butter

In the report the assessments of the radioactivity transfer were made for the actual meteorological conditions. Meteorological conditions according to the scenarios 1 and 2 occured in winter time. Since in this time agricultural products are not produced on lands, radionuclide may enter into the population ration only in the next vegetation period, at that the radionuclide will enter the plants through roots. Radionuclide route through roots is in itself a kind of additional barrier for the radionuclide to get into the ration of the population. So, from the point of view of the radiological safety, these scenarios are favorable. The third scenario is implemented in the spring time, and the radionuclide will penetrate the agricultural products mostly through external aerial contamination of plants during fallouts. These peculiarities were taken into account during calculation of the radiation dose for the selected reference group of population.

During the calculation of the radiation dose due to radionuclides, which penetrated the body with food, it was conservatively assumed that the contamination occurs at the beginning of harvest and the food is consumed immediately.

During the calculation of the radiation dose due to inhalation, radiation from the radioactive cloud and the ground surface, the period of stay of the reference group members in a premise was conservatively not assumed, but instead it was considered, that they had been staying for 24 hours in the open air.

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