Evaluation of Radiation Impacts of Spent Nuclear Fuel Storage (SNFS-2) of Chernobyl NPP– 13495

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ABSTRACT

Radiation effects are estimated for the operation of a new dry storage facility for spent nuclear fuel (SNFS-2) of Chernobyl NPP RBMK reactors. It is shown that radiation exposure during normal operation, design and beyond design basis accidents are minor and meet the criteria for safe use of radiation and nuclear facilities in Ukraine.

INTRODUCTION

Approximately 21,000 spent fuel assemblies (SFA) have accumulated at the Chernobyl Nuclear Power Plant site during the period of operation of its four reactors. the SFA are in a wet pool type spent nuclear fuel storage facility (SNFS-1).

Design life of SNFS -1 expires in 2016, after which the SFAs should be transferred from SNFS -1 to a new facility and SNFS -1 decommissioned. It has been decided that the design life of the new interim storage facility shall be 100 years to allow adequate time for national government decisions about the ultimate fate of the SFAs.

Detailed design of SNFS-2 is currently being reviewed by Regulatory Authorities of Ukraine. The radiation estimates in this paper are based upon the design and technologies identified in regulatory submittals. Estimates are made for normal operations, design basis accidents and beyond design basis accidents.

Short description of SNFS-2 and technology of preparing and storing of Spent Nuclear Fuel (SNF).

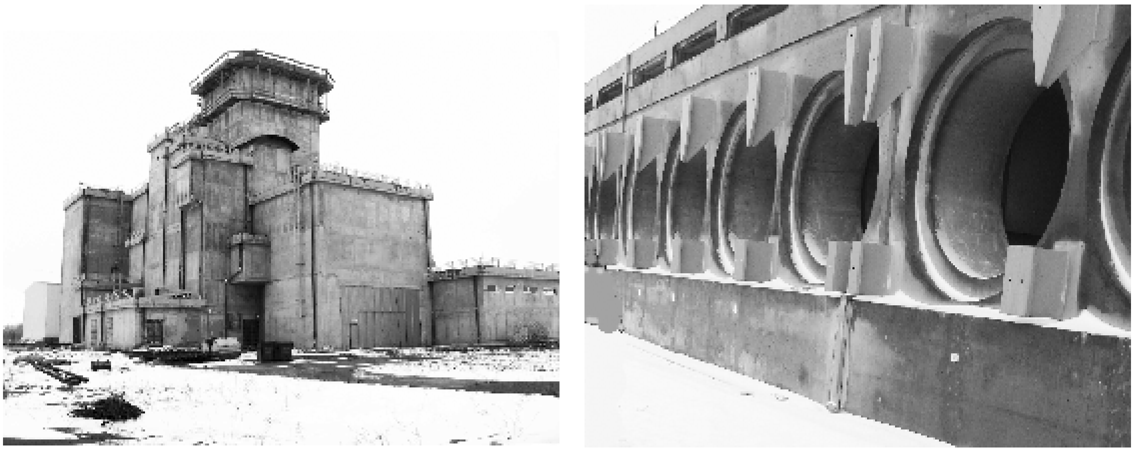
SNFS-2 is a dry type interim surface storage facility for spent nuclear fuel, designed for long-term (up to 100 years) storage of 21,217 spent fuel assemblies and 1,704 additional absorbers (AA) from four RBMK-1000 (Реактор Большой Мощности Канальный) reactors, which operated at

Chernobyl from year 1977 to 2000.

SNFS - 2 is located in the territory of the Chernobyl exclusion zone, at a distance of 2.4 km in a south-easterly direction from the "Shelter" which encloses the destroyed Unit-4.

Transportation of the SFA and the AA from SNFS-1 to SNFS-2 will be on railroad tracks, in special shipping containers (SC-8).

Unloading of SC-8 and preparing of SFA and AA for storage is performed in the building of facility to prepare the spent fuel for storage (FPSF), which building constructions provide sufficient insulation of process facilities from the environment (Fig. 1 (a)).



a) b)

Figure 1. a) General view of FPSF building on the territory of SNFS-2 ; b) –unfilled concrete modules for SNF store on SNFS-2 site.

In the FPSF building, spent fuel assemblies and the AA are fragmented. Then halves of SFA (bundles of fuel rods) are placed in double-walled dry shielded box (DSB), the volume of which can accommodate 93 fragmented of SFA.

Uploaded DSBs are dried and sealed (welded). Further, DSBs are being loading into a special intra-transport container, designed to provide biological protection when moving within the area SNFS-2, and transported to the rail platform for long-term storage of DSBs - concrete storage module (CSM) (Fig. 1 (b)) .

The zone of spent fuel storage there are 58 ventilated horizontal CSMs, each of which is designed for storage of 4 DSB.

According to the technology of SNF preparation, no discharge of liquid radioactive substances into the environment will occur. Liquid and solid radioactive wastes generated during manufacturing operations are temporarily stored in the building of FPSF. Liquid radioactive waste (LRW) will be transferred to existing ChNPP facilities for conditioning and disposal.

DESCRIPTION (methods)

Forecast of radiation effects of SNFS-2 on the environment is based on the calculation of the distribution of radioactive emissions into the atmosphere and their deposition on the ground surface. The mathematical model used to calculate is the Pasquill diffusion model recommended by IAEA and the World Meteorological Organization. The model is based on the assumption of statistical (Gaussian) distribution of contaminants in the atmosphere.

For the calculations, the technique and a set of software were used [1]. This software has been previously tested successfully in the development of other projects in the Chernobyl 30-km exclusion zone [2, 3].

Calculations were made for distribution during the worst weather conditions: atmospheric stability category - F (by Pasquill), wind speed - 1 m/s, wind direction - permanent. Aerosol deposition rate is 0.8 cm/s.

DISCUSSION

When operating the storage facility, radioactive substances are released to the environment by FPSF ventilation exhaust during technological operations with SFA and AA. In this, release of SNFS-2 will be due to sources such as releases from the fuel elements through cracks, loose sediments of SFA and AA formed during their being in the reactor, as well as surface contamination of SFA and AA formed during storage in the SNFS-1.

The value of release due to microcracks in the fuel elements has been estimated based on empirical data. After three days of exposure of leaky SFA, the specific activity of ^{137}Cs in the water of holding box was $3{,}7 \cdot 10^6$ Bq/kg, and the rate of release of ^{137}Cs from leaky assembly did not exceed $6{,}2 \cdot 10^7$ Bq/day. This value, in spite of the reduction in the rate of escape of ^{137}Cs with time was taken for the calculations. Given that the time of 1 SFA being in the building of FPSF is 6 days, out of a single SFA of ^{137}Cs in FPSF is about $3{,}7 \cdot 10^8$ Bq.

Speed of release of ^{239}Pu and ^{90}Sr through cracks taken at the level of 0.1% of ^{137}Cs, which was confirmed by the analysis of actual loose surface contamination found on Chernobyl SFA.

β-emission of radionuclides due to delamination from the SFA and AA deposits is estimated from the data on the mean value of the surface sediment concentrations (10 g/m^2) and the activity of radionuclides in sediments after 10 years of aging. The value of the specific activity of ^{137}Cs was 10^7 Bq/g. The specific activities of transuranic elements (TUE) were calculated from measurements of contamination of ChNPP's SFA and equal for the most active radionuclides $1,1 \cdot 10^5$ Bq/g for ^{238}Pu and $1,3 \cdot 10^5$ Bq/g for ^{241}Am.

Given the surface area of the SFA is equal to 6.79 m^2 and the average values of the surface sediment concentrations (10 g/m^2) total activity of radionuclides in sediments of a assembly was calculated: $2.8 \cdot 10^{10}$ Bq (^{60}Co), $1.7 \cdot 10^{10}$ Bq (^{55}Fe), $2.2 \cdot 10^{10}$ Bq (^{63}Ni), $6.8 \cdot 10^{8}$ Bq (^{137}Cs), $7.7 \cdot 10^{6}$ Bq (^{238}Pu), $1.5 \cdot 10^{6}$ Bq (^{239}Pu), $4.2 \cdot 10^{6}$ (^{240}Pu), $4.0 \cdot 10^{7}$ Bq (^{241}Pu), $8.9 \cdot 10^{6}$ Bq (^{241}Am), $6.2 \cdot 10^{6}$ Bq (^{244}Cm).

Analysis of the technology flow chart shows, no more than 35% of the original activity of radionuclides in sediments of an assembly can pass to the ventilation system during preparation for storage of one SFA.

The release of radioactive substances outside the FPSF building will be minimized by cleaning the exhaust air to the high efficiency filter. Cleaning efficiency is 99.97%.

Figure 2 shows the value of the annual gas and aerosol emissions from FPSF, calculated taking into account the fact that 2500 SFA a year will be putting into storage building, and given the efficiency of cleaning the exhaust air.

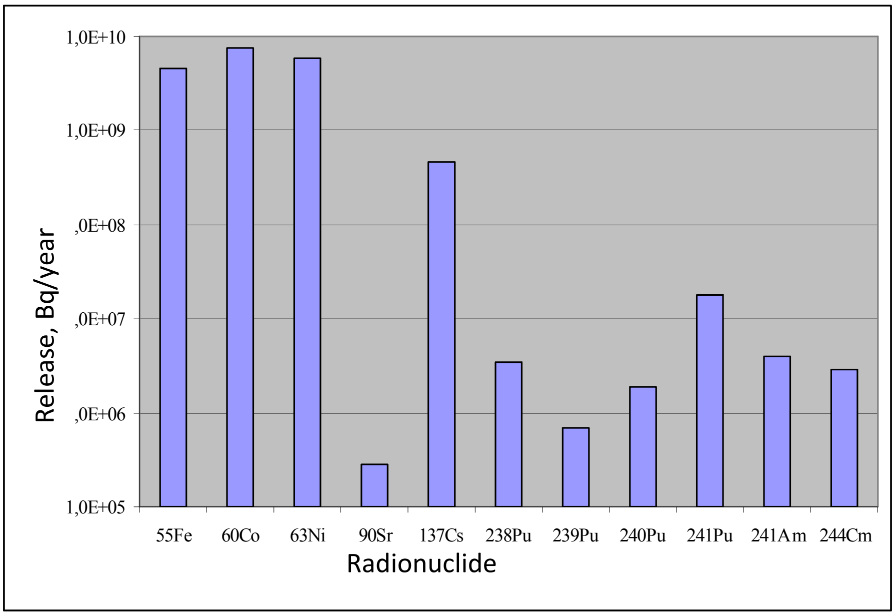


Figure 2 – Annual gas and aerosol release from during normal operation

The obtained values are significantly below the permissible release of individual radionuclides in normal operation of FPSF, which are $6.1 \cdot 10^{11}$ Bq/year (^{60}Co), $2.9 \cdot 10^{12}$ Bq/year (^{90}Sr), $1.7 \cdot 10^{12}$ Bq/year (^{137}Cs), $9.5 \cdot 10^{9}$ Bq/year (α - emitting TUE).

Substantiation of parameters of environmental impact at the design accident at SNFS-2

As a design basis accident, two events were evaluated. The first one is drop of SFA and depressurization of 100% of fuel rods, which is accompanied by the release of radionuclides to the premises of the FPSF building. The calculations assume that all radioactive materials capable to release are released into the vent pipe. Cleaning efficiency is equal to 99.97%, and the height of the ventilation pipe is 40 m

Release of radionuclides due to delamination of sediments from the SFA and AA was estimated using the initial data for the calculation of these emissions under normal conditions. Except for the fact that the surface sediment concentrations of 30 g/m^2 (maximum value – conservative assumption) was taken onto account.

It was shown that in the event of a SFA drop, $1.5 \cdot 10^{11}$ Bq of beta-emitting radionuclides and $2.4 \cdot 10^{8}$ Bq of alpha-emitting radionuclides will get into the ventilation system.

Total accidental release of beta-emitting radionuclides is $4.5 \cdot 10^{7}$ Bq. The total emission of alpha-emitting radionuclides is $7.4 \cdot 10^{4}$ Bq.

The second accident is connected with rupture of the gas supply pipe to the cooler, which is mounted on the roof of the FPSF building by design basis earthquake (5 points on the MSK-64 scale). The earthquake destroyed the pipe section between the HEPA filter and an air-cooled chiller, resulting in the release of gas mixture with the following parameters: the amount of emissions -36 m^3 gas mixture temperature emission - 300 °C, the duration of ejection - 1 hour, altitude of release point - 21.7 m. The rupture occurs after the filter system.

It is assumed conservatively that the emissions generated by the release of radionuclides through the cracks of all 93 SFA, located in the unpressurized DSB for 1.5 days in the drying process.

Thus, with the accident-2 associated with rupture of the pipeline, the ventilation system will get $3.1 \cdot 10^{12}$ Bq of beta-emitting radionuclides and $1.5 \cdot 10^{9}$ Bq of alpha-emitting radionuclides. Accidental release of beta-emitting radionuclides through the vent pipe will be $9.4 \cdot 10^{8}$ Bq, alpha-emitting radionuclides – $4.6 \cdot 10^{5}$ Bq.

Substantiation of parameters of environmental impacts during beyond-the-design accident on SNFS-2

The most severe beyond-the-design accident is a heavy aircraft (class of IL-96-300) falling directly to concrete modules filled with SFA. The worst effect on the environment is the destruction of the maximum possible number of fuel rods, compactly arranged in concrete storage unit. According to the estimates, the thickness of the concrete will be punched up to 4.7 m. Thus, with taking into account the thickness of the unit 1 m and thickness of walls between units of 0.3 m and the design features of SNFS-2, with the fall of the aircraft up to 4 concrete modules can be broken.

In the calculation of the radiological consequences of direct heavy aircraft fall on concrete modules filled with SFA, SFA with exposure time of 20 years were accounted. To characterize the effects, the estimation of emissions of β-emitting radionuclides was performed. Two options of calculation were used: using the model of the accident at Unit 4 of the Chernobyl NPP in 1986, and the empirical model for calculating emissions.

There is a fact, which is in favor of the use of analogy to the events at ChNPP in 1986: in the both accidents similar SFA were involved. A conservative approach is that the scale of the Chernobyl accident was many times greater than the possible failure of the aircraft. Temperature effects on the FA in the accident on the fourth power unit (over 1500 ° C) was significantly higher than the temperature of combustion of aircraft fuel (up to 800 °C), and the time of heat stress on damaged SFA (10 days) was much larger than the combustion of aircraft fuel.

If we take a conservative approach that during the project accident on SNFS-2 completely destroyed SFA will be exposed to temperature extremes at least 4 hours (the duration of the fire, and the impact of debris from the hot storage to their cooling), which is 60 times less than that of the Chernobyl accident, it turns out that the accident emissions will be approximately 0.6% of the total amount of $^{134,137}Cs$ in damaged modules and around 0.07% other radionuclides.

Calculation according to the empirical model is made in [4], where the empirical formula of dependence of diffusion rate of fission products and TUE from UO_2.

The results of calculations of emissions β-emitting radionuclides using the empirical formula and the equivalent model of the Chernobyl caused by heat are similar (see Fig. 3).

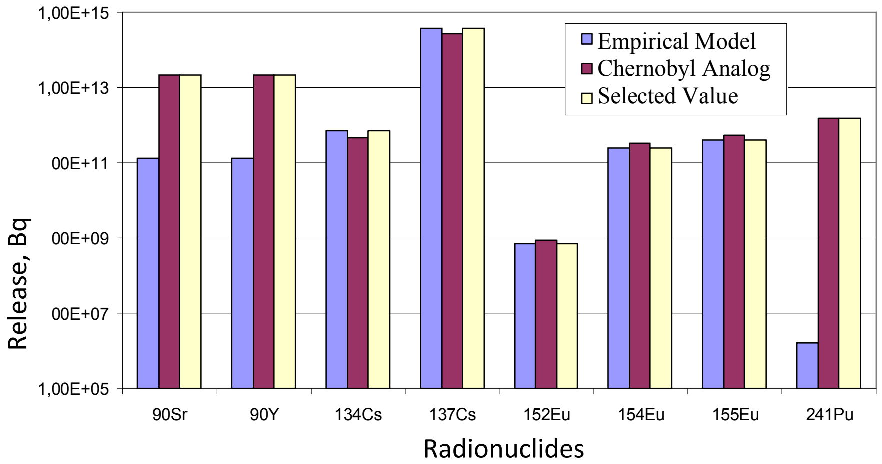


Figure 3. Releases of β-emitting radionuclides due to beyond-the-design accident.

Figure 4 shows similar data for emissions of α-emitting radionuclides. In this case, emissions, estimated by the "Chernobyl" model, is by orders of magnitude higher than those estimated by the empirical model, and for conservative reasons, they are selected for further evaluation of impacts.

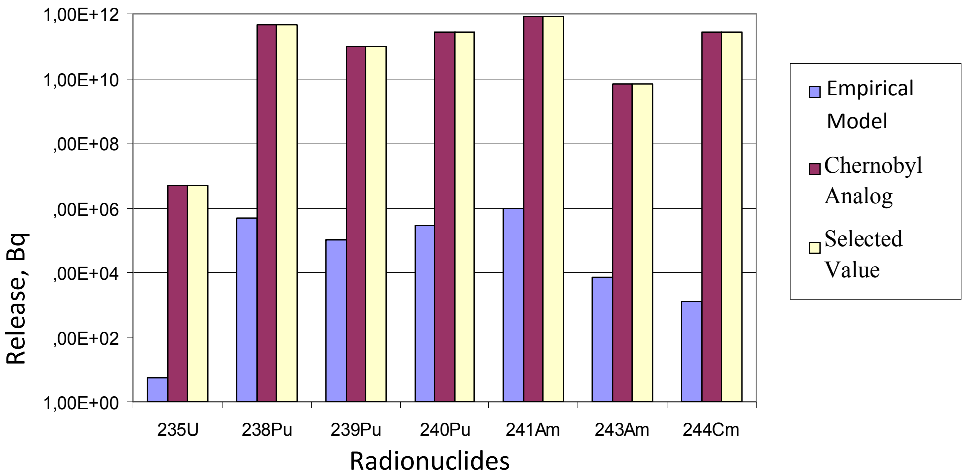


Figure 4. Releases of α-emitting radionuclides due to beyond-the-design accident.

RESULTS

Impact to the air.

Estimation of radioactive aerosols was calculated for different categories of weather conditions - for the average annual weather conditions (weather conditions N1) and for emergency weather conditions (weather conditions N2).

The concentrations of individual (the most important) radionuclides in the atmosphere were calculated, as a function of distance from SNFS-2. Comparisons with the permissible concentrations for staff (PC_A) and the public (PC_B), regulated NRBU-97 [5] and with the control levels (CL) established for the exclusion zone [6] were done. Regulatory limits for staff (radiation workers) are higher than those for the public. Closest to the CL concentration was the concentration of ^{137}Cs (Fig. 5).

Comparison of predicted values of activity concentration of radionuclides in the air due to normal use of SNFS-2 (Figure 6) with national and regional radiation-hygienic rules shows that even under the most conservative estimates, they are significantly less than the established levels of air pollution. A comparative analysis showed that the difference between the forecasted values and routine maintenance performance is so great (from 50 to 120,000 times for different radionuclides) that the combined effect of the additional air pollution will not exceed the regulated radiation-hygienic regulations.

Calculation of maximum activity concentration of various radionuclides in the atmosphere, due to an accidental discharge is shown in Fig. 6.

The maximum value of the volume concentrations in the lower elevation of the atmosphere, due to the design accident involving the fall of SFA, will be observed at a distance of 2000 m from the building of FPSF, where there is only category A staff (radiation workers). Therefore, comparison of the calculated concentration conducted with allowable concentration in the air for staff A (PC_A^{inhal}) [5]. Maximum concentration of radioactive substances in the air in the accident will be for ^{137}Cs – 1.2 Bq/m^3 (PC_A^{inhal} = 60 Bq/m^3), ^{90}Sr -0.8 Bq/m^3 (PC_A^{inhal} = 10 Bq/m^3), ^{60}Co -1.8 Bq/m^3 (PC_A^{inhal} = 70 Bq/m^3), alpha-emitting TUE 0.01 Bq/m^3 (PC_A^{inhal} = 0.03 Bq/m^3).

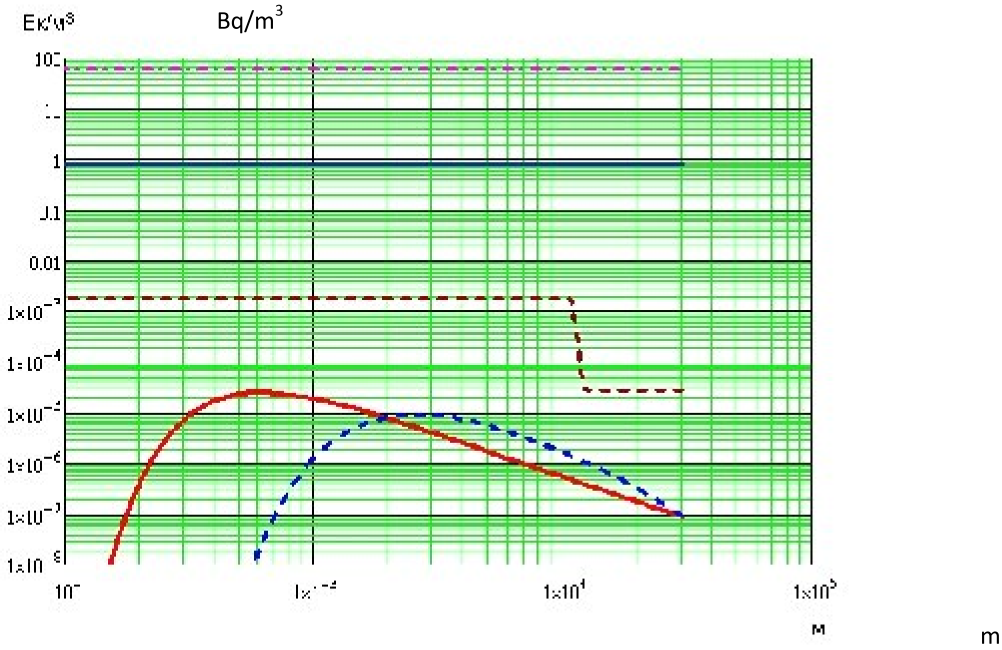


Figure 5 - The annual average volumetric activity of ^{137}Cs (Bq/m^3) in the surface layer of the atmosphere under normal operating conditions of SNFS-2 as a function of distance (m). Solid (red) curve – weather conditions N1, dashed (blue) curve – weather conditions N2, chain line – PC_A, solid line – PC_B, dashed broken (brown) line – CL in the first regime zone (10 km from ChNPP), and in the third regime zone (Chernobyl city).

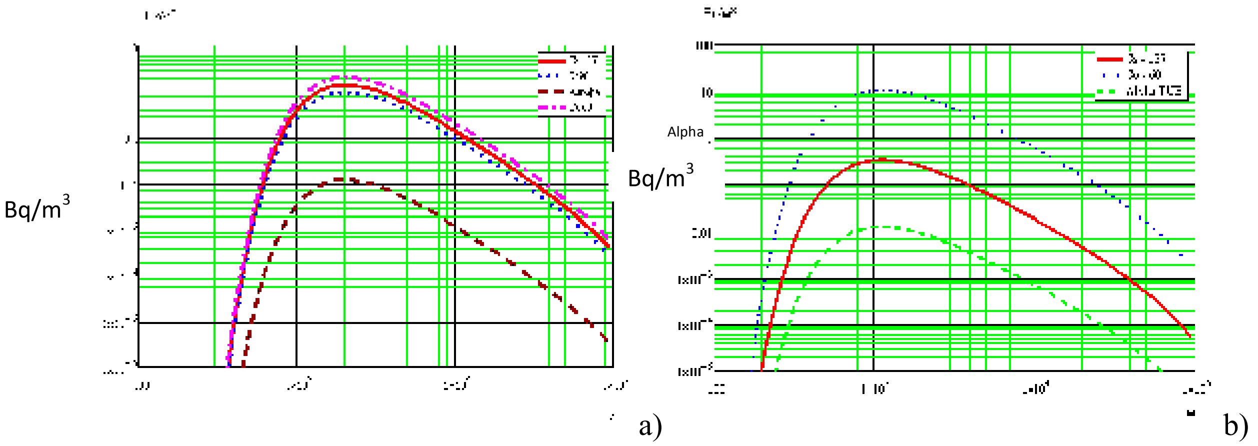


Figure 6 - The dependence of radionuclide activity concentration (Bq/m^3) in the air on the distance (m) to SNFS-2: a) in the case of design accident - SFA drop; b) in the case of design accident -pipeline rupture.

Comparison of maximum values with the value of the sum of ratios of different radionuclides to the appropriate PC_A^{inhal} [5] shows that, as a result of the accident, there will not be a significant impact.

Maximum radioactive air pollution due to rupture of the pipeline will be observed at a distance of 1,000 meters from the building FPSF (Fig. 6 (b)) and the amount of ^{137}Cs – 0.33 Bq/m^3, ^{60}Co – 10.6 Bq/m^3, alpha-emitting TUE - 0.013 Bq/m^3).

Calculation and analysis of the radiological consequences of beyond-the-design accident was conducted by the method of calculating the effects of a fire [7].

The maximum values of activity concentration from a surface release to the atmosphere due to beyond-the-project accident will be observed at a distance of 30 - 35 km from SNFS-2 and do not exceed the following values: ^{137}Cs - to 1000 Bq/m^3, ^{90}Sr - to 50 Bq/m^3, TUE - no more than 8 Bq/m^3.

Concentration of radionuclides in air due to an accident is not regulated, but for qualitative analysis can be compared to PC_v^{inhal}, as at maximum impact distance there is a population. At the maximum, we can see exceeding of the PC_v^{inhal}, but when you consider that PC_v^{inhal} was calculated on the basis of non-exceeding the dose limit due to irradiation during the year (approx. 8000 hours), and for beyond-the-design accident exposure will occur within a few hours, the annual dose limit set for the population, not be exceeded.

Thus, given the low probability of beyond-the-design basis accident, radiation effects on air should be acceptable. The additional radiation exposure to the air environment due to normal operation of SNFS-2, should be considered insignificant. Design accidents of SNFS-2 will not lead to significant impacts on air.

Impact on the water environment

The main type of radiation effects in the aquatic environment is deposition of radioactive aerosols, contained in the operation emissions of SNFS-2, on the open water, as well as on the flood inundated areas. The same effect will be given to the aquatic environment during design and beyond design basis accidents. In this it is conservative assumed that settled on the flood plain aerosols completely washed away by the flood waters to flow and migrate through the drainage area of SNFS-2 impact.

In the calculations it was assumed that during the year the prevailing winds will be north-east (from SNFS-2) direction, i.e. - the most dangerous direction in which water pollution will be most unfavorable. Also it is assumed that all radioactive aerosols will be deposited on the territory washed away by flood waters to the river and will go directly to the water of Pripyat river. Wind speed was taken as constant throughout the year and the corresponding long-term averages.

Calculating of deposition was carried out by integrating of Gaussian equation with limits equal to the distance from SNFS-2 to the nearest (3.6 km) and the farthest (5.2 km) border of flooded surface.

It is estimated that, during normal operations of SNFS-2, additional radionuclide intake to Pripyat river not exceed the following values: $3.6\cdot10^{7}$ Bq/year (^{137}Cs) and $2.3\cdot10^{4}$ Bq/year (^{90}Sr).

Considering the fact that even in low water years characterized by the lowest carry-over of ^{137}Cs and ^{90}Sr - $0,49\cdot10^{12}$ and $1,40\cdot10^{12}$ Bq/year [8, 9] calculated additional radiation impacts on aqueous medium under normal operation conditions SNFS-2 will add up to less than 0,1% from annual carry-over of Pripyat rivers.

Also assuming that water flow rate at the discharge of Pripyat river will be a minimum of 330 m^3/sec [8, 9], one receives conservatively calculated maximum possible additional specific activity of ^{137}Cs and ^{90}Sr in water of Pripyat river owing to SNFS-2 normal operation. It will constitute maximum $3,5\cdot10^{-3}$ and $2,2\cdot10^{-6}$ Bq/m3 being an insignificant value as compared to existing volumetric activity. Existing volumetric activity of ^{137}Cs and ^{90}Sr in water of Pripyat river are 0,05 and 0,12 kBq/m^3 [9].

Similar calculation of ^{60}Co water contamination testifies that additional specific water activity in river Pripyat due to this radionuclide will be at maximum 0,05 Bq/m^3. The maximum permissible quantity of (PC_B^{ingest}) ^{60}Co for drinking water corresponds to $8\cdot10^{4}$ Bq/m^3 [5], this additional impact will be also unessential.

The calculations demonstrate that the maximum value of possible radionuclide settling on Pripyat river surface and the area of its floodplain will not exceed $8,5\cdot10^{6}$ Bq (SFA fall) and $,6\cdot10^{6}$ Bq. Taking into account that the minimum annual carry-over of Pripyat river total activity (^{137}Cs+^{90}Sr) adds up to $1,89\cdot10^{12}$ Bq/year, accident impacts will not exceed 0,001% of annual carry-over and will be unessential.

Consequently, radiation impacts on aqueous medium in normal operation mode as well as in case of design accidents should be considered acceptable.

In estimating of the beyond-the-design accident impacts on surface water it was conservatively assumed that a part of the activity released in the air after accident above the area of Pripyat river with maximum fallout will settle on its surface and carried out outside the Exclusion Zone. However, the value of maximum possible fallout of radionuclides on surface of Pripyat river will not exceed $3\cdot10^{12}$ Bq, that is less than the total annual carry-over of activity with the flow of Pripyat rivers (to 10^{13} Bq by the sum of radionuclides).

Consequently, taking account of low beyond-the-design accident probability, radiation impacts on aqueous medium in case of a beyond design basis (hypothetical) accident will be acceptable.

Impact on the soils

For estimating soil impacts, it was assumed that release takes place with average values of the parameters of weather conditions including the most probable wind direction. It was assumed conservatively that entire fallen activity was accumulated in the upper layer of soil during the total 10-year operating cycle, ignoring its natural decomposition and migration processes.

Analysis of the obtained calculated values suggests that in normal conditions of SNFS-2 operation (in the first 10 years of FPSF operation) maximum possible value of the additional density of surface contamination will not exceed the following values: ^{137}Cs - 30,1 Bq/m^2, ^{90}Sr - 0,02 Bq/m^2; Isotopes $^{239+240}$Pu - 1,6 Bq/m^2.

The above-mentioned maximums of the additional density of surface contamination will be observed at ~ 600 m from FPSF building, i.e. in the limits of the radiation-restricted zone on Exclusion Zone area, whose nearest boundary is 9 km far from the storage. The highest input levels of soil cover contamination are typical for the area immediately adjacent to SNFS-2 site. The density of the areas radiation contamination by ^{137}Cs is up to 18,5-37,0, ^{90}Sr - 18,5 - 26, and $^{239+240}$Pu isotopes - 0,04 - 0,10 MBq/m^2. Calculation suggest that above-mentioned above maximum possible values of additional density of surface contamination will add up to less than 0,1 % from soil cover real contamination which can be considered as an unessential impact.

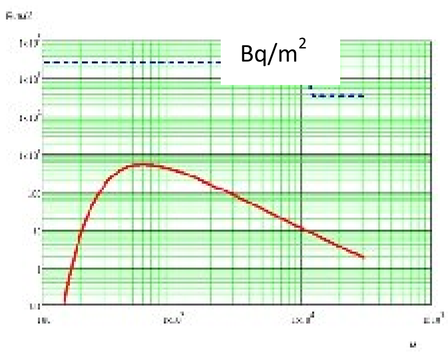


Figure 7 – Dependence of soil surface contamination density by beta – emitting radionuclides (Bq/m^2) from distance (m) under SNFS-2 normal operation conditions

Variation range of soil cover contamination density by ^{137}Cs for 10 km ChNPP zone (SNFS-2 near influence zone) is up to 0,4 - 40 MBq/m^2, ^{90}Sr - 0,09 - 16 MBq/m^2, and $^{239+240}$Pu isotopes –1 - 400 kBq/m^2 [8]. Comparison of the maximal values of additional surface contamination (in 10 years of operation of FPSF) with the lowest values of the soil cover existing contamina m suggests that it will constitute less than 0,2% from the existing contamination.

For the other area of the designed activity affected area (outside ChNPP 10 km zone), density values of soil cover contamination by ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ are in the range from 20 to 260, from 2 to 190 and from 0,1 to 4 kBq/m^2 respectively [9]. Taking into account that that the nearest boundary of 10 km ChNPP zone is located at a distance of 9 km from the storage in normal conditions of SNFS-2 operation (first 10 years of FPSF operation), maximal possible value of the additional density of surface contamination will not exceed the following values: ^{137}Cs - 0,9 Bq/m^2; ^{90}Sr - $5 \cdot 10^{-4}$ Bq/m^2; Isotopes $^{239+240}Pu$ - 0,04 Bq/m^2.

With respect to calculated value, values of soil cover additional contamination will not exceed 0,1% from the existing contamination and radiation impacts will be unessential.

Calculations show that the maximum impact on soil during design basis accidents will be the case of pipe rupture. Fig. 8.1 presents the total surface contamination of soil by ^{137}Cs and ^{60}Co, in order to compare the predicted values with a lower bound on the level of intervention by ^{137}Cs, as these two nuclides have similar properties to the nature of the radiation effects on humans (in [5], the intervention levels for ^{60}Co are not regulated). For other radionuclides dependences are similar - the maximum levels of additional pollution is about three orders of magnitude lower levels of intervention. For accident 1 the difference will be even greater - more than 4 orders of magnitude.

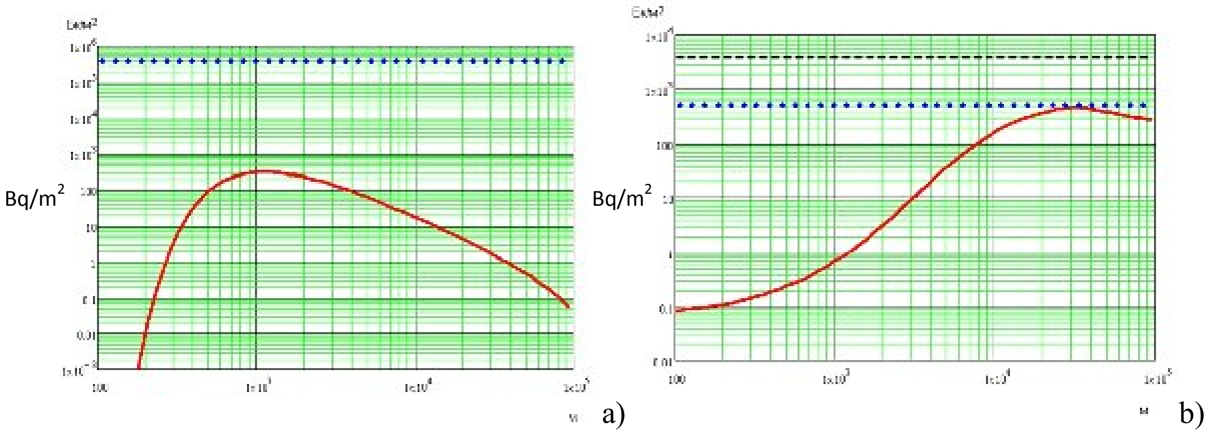


Figure 8 – a) Dependency density of soil surface contamination with the total of ^{137}Cs and ^{60}Co (Bq/m^2) as a function of distance (m) from SNFS-m case of design-basis accident (piping m rupture). b) Density of soil surface contamination with alpha-emitting radionuclides (Bq/m^2) as a function of distance (m) from SNFS-2 in case of beyond-the-design accident. Point line is the lower limit of justified counteractions, dotted - certainly justified the intervention level and the level of action.

Therefore, additional surface contamination of soil as a consequence of maximum design-basis accidents will not produce any significant change in the radiological situation within the SNFS-2 zone of impact.

The results of calculation of additional alpha emitting radionuclides contamination of the soil surface due to the accidental release are shown in Figure 8 (b). The figure is contamination of these radionuclides, as the contamination is closest to the lowest level of the justification for the intervention.

Analysis of calculation results shows that maximum fall-out of air-borne radioactivity as a consequence of the potential beyond-design accident on SNFS-2 will be observed 34 km away from SNFS-2 and will not exceed $1.1 \cdot 10^5$ Bq/m^2 for ^{137}Cs, $5.8 \cdot 10^3$ Bq/m^2 for ^{90}Sr, and 464 Bq/m^2 for alpha-emitting radionuclides.

Comparison of calculated predictions with the lower interference levels, which correspond for ^{137}Cs to 400 kBq/m^2, for ^{90}Sr to 80 kBq/m^2, for alpha-emitting radionuclides to 0.5 kBq/m^2, demonstrates that there is no need for additional counter-measures. Resettlement will accordingly not be necessary either, as contamination of soil will not reach obligatory resettlement levels

Impact on the personnel and populations

The parameters of radioactive contamination in most of the Exclusion Zone area, which corresponds to the SNFS-2 impact zone, currently exceeds the limiting values set for areas considered suitable for residence. However, there is an area inside the Exclusion Zone where temporary residence is permitted: part of the town of Chernobyl, which includes the hostels for shift personnel and other support infrastructure objects [6]. At the same time, this 'residential' area is characterised with certain levels of radioactive contamination, which requires evaluation of the additional exposure as a consequence of the intended SNFS-2 operations of personnel located within the 'residential' zone. Another feature of the SNFS-2 zone of impact is the presence of the so-called 'self-settlers' or illegal squatters – a group of population (category B) who have arbitrarily returned to their former residences that they occupied before the 1986 accident and live off their kitchen gardens.

The radiation impact on personnel of enterprises located within the Chernobyl 'residential' zone during normal operation will be attributable primarily to inhaled air-borne radioactivity released from the SNFS-2. The following assumptions were used for calculations: Duration of time during which personnel are in the zone - 4,000 hours a year, special means of protection - none, breathing rate - 1.5 m^3/hour.

Volumetric specific activity in the near-surface layer of air is adjusted to take into account the secondary wind-driven processes of air-borne radioactivity formation from the nuclides that had precipitated on the soil surface as a result of SNFS-2 operations.

Additional dose from internal exposure of personnel located in the 'residential' subzone during normal operation SNFS-2 will be no more than $8 \cdot 10^{-3}$ μSv per year. For the purposes of SNFS-2 impact assessment, personnel living in the 'residential' area were treated as members of the general public. In this area it is prohibited to produce food, so the only way of radionuclides intake into the body is with inhalation. The additional individual dose from internal exposure of personnel is about five orders of magnitude lower than the reference level for internal exposure dose for subgroup II of the Exclusion Zone personnel, which is 0.7 mSv/year [6]. The additional exposure dose to the public living outside of the Exclusion Zone will be negligibly small compared with the exposure dose limit quota of 40 μSv established by NRBU-97 for NPPs and radwaste management facilities.

The radiation impact on personnel of enterprises located in the 'residential' Chernobyl zone as a result of maximum design-basis accidents 1 and 2 and beyond-design accidents will primarily be attributable to inhalation of gaseous and air-borne radioactivity releases from SNFS-2.

Calculations have shown that for personnel living in Chernobyl, additional internal dose will not exceed 0.01 mSv per event (accident due to fall in SFA) and 0.03 mSv per event (accident due to rupture the pipe). The dose from an accident due to rupture of the pipeline three times more than the dose of the accident with the fall SFA, but this value is still substantially less than the limit dose, even for normal use, not only for staff of A category (20 mSv per year), but also for the population (1 mSv per year). Initial data for calculation of doses (the concentration of radioactive substances in the air and an additional surface contamination of the Chernobyl accident in the case of accident 2 are shown in Figure 9. Fig. 9b shows a comparison of surface contamination with existing.

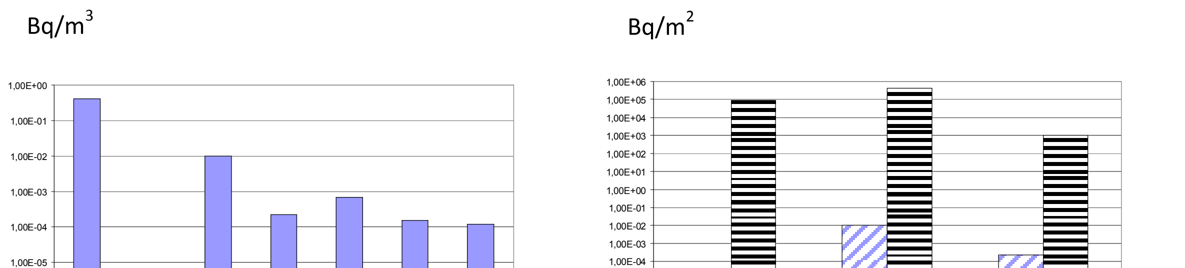


Figure 9. Radiation environment in "residential" area (Chernobyl) due to the design accident 2, a) - the concentration of radioactive substances in the air, b) - additional surface contamination in Chernobyl.

The nearest residential town is located at a distance of 21 km from the site SNFS-2 (south-west direction). But conservatively assumed that the population (category B) is on the short edge exclusion zone - 12 km to the east of SNFS-2. In the event of a design basis accident, the radiation exposure to personnel, located in the residential area (Chernobyl), and the population at the nearest boundary of the exclusion will be identical due to the same distance from the SNFS-2. Thus, an additional dose of the population in the event of implementation of design accidents will be less not only than the limit of the radiation dose of the population, but with a quota limit of radiation dose (40 mSv) for normal operation, which is regulated by the [5] for nuclear power plants or companies for radioactive waste in normal operation

Table 2 provides the values of volumetric specific activity and density of surface contamination in Chernobyl city for beyond-design accident.

Table 2 – Gaseous and air-borne radioactivity release from beyond-design (hypothetical) accident

Radionuclide	Volumetric Activity, Bq/m^3	Surface Contamination Density, Bq/m^2
^{137}Cs	430	$4.9 \cdot 10^4$
^{90}Sr	24	$2.7 \cdot 10^3$
$^{238\text{-}240}$Pu	0.93	110
^{241}Pu	1.7	200
^{241}Am	0.96	110

Additional dose due to internal exposure from beyond-design accident will be no more than 0.4 mSv per event.

It should be noted that the derived values of additional internal exposure dose for an accident event are an order of magnitude lower than the values than the potential exposure doses stipulated by NRBU-97/D-2000, the Ukrainian regulations for radiation exposure. Therefore, the radiation impacts on the social environment in case of design-basis accidents should be considered to be acceptable.

CONCLUSIONS

Radiation impacts on the environment during normal operation of SNFS-2 correspond to the criteria of safe operation of radiation-nuclear facilities in Ukraine. The low values of the calculated emission activity demonstrated acceptability of the proposed technology in terms of radiation protection of the environment.

Radiation exposure to personnel and the environment in case of implementation of the project's most dangerous accidents in SNFS-2 are minor and meet the criteria for safe use of radiation and nuclear facilities in Ukraine. Radiation-hygienic rules for impacts of design basis accidents at radiation hazardous objects in many parts of the environment are not well defined in Ukraine. Therefore the regulations in this area need to be improved, especially given the prospects for the development of nuclear energy in Ukraine.

Radiation exposure to personnel and the environment in case of implementation of the most dangerous beyond-the-design accident on SNFS-2 are minor and meet the criteria for safe use of radiation and nuclear facilities in Ukraine.

Given the availability of under-utilized property in the radioactively contaminated Chernobyl exclusion zone, more intense use it for development and operation of nuclear facilities can be undertaken with acceptable environmental impacts.

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