

Attachment A – Report on interdepartmental meeting

Refer to Vol.1, part 4.

Attachment B – Calculation procedure of impacts of radioactive emissions

The probability of emissions of gas-aerosol radioactive substances in the atmosphere under CSFSF construction and normal operation is high. Release of radioactive substances results in environmental contamination and increases the danger of exposure of the personnel working in immediate proximity to ISF and staying in the exclusion zone.

Transfer of gas-aerosol impurity are resulted by wind and atmospheric diffusion.

According to recommendations of IAEA and the World meteorological organization the Pasquill model of diffusion which is based on statistical (Gaussian) distribution of impurity in the atmosphere is selected as the model of diffusion.

The emissions are distinguished by duration of radioactive aerosols emission in the atmosphere:

- Short-term,
- Long-term.

By arrangement of emission source it is possible to distinguish:

- Emissions from high pipe,
- Emissions at level of building roofs.

Short-term emission

Emission can be defined as short-term in case when its duration is comparable to the time of movement of the released impurity to place of its fall-out with remaining the direction of wind.

Emissions from vent stack

Let us consider emission of gas-aerosol radioactive substances through the ISF vent stack. We shall assume that behavior of the radioactive substances through-out the vent stack are the same as for emission from high stack, i.e. the jet of emission will get in area of non indignant stream.

Let us enter a rectangular system of coordinates (x, y, z) with center in the basis of stack (emission sources). In the given system of coordinates the axis x coincides with direction of the accumulating wind stream, coordinates y and z – distances in horizontal and vertical directions up to the detecting point. It is assumed that at the moment of time t=0 in point with coordinates x=0, y=0, z=h there was an emission of radioactive aerosols Q₀ (Bq) with the capacity Q (Bq/SEC) in time T_{release} (SEC). Thus Q₀ = Q · T_{release} at the moment of time t of volumetric concentration of radioactive impurity will be equal A_v (x, y, z, t). By integrating of value A_v on time and neglecting diffusion of impurity in direction of axes x, volumetric concentration radioactive impurity A_v (Bq/m³) it is calculated by formula [1]

$$A_v(x, y, z) = \frac{QF(x)}{2\pi\sigma_y\sigma_z u(h)} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{ \exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right) \right\} \quad (B1)$$

Here h – effective height of emission, (m);

$u(h)$ horizontal component of wind speed depending on effective height of emission, (km/s);

σ_y, σ_z – mean square deviation of distribution of impurity in cloud of emission due to turbulent diffusion in direction axes y and z, accordingly (m);

$F(x)$ – function of exhaustion of radioactive cloud as a result of dry deposition, precipitation scavenging ("wet" deposition) and radioactive decay.

Effective height of emission calculated as follows [5]:

$$h = h_0 + \frac{6 \cdot w_0 \cdot r}{u(h_0)}$$

where h_0 – geometrical height of vent stack, m;

w_0 – speed of release of impurity from vent stack, m/s;

r - radius of vent stack, m.

Function of exhaustion of radioactive cloud as a result of dry deposition, precipitation scavenging ("wet" deposition) and radioactive decay:

$$F(x) = \exp \left[- \sqrt{\frac{2}{\pi}} \cdot \frac{v_g}{u(h)} \cdot \int_0^x \frac{1}{\sigma_z} \cdot \exp \left(- \frac{h}{2 \cdot \sigma_z^2} \right) dx \right];$$

where v_g - speed of dry deposition, m/s.

$$u(h) = u(2) \cdot \left(\frac{h}{2} \right)^p;$$

where $u(2)$ - wind speed at height of 2 m;

p - factor from table B1.

Table B1 Exponential factor p for calculation of wind speed [5]

Standard conditions					
Category of atmospheric stability by Pasquill					
A	B	C	D	E	F
0,07	0,07	0,10	0,15	0,35	0,55
City conditions					
Category of atmospheric stability by Pasquill					
A	B	C	D	E	F
0,15	0,15	0,20	0,25	0,40	0,60

Factors of dispersion σ_y , σ_z are determined depending on weather conditions under Smith - Hoker formulas [1]:

$$\sigma_y(x) = c_3 x / (1 + 0.0001x)^{1/2}; \quad (B2)$$

$$\sigma_z(x) = \begin{cases} f(z_0, x) g(x) \text{ npu } f(z_0, x) g(x) \leq \sigma_z^{\max}; \\ \sigma_z^{\max} \text{ npu } f(z_0, x) g(x) > \sigma_z^{\max}, \end{cases} \quad (B3)$$

where c_3 – the factor dependent on category of atmospheric stability; σ_z^{\max} – Limiting value of σ_z for the given category of atmospheric stability; z_0 – height of roughness of underlying surface (cm); x – distance from emission sources (m); functions $g(x)$ and $f(z_0, x)$ are calculated depending on categories of atmospheric stability under formulas [1]:

$$g(x) = a_1 x^{b_1} / (1 + a_2 x^{b_2}); \quad (B4)$$

$$f(z_0, x) = \begin{cases} \ln [c_1 x^{d_1} (1 + c_2 x^{d_2})] \text{ npu } z_0 > 10 \text{ cm}; \\ \ln [c_1 x^{d_1} / (1 + c_2 x^{d_2})] \text{ npu } z_0 \leq 10 \text{ cm}. \end{cases} \quad (B5)$$

The factors necessary for calculations are given in tables B2-B4.

Table B2. Factors used for calculation of cross dispersion of jet σ_y and functions $g(x)$ [1]

Category of atmospheric stability by Pasquill	σ_z^{\max} m	c_3	a_1	B_1	a_2	B_2
A (extremely unstable)	1600	0,22	0,112	1,06	5,38(-4)	0,815
B (moderately unstable)	920	0,16	0,130	0,950	6,52(-4)	0,750
C (slightly unstable)	640	0,11	0,112	0,920	9,05(-4)	0,718
D (neutral)	400	0,08	0,098	0,889	1,35(-3)	0,688

Category of atmospheric stability by Pasquill	σ_z^{\max} m	c_3	a_1	B_1	a_2	B_2
E (slightly steady)	220	0,06	0,0609	0,895	1,96(-3)	0,684
F (moderately steady)	100	0,04	0,0638	0,783	1,36(-3)	0,672

Table B3. Factors of function $f(z_0, x)$, modifying σ_z for various height of roughness of z_0 [1]

Height of roughness z_0 , cm	c_1	d_1	c_2	d_2
1	1,56	0,0480	6,25(-4)	0,45
4	2,02	0,0269	7,76(-4)	0,37
10	2,73	0	0	0
40	5,16	-0,098	5,38(-2)	0,225
100	7,37	-0,00957	2,33(-4)	0,6
400	11,7	-0,128	2,18(-5)	0,78

Table B4 Height of a roughness z_0 for various types of a microrelief of surface [1]

Micro relief	z_0 , cm
Snow, lawn with height 1 cm	0,1
Cut and low grass up to 15 cm	0,6-2
High grass up to 60 cm	4-9
Non-uniform surface with alternating areas of grass, bushes, etc.	10-20
Park, forest with height up to 10 m	20-100
City constructions	100

As emission cloud moves there is fallout of radioactive aerosols on the surface of the ground and a surface source of external irradiation is formed. The density of fallout of radionuclides on topsoil A_s (Bq/m²) after short-term emission Q_0 (Bq) determined by formula

$$A_{s0}(x, y) = Q_0 (G_0 v_g + G^z A) \quad (B6)$$

Here $Q_0 = Q \cdot T_{\text{release}}$;

$G_0(x, y, 0)$ – factor of meteorological dilutions (c/m³) which is understood as relation of volumetric activity of radionuclide in the atmosphere to emission per a unit of time $G_0 = A_{v0} / Q_0$ at $z = 0$, where A_{v0} is calculated by formula (A1) in which value Q_0 (Bq) is substituted instead of Q (Bq/sec);

$$G^z(x, y) = \int_0^{H_z} G(x, y, z) dz \quad (B7)$$

, where H_z – height of the bottom boundary of cloud – source of precipitation (m);

v_g – speed of dry fallout (m/s).

Speed of dry fallout v_g is not a speed in the kinematic sense and is identified by the ratio:

$$V_g = \frac{\text{Fallout intensity, Bq/(m}^2 \cdot \text{sec)}}{\text{Concentration in air surface layer}} \quad (B8)$$

A – Constant value of scavenging (1/sec), dependent on of type precipitation, spectrum of rain drops and intensity of precipitation.

The constant value of scavenging is calculated by formula [1]

$$\Lambda = k_r k_0 I, \quad (B9)$$

where I – intensity of precipitation (mm / hour);

$k_r = 10^{-5}$ hour/(mm*sec) – standard value of absolute scavenging ability of rain (for all nuclides, except for noble gases), intensity I typical for rain = 1 mm / hour;

k_0 – relative scavenging ability for various types of fallouts (ref. table B. 5)

Table B. 5 Relative scavenging ability for various types of fallouts [1]

Type of fallouts	K_0
Rain	1,0
Rain with thunder-storm	1,1
Snow with thunder-storm	2,4
Downpour	2,8
Snow	3,0
Drizzle	4,5
Fog	5,0

Emissions at level of roof of buildings

In case when an emission of radioactive aerosols by intensity Q (Bq/sec) per time T_{release} (sec) at level of roof of buildings, aerosols will get in the area of aerodynamic shadow upon the leeward of building, mix in turbulent jet created by the air stream at flow of building, and quickly reach the surface of the ground. Thus in an area of steady air circulation the source of radioactive impurity in volume V (m^3) is formed:

$$V = C_R \cdot S_b \cdot u \cdot T_{\text{release}}, \quad (B10)$$

with concentration A_v (Bq/m^3):

$$A_v = Q / (C_R S_b u). \quad (B11)$$

Here u (m/s) – wind speed;

S_b (m^2) – the area of section of building which is perpendicular to direction of wind;

C_R – factor of building shape. During calculations it is accepted that $C_R = 0,5$ [2,3].

Long-term emission

Emission can be defined as long-term in case when time of emission exceeds time of movement of the released impurity from place of generation to the place of its falls-out or direction of wind is changed for this time.

For long emission Q (Bq/sec) the expression for definition of average (for the determined period of time t) volumetric concentration of radioactive impurity A_v (Bq/m^3) in direction of axis x is obtained based on formula (A1) taking into account distribution of wind speed in direction (wind rose) and value of return period of weather category by Pasquill, as well as in view of quantity of possible precipitation [1]:

$$A_v(x, z) = \frac{Q \eta_x}{(2\pi)^{3/2} x} \sum_i \frac{\omega_i F_i}{\sigma_{z,i} \bar{u}_i} \left\{ \exp \left[-\frac{(z-h)^2}{2\sigma_{z,i}^2} \right] + \exp \left[-\frac{(z+h)^2}{2\sigma_{z,i}^2} \right] \right\}. \quad (B12)$$

Here The index i marks the values typical for i category of atmospheric stability by Pasquill;

ω_i - return period i weather category in time t ;

η_x - elongation of wind rose in direction of axis x , determined by ratio $\eta_x = n_x/n_0$, where n_x - return period of direction of wind in direction of axes x at actual wind rose, n_0 - ditto, at equiprobable direction of wind.

Intensity of fallout of an impurity on surface of topsoil in time $t - \dot{A}_s \cdot t$ (Bq/(m²)) in direction of axis x at continuous emission is determined by formula:

$$\dot{A}_s(x) \cdot t = \frac{Q \eta_x}{(2\pi)^{3/2} x} \left[2v_g \sum_i \frac{\omega_i F_i}{\sigma_{z,i} \bar{u}_i} \exp\left(-\frac{h^2}{2\sigma_{z,i}^2}\right) + \sqrt{2\pi} \Lambda \sum_i \frac{\omega_i F_i}{\bar{u}_i} \right], \quad (\text{B13})$$

where Q (Bq) - emission per time t .

Calculation of the individual radiation doses formed by radioactive emissions [1]

Individual effective dose which will be taken by the person as a result of emission of radioactive aerosol impurity in the atmosphere consists of two components:

- effective dose of external irradiation;
- effective dose of internal exposure.

These doses are calculated for every specific radionuclide and then summarized.

Equivalent dose rate of external irradiation \dot{H}_v (Sv/sec) due to one nuclide per person who is staying on the ground surface ($z = 0$) caused by cloud of radioactive aerosols which was generated as a result of short-term emission, determined by formula [1]:

$$\dot{H}_v = A_v \tilde{B}_{ay}. \quad (\text{B14})$$

Here A_v (Bq/m³) - volumetric activity of radionuclide;

\tilde{B}_{ay} - transitive dosimetric multiplier (Sv·m³/(sec·Bq)) which is characterizing equivalent dose rate created by cloud of radioactive aerosols of unit concentration on the open ground surface. This multiplier substantially depends on the shape of a cloud.

At the further calculations the mixed model was used, according to which

$$\tilde{B}_{ay}(x) = k^2 B_{ay} + [1 - k^2] B_{ay}^n(x). \quad (\text{B15})$$

Here B_{ay} - transitive multiplier received at modeling of the form of emission by semi-infinite space:

$$B_{ay} = 6,810 \cdot 10^{-14} E, \quad (\text{B16})$$

where E (Mev/spread) - full energy of photons on decay;

B_{ay}^n - transitive multiplier received at modeling of the form of emission by linear extended source of radius R (m) taking place at height h (m) above the flat topsoil surface.

Transitive multiplier B_{ay}^n is identified by ratio:

$$B_{ay}^n(x) = r \Gamma_\delta R^2 [F(\theta, \mu h) + F(\pi/2, \mu h)] / h, \quad (\text{B17})$$

where $r = 1,09 \pm 0,002$ (Sv/Gr) - transitive multiplier from absorbed dose in the air to the absorbed dose in biological fabric;

Γ_δ (Gr m² / (sec Bq)) - kerma - constant of a nuclide;

$F(\theta, \mu h)$ - Sivert function;

μ (1/m) - linear attenuation factor of photons in the air;

$\theta = \arctg(x/h)$.

Factor k , characterizing effect of raised jet, looks like

$$k(x) = \exp[-h^2 / 2\sigma^2(x)], \quad \sigma^2(x) = \sigma_y^2(x) + \sigma_z^2(x). \quad (\text{B18})$$

Equivalent dose rate of external irradiation \dot{H}_v (Sv/sec) for case of continuous emission is under the above-stated formulas, which accept $k(x) \equiv 1$.

Expected equivalent dose H_s^c (Sv) to whole body from photon radiation for surface topsoil contamination Q_0 (Bq) generated as a result of short-term emission is identified as follows:

$$H_s^c = A_{s0} B_{sy}^c. \quad (B19)$$

Here A_{s0} (Bq/m²) – surface contamination from short-term emission;

B_{sy}^c (Sv m² / Bq) – expected dose from surface topsoil contamination for initial surface activity $A_{s0} = 1$ Bq/m².

Expected dose from surface topsoil contamination B_{sy}^c is identified by ratio

$$B_{sy}^c = B_{sy} t, \quad (B20)$$

where B_{sy} (Sv m² / sec Bq) – transitive the dosimetric multiplier characterizing dose rate in the air at height 1m from the polluting surface;

t (c) – time of exposure.

Expected equivalent annual dose \dot{H}_s (Sv / year) from surface contamination as a result of continuous emission of intensity Q (Bq/year) is calculated by formula:

$$\dot{H}_s = \dot{A}_s B_{sy}^c, \quad (B21)$$

where \dot{A}_s (Bq/m² year) – intensity of surface contamination.

Calculation of dose from external β -radiation of a cloud of radioactive emission is made by immersing method, simulating source in the shape of semi-infinite space. In this case the equivalent dose rate \dot{H}_β (3B/c) looks like:

$$\dot{H}_\beta = A_v B_{a\beta}, \quad (B22)$$

where A_v (Bq/m³) – volumetric activity of radionuclide;

$b_{a\beta}$ (Sv m³ / (sec Bq)) – dose factor in basal layer of the skin, created by β -radiation.

Effective dose H_{int} (Sv) caused by inhalation intake of radioactive aerosol is calculated by formula:

$$H_{int} = V k_u k_{cu3} T e_\tau A_v, \quad (B23)$$

where V (m³ / hour) – breathing rate;

k_u – the factor which is taking into account intensity of work;

k_{cu3} – the factor which is taking into account intensity of work;

T (hour) – time of stay in a cloud of an aerosol;

e_τ (Sv/Bq) – dose on unit of intake of activity in the inhalation way (ref. table B. 5);

A_v (Bq/m³) – volumetric activity.

Dose factors and other input data which have been used at calculations are given in [1].

Data given in table A. 6 makes possible to estimate category of atmospheric stability by Pasquill for carrying out of conservative assessments of relocation of activity in the atmosphere and its dispersion. Average annual wind speed at the SO site makes 3,3m/s. Therefore, the category of stability in the afternoon will be B or C (depending on insolation), and at night – D or E (depending on cloudiness).

Table B. 7 Interconnection of category of atmospheric stability by Pasquill with average wind speed in the air ground layer [1]

Wind speed at height 10m, m/s	Afternoon, insolation			Night	
	strong	moderate	weak	Thin continuous clouds or 4/8 cloudy covers at least	3/8 cloudy covers at least
less 2	A	A-B	B	F	F
from 2 to 3	A-B	B	C	E	F
from 3 to 5	B	B-C	C	D	E
from 5 to 6	C	C-D	D	D	D
more 6	C	D	D	D	D

The radioactive emissions can be both short-term and long-term under emergency conditions. The represented calculation procedure for radioactive emissions under normal conditions of works can be also used for calculation of radioactive emissions for accidents taking into account that emissions will be much more intensive in the latter case.

Calculation of dose from intake through food chains

According to [1], the individual average capacity of annual dose caused by intake of radioactive substances in human organism with food stuffs is determined as follows:

$$\dot{H} = \dot{A}_s \cdot K_{FD}, \quad (B24)$$

where \dot{H} – individual average capacity of annual dose, Sv/sec,

\dot{A}_s – intensity of contamination, Bq / (m²·sec),

$$K_{FD} = K_{FI} \cdot B_{ig}, \quad (B25)$$

where K_{FI} –factor connecting level of fallout with intake of radionuclide in organism, m²;

B_{ig} –factor connecting activity incoming with food with effective dose (depends on age)

[6], Sv/Bq.

Calculation of permissible release

For calculation of permissible release the PRC-1 code was developed which makes it possible to calculate PR taking into account all described ways of dose generation from emissions. Possibilities of the code make it possible to work with all input data, change them in MS Excel, as well as output any required information in graphic or tabulated type.

For the greater presentation and simplification of work with the code, it is made as follows. In the beginning the impact of individual emission on the population is calculated on the basis of the above mentioned formulas, then by iterations with indicated accuracy the selection of emission is made with for achievement required NRBU - 97 quotas of dose (40 mkSv).

Input data, used in calculations

The given section contains input data which were accepted during calculations of emissions of radioactive substances in the atmosphere which can occur during construction and CSFSF operation, as well as a result of occurrence of emergencies.

Civil work

For assessment of ground concentration of radioactive substances in the air, as well as expected additional surface contamination the following input data were used:

- density of volumetric contamination of soil: ^{137}Cs - $2,67 \cdot 10^4$ Bq/kg, ^{90}Sr - $5,33 \cdot 10^3$ Bq/kg, $^{238-240}\text{Pu}$ - 280 Bq/kg, ^{241}Am - 36 Bq/kg (received by recalculation from activity $^{238-240}\text{Pu}$ taking into account radionuclide content of fuel of destroyed 4-th power unit at the moment of accident in 1986; bulldozer properties: speed of movement - 1 m/s, width of a bucket - 2 m; meteorological conditions:

- 1) category of atmospheric stability by Pasquill - D, wind speed - 3,3 km/s (95 % of time);
- 2) category of atmospheric stability by Pasquill - F, wind speed - 1 km/s (5 % of time);
- speed of sedimentation of aerosols - 0,8 cm/sec, precipitations are unavailable, thickness of topsoil layer contaminated with radionuclides - 10 cm.
- topsoil: it was conservatively assumed that the topsoil is represented by sand, humidity of material is not taken into account. Bulk emission of dust at loading, unloading and storing of sand is calculated by formula:

$$M_c = \beta \cdot \Pi \cdot Q \cdot K_{1w} \cdot K_{2w} \cdot 10^{-2}$$

where β - factor which is taking into account loss of material as dust, fractions of unit [β of sand = 0.05]

Π - loss of material, % (at unloading 0.4 %, at loading 0.4 %, at storing 0.5 %)

Q - weight of construction material, t/year

K_{1w} - factor which takes into account humidity of material

K_{2w} - factor which takes into account conditions of storage

CSFSF normal operation

During CSFSF normal operation emission of radioactive aerosols in the environment due to contaminations of external surface of MPC is possible.

During loading of MPC with SFA (in pre-design fuel pool on NPP) various measures are envisaged for decrease of radioactive contamination of its external surface which occurs due to ingresses and evaporation of water solution from the fuel pool. According to input data, the maximum permissible residual radioactive contamination of external surface of the MPC which is ready for sending for storage will not be more than 10^{-4} mCi / cm^2 for β emitters and 10^{-5} mCi / cm^2 for α emitters [7].

Taking into account such a fact that release of activity directly from the container is impossible under normal operation conditions of the storage facility, emission of radioactive substances in the environment is expected only during dust release from the contaminated external surface of MPC.

The dust release is possible in two cases: at the moment of overloading the MPC from HI-STAR to HI-STORM in the reception building of the storage facility and, directly, during storage. In the first case, generated radioactive aerosols enter to the active ventilating system of the CSFSF reception building and released to the environment through the vent stack. In the second case, aerosols enter to the passive ventilating system of HI-STORM, installed on the storage area and can dissipate in the atmosphere outside the limits of the storage facility territory.

For the analysis of radiation impacts of emissions from the vent stack and from HI-STORM, and for final assessment of impacts under normal operation, the worst values were conservatively selected from the received results.

Emission of radioactive aerosols from reception building. Applying the conservative approach for calculations it was accepted that the surface of MPC arriving for storage at CSFSF has the maximum permissible contamination which completely passes into the environment. Taking into account the greatest possible quantity of spent nuclear fuel annually incoming in the storage facility –

12 MPC-31 and 3 MPC-85 [8], during the active operation period (filling) of CSFSF, emission of radioactive aerosols in the environment will not exceed 16,1 MBq a year or 44 kBq a day.

The radionuclide content of surface contamination of MPC with the greatest probability will be represented by corrosion products of structural elements of spent fuel assemblies - ^{51}Cr , ^{54}Mn , $^{55,59}\text{Fe}$, $^{58,60}\text{Co}$ and ^{65}Zn available in water solution of a near-reactor fuel pool. For calculation of individual effective equivalent radiation dose from emissions at CSFSF normal operation, it was conservatively supposed that the radionuclide content of surface contamination of MPC is represented exclusively with ^{60}Co which has the greatest dose factor and half-life period (5,27 years).

For calculation of radiation impacts of the CSFSF on the environment for normal operation, the following input data were used:

- quantity of railroad platforms with HI-STAR accepted in the course of a year – 15 pcs;
- total surface contamination of all railroad platforms by ^{137}Cs after their travel to the EZ and OEA territory is conservatively 190 Bq;
- maximum permissible surface contamination by ^{60}Co of MPC-31 - 1,13 MBq;
- maximum permissible surface contamination by ^{60}Co of MPC - 85 - 0,86 MBq;
- dose factor of radionuclide ^{60}Co – $1,02 \cdot 10^{-8}$ Sv/Bq;
- height of point of emission (vent stack of reception building) - 21 m;
- speed of emission – $6,95 \text{ m}^3/\text{sec}$;
- category of atmospheric stability (by Pasquill) – D;
- wind speed – 2,1 km/s;
- duration of emission – 1 year.

Emission of radioactive aerosols during storage of spent nuclear fuel. Emission of radioactive substances from HI-STORM is possible due to contamination of the external surface of MPC that results in generation and release of radioactive aerosols in the environment.

For calculations of radiation impacts for CSFSF normal operation it was conservatively assumed that the multi-purpose container incoming for storage has the maximum permissible level of contamination of external surface. Also it is accepted that after installation of HI-STORM to the storage area, all surface contamination of the multi-purpose container releases into the environment over one year.

For calculation of radiation impacts on the environment for storage of spent nuclear fuel in HI-STORM, the following input data were used:

- maximum permissible surface contamination by ^{60}Co of MPC-31 - 1,13 MBq;
- maximum permissible surface contamination by ^{60}Co of MPC - 85 - 0,86 MBq;
- quantity of HI-STORM 100 with MPC-31, installed in the course of the year – 12 pieces;
- quantity of HI-STORM 100 with MPC-85, installed in the course of the year – 3 pieces;
- height of emission point (height of HI-STORM 100) - 6 m;
- atmospheric stability – category D (by Pasquill);
- wind of permanent direction, average speed – 2,1 km/s;
- dose factor of radionuclide ^{60}Co – $1,02 \cdot 10^{-8}$ Sv/Bq;
- duration of emission – 1 year.

Accident during construction (local forest fire)

The speed of fire propagation is 1 m/min., direction of wind in the direction ChNPP and the point of occurrence of a fire - on a trace axis. In 4 hours the forest will burn out a total area of about 72 thousand m^2 , total activity of emission will be about $5.4 \cdot 10^{10}$ Bq of ^{137}Cs , $2.9 \cdot 10^{10}$ Bq of ^{90}Sr and $5.8 \cdot 10^8$ Bq of α - active TUE. The time t is time when full combustion of the forest underlayer in

condition of dynamic balance about 1000, the area of intensive burning - about 5 thousand m², speed of emission - about $3.8 \cdot 10^6$ Bq/sec of ¹³⁷Cs, $2.0 \cdot 10^6$ Bq/sec of ⁹⁰Sr and $4.0 \cdot 10^4$ Bq/sec of α-active TUE.

Maximum Design Basis Accident

Emergency emission from vent stack of the reception building. Such emergency emission is possible at the moment of opening of HI-STAR and withdrawing of MPC from it. Thus radioactive aerosols get into the active ventilating system of the reception building of the storage facility and are released through the vent stack into the environment. For calculations the following input data were used:

- height of emission - 21 m (vent stack in reception building);
- atmospheric stability - the worst, category F (by Pasquill);
- direction of wind is permanent, average speed - 1 km/s;
- dose factor ⁶⁰Co - $3,1 \cdot 10^{-8}$ Sv/Bq [12];
- character of emission duration – short-term.

Emergency emission from a HI-STORM storage module at the storage area. Such emergency emission is possible from a single HI-STORM during loading of MPC with surface contamination which exceeds the maximum permissible value. Radioactive aerosols generated inside HI-STORM, due to thermosiphon effect, leave through the passive ventilation system into the environment. It was conservatively considered that all activity from surface contamination of the multi-purpose container in regular intervals is released from the HI-STORM over 1 year.

For calculations the following input data were used:

- emission source – dot, height - 0 m;
- atmospheric stability – worst, category D (by Pasquill);
- direction of wind is permanent, average speed - 2,1 km/s;
- dose factor ⁶⁰Co - $3.1 \cdot 10^{-8}$ Sv/Bq [12];
- time of emission - 1 year.

Beyond Design Basis Accident

As the Beyond Design Basis Accident (BDBA) is considered an accident by analogy with [10]. For licensing the technology of HI-STORM storage in the USA according to NUREG/CR-6487 [11], the emission of radionuclides from depressurized MPC is considered. For assessment of consequences of the accident, spent nuclear fuel of USA PWR reactors with the maximum burn-up of 70,000 MW-day/kgU, stored in a fuel pool for 5 years and having initial enrichment 4,8 % of ²³⁵U. The radionuclides content is given in table B8. Within the framework of considerations of accident influence, the increase of pressure inside of the MPC due to decay heat generated by spent nuclear fuel stored in the MPC on value of leakage MPC was assessed according to the requirements of ASME section III, subsection NB, taking into account performance of welds according to the regulations.

For assessment of accident an increase of internal pressure in the MPC up to 1,4 MPa, the leakage from the MPC related to such pressure was considered. As the criterion of leakage at normal operation, leakage in 5×10^{-6} atm-cm³/sec at internal pressure up to 0,69 MPa which meets the requirements of the Data sheet of the storage facility in the USA is accepted. Further increase of internal pressure up to 1,6 MPa is considered and the greatest possible leakage in $3,3 \times 10^{-4}$ cm³/sec is estimated. Fractions of emission are regulated by NUREG-6487 [24]:

- ⁸⁵Kr - 0,3;
- ⁶⁰Co - 1;
- ⁹⁰Sr, ¹³⁴Cs, ¹³⁷Cs, ¹⁰⁶Ru - $2,0 \times 10^{-4}$;
- ²⁴¹Pu, ¹⁴⁴Ce and other elements $3,0 \times 10^{-5}$.

The quantity of ^{60}Co is caused by the maximum surface activity of spent fuel assemblies. For spent fuel assemblies of PWR reactors in the USA according to NUREG-6487 [11], surface contamination of spent fuel assemblies by ^{60}Co is $5,18 \times 10^6 \text{Bq/cm}^2$.

- According to NUREG-1536 [12], emission over 720 hours (30 days) is considered. Thus it is assumed that the person stays for 24 hours a day for 30 days on the open area. Thus, all fuel assemblies in the multi-purpose container collapse and leakage in the environment $3,3 \times 10^{-4} \text{ cm}^3/\text{sec}$ occurs.

Such accident is an absolutely hypothetical case of damage of all fuel assemblies in the MPC with the subsequent release of gaseous fission products. It is impossible to determine actual initial events with direct consequences which would entail simultaneous damage of MPC and all fuel assemblies inside. A unique type of impact on the storage module of HI-STORM which can result in simultaneous damage of the MPC and all fuel assemblies is a significant external dynamic impact (for example, as a result of application of special ammunition, etc.). The given accident is considered for demonstration of the relatively insignificant radiation consequences of accidents in CSFSF even taking into account hypothetical initial events.

From the point of view of radiological consequences the given accident is considered as BDBA with the maximum consequences.

Calculation and analysis of radiation consequences of the BDBA was carried out by calculation procedure of consequences of short-term emissions, using the following assumptions and input data:

- height of emission - 0 m;
- atmospheric stability - category F (by Pasquill);
- direction of wind is permanent, average speed 2 km/s,
- fuel is supplied in ISF after 5 years of endurance
- dose factors of radionuclides are represented in table A8
- gravitational sedimentation was not taken into account

Table B8. Input data for the BDBA

Radionuclide	Activity per one spent fuel rod	Dose factor for inhalation intake, Sv/Bq
H 3	3,68E+02	1,73E-11
I129	3,31E-02	4,69E-08
KR 85	5,86E+03	0,00E+00
Co-60	2,18E+01	5,91E-08
SR 90	6,32E+04	3,51E-07
RU106	1,59E+04	1,29E-07
CS134	4,04E+04	1,25E-08
CS137	9,82E+04	8,63E-09
PU241	8,53E+04	2,23E-06
Y 90	6,32E+04	2,28E-09
PM147	2,63E+04	1,06E-08
CE144	8,14E+03	1,01E-07
PR144	8,14E+03	1,17E-11
EU154	5,90E+03	7,73E-08
CM244	1,01E+04	6,70E-05

Radionuclide	Activity per one spent fuel rod	Dose factor for inhalation intake, Sv/Bq
PU238	5,81E+03	1,06E-04
SB125	2,30E+03	3,30E-09
EU155	1,65E+03	1,12E-08
AM241	9,00E+02	1,20E-04
TE125M	5,61E+02	1,97E-09
PU240	4,05E+02	1,16E-04
SM151	3,38E+02	8,10E-09
PU239	2,04E+02	1,16E-04
BA137M	9,27E+04	0,00E+00
RH106	1,59E+04	0,00E+00
PR144M	1,14E+02	0,00E+00
AM243	4,87E+01	1,19E-04
CM242	3,23E+01	4,67E-06
CM243	3,63E+01	8,30E-05
NP239	4,87E+01	6,78E-10
NP237	3,88E-01	1,46E-04
PU242	2,85E+00	1,11E-04
AM242	8,72E+00	1,58E-08
AM242M	8,76E+00	1,15E-04

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