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Environmental impact assessment for activities during preparation and retrieval of spent nuclear fuel from dry storage unit 3A at Andreeva Bay

DSA

Norwegian Radiation
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Gaponov I.A., Dyakov A.V., Kazennov A.Yu., Kiknadze O.E., Knivel N.Ya., Kuznetsova T.I., Mironenko-Marenkova M.E., Opanasiuk Yu.R., Smagina N.A., Stepennov B.S., Sukhoruchkin A.K. Environmental impact assessment for activities during preparation and retrieval of spent nuclear fuel from dry storage unit 3A at Andreeva Bay . DSA Report 2021:4. Østerås: Norwegian Radiation and Nuclear Safety Authority, 2021.
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Andreeva Bay, EIA, spent nuclear fuel, dry storage unit 3A

Abstract
This report, originally written in Russian, by experts at the Kurchatov Institute, details an environmental impact assessment completed by Russian authorities at the request of DSA to study possible consequences of handling spent nuclear fuel contained in dry storage tank 3A. The work is part of the on-going cooperaption between Norway and Russia in the Norwegian Nuclear Action Plan.

Referanse
Gaponov I.A., Dyakov A.V., Kazennov A.Yu., Kiknadze O.E., Knivel N.Ya., Kuznetsova T.I., Mironenko-Marenkova M.E., Opanasiuk Yu.R., Smagina N.A., Stepennov B.S., Sukhoruchkin A.K.DSA-rapport 2021:4 Environmental impact assessment for activities during preparation and retrieval of spent nuclear fuel from dry storage unit 3A at Andreeva Bay
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Emneord
Andreevabukta, EIA, spent nuclear fuel, dry storage unit 3A

Resymé
Rapporten er opprinneleg skrive på russisk av ekspertar ved Kurtsjatov-instituttet. Den inneheld ei konsekvensutgreiing som er utført av russiske myndigheiter på førespurnad frå DSA for å studere moglege konsekvensar av handtering av brukt atombrensel som finnast i tørrlagringstank 3A i Andrejev-bukta. Arbeidet er ein del av samarbeidet mellom Noreg og Russland under atomhandlingsplanen.

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Environmental impact assessment for activities during preparation and retrieval of spent nuclear fuel from dry storage unit 3A at Andreeva Bay

Contents

Extended Abstract

This DSA report is based on an initiative by the Norwegian authorities as part of the bilateral cooperation between Russia and Norway. It is an assessment of possible consequences for humans and the environment when retrieving the spent nuclear fuel stored in Dry Store Unit (DSU) 3 A at the Andreeva Bay facility. The report considers the background conditions at Andreeva, DSU conditions and operations, before studying the potential impacts that may arise from different accident scenarios, ranging from normal operations to beyond design base accidents. Results from calculations are presented in this report that provide estimates of the spread of radioactive material if such accidents occur during retrieval operations. The work on the report was funded through the Ministry of Foreign Affairs Nuclear Action Plan. The project is developed in a cooperation between The Office of the Troms and Finnmark County Governor and North-Western Centre for Radioactive Waste Management SevRAO –Branch of Federal State Unitary Enterprise «Federal Environmental Operator».

This environmental impact assessment has been approved by Russian regulatory authorities. A number of Russian experts have authored the original report, the original language of which was Russian. The report was translated to English by Russian colleagues and thereafter edited by DSA. Edited extracts from this translation regarding radiological consequences that potentially could arise due to hypothetical accidents are presented in this DSA report. DSA has completed this report in dialogue with Russian colleagues. We are satisfied that the reports contents are a true and faithful representation of the Russian consequence analysis. Norwegian and international efforts together with a significant Russian effort have meant that the fuel can be retrieved in a safe and secure manner with as a low a risk as possible. Conducting a consequence/impact analysis leads to better work planning such that the risk for an accident may be reduced. The EIA materials developed for operations on preparation of the DSU-3A tank for retrieval ensures nuclear, radiation and environmental safety.

This work has been financed with funding from DSA under the Norwegian Governments Nuclear Action Plan.

Sammendrag

Denne DSA-rapporten er basert på et initiativ fra norske myndigheter som en del av det bilaterale samarbeidet mellom Russland og Norge. Det er en vurdering av mulige konsekvenser for mennesker og miljø ved uttak av brukt atombrensel fra lagringstank 3 A i Andreeva Bay-anlegget (DSU 3A). Rapporten tar for seg forholdene ved Andreeva, DSU-forhold og operasjoner, og vurderer potensielle påvirkninger som kan oppstå ved forskjellige ulykkesscenarier, alt fra normale operasjoner til «beyond design» ulykker. Resultater fra beregninger er presentert i denne rapporten for spredningen av radioaktivt materiale hvis slike ulykker inntreffer ved arbeidsoperasjonene. Arbeidet med rapporten ble finansiert gjennom Utenriksdepartementets atomhandlingsplan. Fylkesmannen i Finnmark (FMFI - nå fylkesmann i Troms og Finnmark) mottok midler fra DSA for å starte et arbeid i dialog med Andreeva SevRAO og Kurchatov-instituttet. Overingeniør Per Einar Fiskebeck (FMFI) var norsk prosjektleder.

Denne miljøkonsekvensvurderingen er godkjent av russiske regulerende myndigheter. En rekke russiske eksperter har forfattet den opprinnelige rapporten, der originalspråket var russisk. Rapporten ble oversatt til engelsk av russiske kolleger og redigert av DSA. Redigerte utdrag fra denne oversettelsen angående radiologiske konsekvenser som potensielt kan oppstå på grunn av hypotetiske ulykker, presenteres i denne DSA-rapporten. DSA har fullført denne rapporten i dialog med russiske kolleger. Norsk og internasjonal innsats, sammen med en betydelig russisk innsats, i planlegging har bidratt til det brukte kjernebrenselet kan tas ut på en trygg og sikker måte med en så lav risiko som mulig. Gjennomføring av miljøkonsekvensvurderingen fører til bedre arbeidsplanlegging slik at risikoen for en ulykke kan reduseres og at sikkerheten ivaretas av hensyn til helse og miljø.

Arbeidet er finansiert med midler fra DSA under regjeringens atomhandlingsplan.

1 Background

The SNF and RW temporary storage facility at the Andreeva Bay (hereinafter referred to as Andreeva Bay SNF and RW TSF) is located in the Murmansk Region, 45 km away from the Russian-Norwegian border, at the Zapadnaya Litsa Bay which opens into the Motovsky Gulf of the Barents Sea. The location of the Andreeva Bay SNF and RW TSF is shown on the map of the northern coast of the Kola Peninsula (Figure 1).

Figure 1. Location of the Andreeva Bay facility (Source: Google Earth).

1.1 Environmental Conditions

The Murmansk Region occupies the Kola Peninsula and part of the adjoining mainland to the west and south-west. Almost all its territory is situated above the Article Circle. The Barents Sea is to the north and northeast, and the White Sea to the east and south. The area of the Murmansk Region is 144 900 km^2. The Murmansk Region borders two states – Norway and Finland. The Republic of Karelia is located to the south of the Region. The Region includes five districts: Kovdorsky, Kolsky, Lovozesky, Pechengsky and Tersky; there are six cities under the jurisdiction of Murmansk Region: Apatity, Kandalaksha, Kirovsk, Monchegorsk, Olenegorsk, Polyarnye Zori. The nearest city to the Andreeva Bay SNF and RW TSF is Zaozyorsk, 6 km southeast of the site. Pechenga railroad station is 60 km west of the site and the nearest seaport in Murmansk, 80 km southeast of the site.

The Andreeva Bay SNF and RW TSF territory stretches from north to south and occupies the entire peninsula of Andreeva Bay, on the west coast of the Zapadnaya Litsa Bay. The topography is for the most part rugged, low-mountains, with absolute elevations of 25 - 60 m. The uplands are rocky, with steep slopes. The climate of the Kola Peninsula is determined by its geographical location above the Arctic Circle between the continent in the south and Arctic Basin in the north, and by its vicinity to the warm sector of the Atlantic. General atmospheric circulation in the region is predominantly winds blowing in southwestward, southward and westward directions: their frequency is 53%, while the least frequent (6%) is the wind blowing in an eastward direction. The average annual wind speed for the Andreeva Bay is 6.6 m/s. The highest wind speeds are observed in winter, in the end of autumn and beginning of spring. The frequency of the wind with the speed of 1 to 5 m/s is 52.4%, and with the speed of 6 to 10 m/s – 25.4%. The average annual number of days with strong winds in the Andreeva Bay is 68; such winds may occur in every month of the year. The relative humidity of the air is rather high throughout the entire year – 75-85%. The lowest relative humidity is observed in May and June, and the highest (up to 86%) in February and August.

The area where the Andreeva Bay is situated is qualified as a humid zone; the long-term average annual precipitation is about 500 mm a year. On average, half of the precipitation occurs as rain and the other half is mixed. The precipitation is unevenly distributed throughout the year, with the greatest amount (up to 63 mm) occurring in autumn (August and September) and up to 28 mm in April. There are about 200 days with precipitation during a year. The average annual air temperature at the Andreeva Bay location is +1.2^{0}C. The coldest month is February with the lowest temperature of minus 6-10^{0}C, and the warmest months is July when the temperatures can rise to 10-12^{0}C.

The long-term average annual atmospheric pressure above sea level is 1011 hPa. The variation of mean monthly values of atmospheric pressure is small: the annual amplitude of fluctuation of mean monthly values of atmospheric pressure is 8-10 hPa.

The site of the Andreeva Bay SNF and RW TSF is characterized by an uncomplicated geology. The coastal area is flattened rocky low-hill terrain covered by man-made soils and sea deposits. The man-made soils comprise pebble soils and sands of mixed sizes. The topsoils are in various shades of gray, wet and waterlogged. The thickness of the topsoils varies from 0.0 to 8.3 meters. Tectonic conditions in the region are characterized by low activity due to it's stability. The probability of a disastrous earthquake in the next 50 years is zero. The baseline seismicity of the area where the Andreeva Bay SNF and RW TSF is located has been recently increased to 7 points, which corresponds to the probability of 1% according to the MSK-64 seismic intensity scale (GOST 57546) [8, 27].

Hydrogeological conditions are characterized by the presence of three aquifers. The first aquifer is perched and has a local character within the area; it is associated with the man-made deposits with an underlying bed of clayey soils of marine origin. The second, basal aquifer is associated with soils of marine and glacial origin and is found at depths of 3.0-9.7 m. The aquifer is unconfined; the underlying bed is rocky soil. The third aquifer within the site is associated with fractured zones of the rocky soil. The groundwater is under pressure; the depth of the emerged groundwater level is 5.2 m and of the standing level is 4.8 m. The water head is 0.4 m.

The hydrogeological regime of the region is defined by climatic characteristics, patterns of water exchange with surrounding water areas, and seabed topography. Andreeva Bay penetrates the northwestern coast of the Zapadnaya Litsa Bay 40 km from its head. The sea depth at the entrance to the bay is about 90 m, while closer to the bay-head and coast it decreases sharply. In the southern part of the bay, the width of the tidal zone is 5-10 m, and along the northern part of the coast it widens to 150 m. The thermal state of waters has a major impact on the direction of currents and ice-formation processes. In winter, the sea surface temperature is 0.8^{0}C, and in summer – up to +17^{0}C. Tidal phenomena that have a semidiurnal pattern play a key role in forming the sea level regime. The mean range of tide is 240 cm. The durations of fall and rise of tide are almost equal. The major role in forming the current regimes is played by tidal and permanent currents. At high tide, the currents set towards the head of the Zapadnaya Litsa Bay, and at low tide – out of the Bay. The velocity of the permanent current directed from the bay-head does not exceed 2 knots (1.01 m/s). Mean velocities of summary currents are 2-2.5 knots; the maximum velocity is 3 knots (1.54 m/s)

The territory of Murmansk Region is situated in two geographic zones – taiga and tundra, with forest tundra extended in a narrow band in between. The woodland occupies a little less than 80% of the area of the peninsula. The forests are open and light here, trees are no higher than 10-12 m. Pines, spruces and birches grow in the forests. Spruces are concentrated for the most part in the east and north, and pines in the west and south. Spruce or pine forests in pure form are rare; usually they include also birches. The most common forest in the Kola Peninsula are so-called lichen pine forests. They grow on dry and poor soils (sands, gravels). The carpet of lichen covers from 50 to 90% of the soil surface. Bushes that grow in the area include heather, cowberry and crowberry.

1.1.1 Environmental radioactivity

The radiation situation in Murmansk Region is defined by activities at civil and military nuclear facilities; hence one of the main environmental issues in the region is the safe management of accumulated RW and SNF. Radiation monitoring within the Murmansk Region territory is performed at 32 main control points (hydrometeorological stations) and 29 ADER measurement points.

Observed data on fallout and total volumetric beta-activity ($\Sigma\beta$) in the air at the NRHF sites located along the coast of the Kola Peninsula are presented in Table 1.

Table 1 – Average monthly (a) and maximum daily (m) values of fallout (P, Bq/m^2d) and volumetric $\Sigma\beta$ the air (q, 10^{-5} Bq/m^3) in the area of radiation-hazardous facilities along the northern and northeastern coast of the Kola Peninsula in 2019 (Murmansk TAHEM's data)

Month		Polyarnoye	Pechenga	Murmansk	
		P	P	P	q
January	a	1.02	1.10	0.87	7.60
	m	2.86	4.69	1.30	22.80
February	a	1.02	1.23	0.92	11.10
	m	1.57	3.88	1.28	30.60
March	a	1.13	0.95	0.88	7.00
	m	2.63	1.33	1.23	13.80
April	a	0.94	1.19	0.88	10.60
	m	2.41	3.02	1.50	27.70
May	a	1.03	1.07	0.99	8.70
	m	2.18	1.69	1.73	23.80
June	a	1.08	1.10	1.11	8.10
	m	3.11	2.46	2.10	18.90
July	a	1.37	1.76	1.55	7.80
	m	5.07	5.24	4.48	20.90
August	a	0.97	1.05	1.52	9.10
	m	1.79	2.51	2.94	18.90
September	a	1.03	1.17	0.95	7.60
	m	2.35	2.13	1.88	19.50
October	a	1.13	1.13	1.02	5.40
	m	2.24	2.45	2.41	16.10
November	a	1.03	1.17	1.03	5.90
	m	1.79	2.66	1.34	14.80
December	a	1.32	1.98	1.20	6.80
	m	3.63	4.79	2.52	15.10

Month		Polyarnoye	Pechenga	Murmansk	
		P	P	P	q
Average:	2019	1.09	1.24	1.08	7.98
	2018	1.00	1.16	0.91	8.59
	2017	1.08	1.04	0.99	7.2

Average annual values of $\Sigma\beta$-active daily fallouts in the area of NRHF located in the Kola Peninsula have remained stable and did not exceed the level of the year 2018. The average monthly volumetric activity $\Sigma\beta$ in Murmansk varied from $5.4\cdot10^{-5}$ Bq/m^3 to $11.1\cdot10^{-5}$ Bq/m^3 at the average annual value of $7.98\cdot10^{-5}$ Bq/m^3. There were no cases observed in the region when daily values of volumetric activity $\Sigma\beta$ exceeded the background levels by 5 times or more.

The dynamics of annual and quarterly average volumetric activities of technogenic radionuclides ^{137}Cs and ^{90}Sr in the surface layer of the atmosphere in Murmansk for the period of 2015 - 2018 is presented in Table 2.

Table 2 Volumetric activities of ^{137}Cs and ^{90}Sr in the surface layer of the atmosphere in Murmansk, 10^{-7} Bq/m^3 (data of the Murmansk TAHEM and FSBI "NPO "Typhoon")

Observation point	Year	Q I	Q II	Q III	Q IV	Yearly average	Weighted average for the Subarctic territory
				137Cs			
Murmansk	2015	n/a	n/a	n/a	1.5	n/a	1.4
	2016	1.8	0.7	38.4	1.7	10.7	1.2
	2017	1.1	2.6	1.7	16.2	5.4	1.2
	2018	1.9	1.2	2.1	0.9	1.5	0.7
	2019	1.2	1.1	1.1	BDL	1.1	0.7
				90Sr			
Murmansk	2015	n/a	0.26	0.27	0.27	0,08	0,21
	2016	1.03		0.19		0.61	0.55
	2017	0.67		0.22		0.45	0.53
	2018	0.29		0.22		0.26	0.36
	2019	n/a		n/a		0.26	0.45

Notes: n/a – data not available; * – data for November and December 2015; BDL – below detection limit.

As Table 2 shows, the volumetric activity of ^{137}Cs in the surface layer of the atmosphere within Murmansk in 2019 varied from the value below the limit of detection in the fourth quarter to $1.2\cdot10^{-7}$ Bq/m^3 in the first quarter, with the average annual value of $1.1\cdot10^{-7}$ Bq/m^3. Fallout levels of ^{137}Cs observed in Murmansk, Pechenga, Polyarnoye and Teriberka were 0.11 Bq/m$^2\cdot$year in 2019.

The tritium content of atmospheric precipitation in Murmansk was determined on a monthly base. The samples were analyzed at the FSBI "NPO "Typhoon". In 2019 the average monthly volumetric activity of tritium in precipitation varied between 0.75 Bq/l (in October) and 2.36 Bq/l (in July). The average annual value of the volumetric activity of tritium in 2019 increased against 2018 and reached 1.25 Bq/l, which is

1.4 times lower that the average value of the volumetric activity of tritium in precipitation on the territory of the Russian Federation in 2019 (1.78 Bq/l).

Results of long-term observations show that levels of contamination of the surface layer of the atmosphere by technogenic radionuclides ^{90}Sr and ^{137}Cs are six to seven orders of magnitude lower than limits specified in NRB-99/2009, and do not pose a hazard to health of the population.

Observations over the content of ^{90}Sr in water bodies on the territory of Murmansk Region are carried in the Imandra Lake and Barents Sea. Results of radiochemical analysis of water based on data from two observation points (Molochnaya Bay and Zasheyek) showed that average annual ^{90}Sr activities in the Imandra Lake were at the level of 2 mBq/l in 2015-2019. Results of analysis of water samples taken from the Barents Sea in Teriberka (Murmansk TAHEM, FSBI “NPO “Typhoon”) presented in Table 3 show that in 2019 the volumetric activity of ^{90}Sr in seawater samples varied between 1.80 and 2.45 Bq/m^3 at the average of 1.93 Bq/m^3 and is almost the same as the values obtained in 2016-2018 (from 1.8 to 2.0 mBq/l).

Table 3 – Volumetric activity of ^{90}Sr in seawaters of Murmansk Region, mBq/l (data of the FSBI “NPO “Typhoon”)

Sample date		Barents Sea Sampling point coordinates 68°37'n, 33°03'e
13.03.2019		1.8
23.05.2019		1.80
08.07.2019		1.67
14.11.2019		2.45
Average:	2019	1.93
	2018	1.95

According to results of multi-year joint Russian-Norwegian research, the activity variations in the Barents Sea are strongly influenced by transboundary transport by sea currents of radionuclides removed to the Irish Sea and English Channel from spent nuclear fuel reprocessing plants in England and France. Potential sources of technogenic radionuclides getting into the Barents Sea include nuclear submarines which sank by accident: Komsomolets in the Norwegian Sea with waters exchange with the Barents Sea, and K-159 in the Barents Sea. Their location areas are regularly subjected to comprehensive field surveys of the marine environment, including water, bottom sediments and marine organisms. The studies have shown that the sunken submarines are not leaking radioactive materials.

The Barents Sea ecosystem is continuously monitored by Rosgidromet and Russian Academy of Sciences (Murmansk Marine Biological Institute of Kola Scientific Center of the RAS). Results of surveys in the area of the Andreeva Bay SNF and RW TSF were published in 2017. They show that operation of the Andreeva Bay SNF and RW TSF has no significant adverse effect on the radiation situation and condition of marine ecosystems outside the Andreeva Bay [12]. Radioactive contamination of aquatic environment in the territory of Murmansk Region is at the level which is considerably lower that the level prescribed by NRB-99/2009, with a downward trend observed since 2016.

Average annual values of ADER in the areas of NRHF in Polyarnoye, Murmansk and Ura-Guba were no different from the natural background gamma radiation levels and varied between 0.08 μSv/h (Ura-Guba) and 0.12 μSv/h (Murmansk). Maximum ADER values were no greater than 0.14 μSv/h, which is within the fluctuation of the background radiation observation data in the previous period of 2016-2018.

2 Andreeva Bay: Current operations

The Andreeva Bay coastal maintenance base (CMB) was constructed and put in operation in 1961-1963 for the following purposes:

a. operational support for nuclear-powered submarines.
b. receipt of spent nuclear fuel, its temporary storage, preparation, retrieval and removal for reprocessing.
c. collection, treatment, and temporary storage of solid and liquid radioactive waste.

The CMB ceased operating in 1989. In 2000 the North-Western Center for Radioactive Waste Management “SevRAO” (NWC “SevRAO”) was established, a branch of FSUE “RosRAO” (now NWC “SevRAO”, a branch of FSUE “FEO”), which is under economic management of the State Corporation “Rosatom”. The Andreeva Bay Division is affiliated with the parent enterprise.

The main activity areas of the enterprise include:

a. management of legacy wastes during their storage, transportation, and processing.
b. nuclear, radiation, environmental safety assurance and physical protection of facilities.
c. construction, repairs and upgrading of infrastructure required for implementation of the Concept of Remediation of CMBs in the Northwest Russia approved by Rosatom.
d. disposal of military nuclear power systems, their ground-based prototype test facilities, and components.

Large quantities of SNF and RW are stored at the Andreeva Bay SNF and RW TSF site. Two complexes were built for their management: the RW management complex and SNF management complex. The RW management complex is designed for storage and processing of accumulated radioactive waste and waste generated during SNF and RW management operations.

The RW management complex includes the following buildings and structures:

a. two enclosure buildings over the existing SRW storage facilities and areas, designed for preventing the exposure of the stored SRW to atmospheric precipitation, safe year-round retrieval of SRW from storage, and minimization of release of radioactive substances to the environment.
b. conditioned SRW storage facility designed for temporary storage of SRW containers.
c. auxiliary buildings, structures, utility systems.

The SNF management complex is designed for preparation and removal of SFAs from the site for reprocessing, including retrieval from DSU cells, re-canistering, placing the SFAs into a TUK-108/1 (TUK-18) transport package, transportation within the site, temporary storage, loading the TUK with the SFAs onto the container ship.

The SNF management complex includes the following structures:

a. enclosure building over three storage tanks: DSU-2A, DSU-2B and DSU-3A (Building 153) is designed for remote retrieval of SFAs from the storage cells into a transfer cask using a special handling machine (HM), reloading of the SFAs into new canisters, transfer of the canister in the transfer cask to the TUK loading area, and forming the TUK for further transportation to the accumulation pad and to the berth using a special vehicle.
b. TUK accumulation pad (Building 151) is designed for temporary storage of empty TUKs and TUKs containing canisters with SFAs.

c. fixed berth PMK-67 with the length of 129 m along the wharf face, equipped by a special double-cantilever crane for transfer of the TUKs from the shore to the container ship and back.
d. mechanical repair shop (Building 154) with the decontamination area is designed for making repairs to general-purpose mechanical and electrical equipment and decontamination of special equipment.
e. laboratory and technical building.

2.1 The DSU tanks

The DSU-3A was built for temporary storage of SFAs discharged from marine reactors. The storage tank is 18.8 m in inner diameter and ~6.0 m deep. The tank contains storage cells representing vertically mounted steel tubes of diameter 325 mm, with concrete filling the intertubular space (Fig. 2). In 2004, a leak tight shelter with a framed covering and corrugated metal roofing was constructed over the storage tank. The radiation situation at the DSU-3A stabilized, but radiation levels still did not meet the radiation safety requirements: on the slab covering the dose rate ran up to 3.2 mSv/h, and on the tank surface it was up to 42.0 mSv/h. Personnel could only stay for a short time in such conditions (~20 h to receive the permissible annual dose) which hindered the planned removal of SNF from the DSU-2A and DSU-2B tanks. Works aimed at improvement of the radiological environment (IRE) at the DSU-3A were carried out in 2010-2012 in order to reduce the radiation to acceptable levels and provide access to the tanks for personnel to perform construction and necessary routine tasks [14].

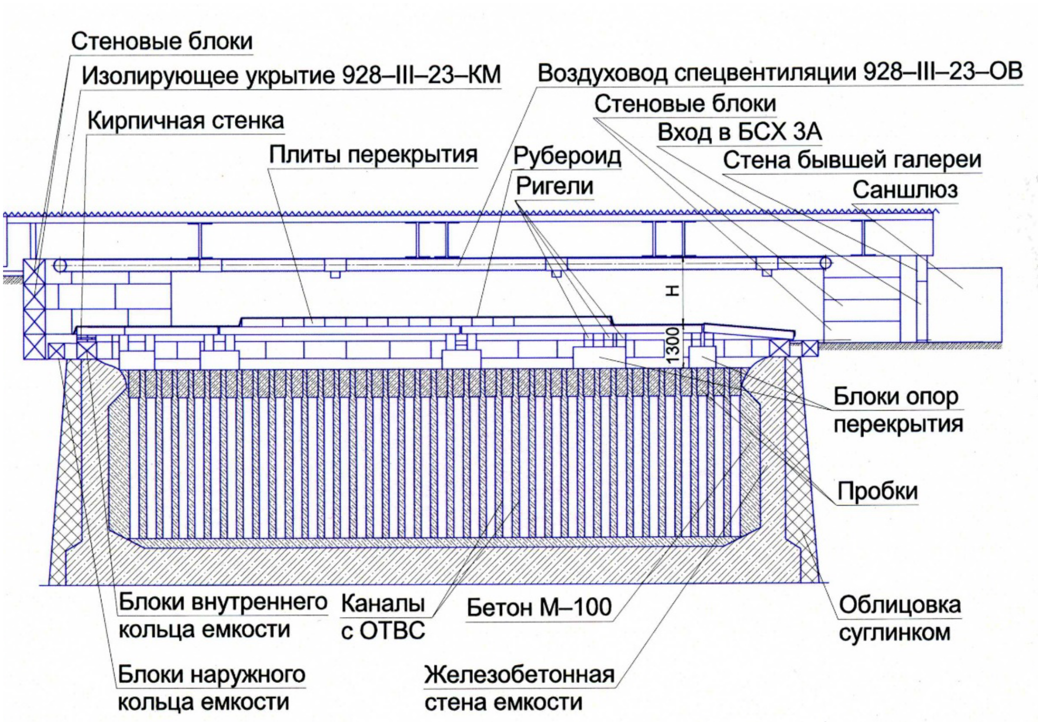

Figure 2. Vertical section through the DSU-3A tank along the diameter running north-south

Altogether, based on the ARSMS data, in the course of active operations on improvement of the radiological environment, the ADER values reduced more than a hundredfold – from 1.6 mSv/h in September 2011 to 14 μSv/h in February 2012.

The main facility of the SNF management complex is the enclosure building accommodating the DSU-2A, DSU-2B and DSU-3A tanks (Building 153), which performs the following functions:

a. provision of safe working conditions for personnel involved in retrieval of SFAs from DSU cells, transfer of the SFAs into ChT canisters and preparation of TUK-108/1 (TUK-18) packages.
b. support of operation of the handling machine, overhead cranes, transfer trolleys and special SFA handling equipment.
c. protection of the DSUs, containers and canisters against atmospheric precipitation.
d. limitation of release of radioactive substances and ionizing radiation to the environment during normal operation and in accidents.

Figure 3. Installation of the biological shielding on the surface of the DSU-3A tank.

According to OSPORB-99/2010, Building 153 belongs to category I of potential hazard. The building is intended for performance of class I works, and includes the following three zones:

a. zone 1 – unattended premises which are the major source of ionizing radiation and radioactive contamination.
b. zone 2 – temporarily attended premises intended for unloading of SFAs, making repairs of the equipment, accommodation of RW collection and unloading areas.
c. zone 3 – premises permanently attended by personnel during the shift.

All rooms in Building 153, except for the forced ventilation and electrical control rooms, are included in the controlled access zone. Personnel get to zone 3 via a gallery connecting the Sanitary Pass (Building 160) with Building 153. There is a sanitary air lock between the zone 3 and zone 2 rooms.

According to the Hygienic Requirements for Designing of Nuclear Industry Enterprises and Facilities (SPP PUAP-03), air flows are directed from rooms with lower potential radioactive contamination to rooms with higher potential radioactive contamination. To reduce contamination of main air ducts as required by Para 3.9.11 of OSPORB-99/2010, filters are installed in separate rooms in immediate proximity to contamination sources. To minimize the volume of radioactive aerosols released to the environment, contaminated air from local exhausts is discharged into the atmosphere through a tall vent stack (40 m).

The TUK accumulation pad (Building 151) is intended for keeping TUK-108/1 (TUK-18) shielding containers with SFA arriving from Building 153 before transporting them to the berth for loading onto the container ship. The following TUK servicing areas are located in Building 151:

a. TUK storage area.
b. area for unloading/loading of TUKs from/onto vehicles.
c. auxiliary equipment storage area.

All handling operations inside Building 151 are performed using a special electric overhead crane with a lifting capacity of 50/12.5 t. Building 151 has a vehicle access and a rail track going out of the building onto the trestle for the rail-guided trolley. The ventilation system is natural. The air from the TUK storage hall leaves the building without purification through louvres at the height above ground level of 12 m.

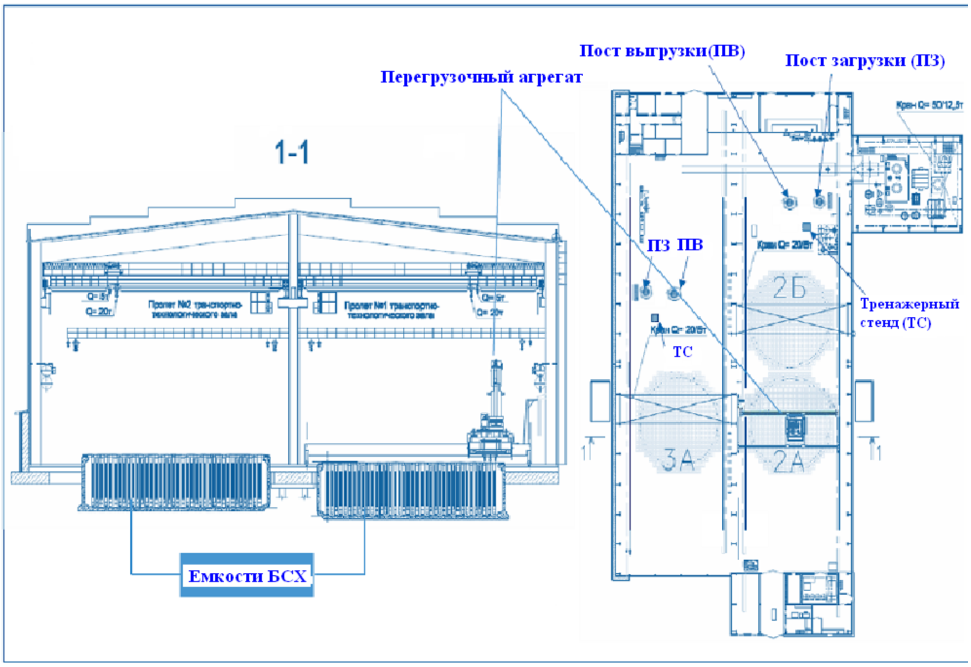

Figure 4. Layout of Building 153.

Figure 5. Handling machine above the DSU-2A tank.

2.2 On-site radiation conditions

Structures designed for management of SNF, SRW and LRW are sources of radioactive contamination of the environment and have impact on the radiation situation at the Andreeva Bay SNF and RW TSF site. Main sources of elevated levels of gamma, beta and alpha radiation include:

a. structure 67A – SRW storage. The wastes are stored in temporary packages and sacks.
b. structure 7 – area for SRW storage. The wastes include ionizing radiation sources, ionization chambers, polyethylene cans and sacks with waste, filters, equipment.
c. structure 7A where temporary SRW packages are stored.
d. LRW storages in Building 6 and structure 7V.
e. areas 7G, 7E, montejus area for storage of SRW such as temporary packages, filters, handling equipment, concrete beams, and type 6 containers.

In other areas of the site, the radiation situation with respect to external gamma radiation is within the levels permissible for permanent operation of personnel, and contamination of the soil does not exceed background levels. Over the last 5 years the radiation situation inside and outside the buildings and in some spots at the SNF and RW TSF site improved as a result of the completed activities aimed at clean-up of some of the contaminated areas, removal of the accumulated SRW to the Regional Center for Radwaste Conditioning and Long-term Storage in Saida Bay (CCLS RW), and removal of large number of SFAs from the DSU-2A to PO Mayak for reprocessing.

Values of the gamma dose rate and density of contamination by alpha- and beta-active substances in structures at the Andreeva Bay SNF and RW TSF site are given in Table 4 (as of 2020).

Table 4 – Gamma dose rate and density of contamination of structures by alpha and beta-active substances (as of 2020)

#	Area (structure)	Gamma dose rate, μSv/h		Density of contamination by alpha- and beta-active substances (average), particles/cm^2×min	
		Average	Maximum	Alpha emitters	Beta emitters
1	CAZ of Building 5	5.06	6.38	<6	1000
2	Structure 7D	0.50	0.61	<6	18
3	Structure 67A	30.0	40.0	<6	6
4	Structure 7V	0.51	0.82	<6	6
5	Structure 7G	8.0	12.0	<6	800
6	Structure 7B1	0.91	1.23	<6	120
7	Structure 202	3.52	8.22	<6	600
8	Structure 201	9.0	12.0	<6	5400
9	Structure 7A	11.3	12.0	<6	3240
10	Structure 7	550.0	838.0	<6	10000
11	DSU tanks	5.58	7.96	<6	4200
12	Structure 67	0.92	1.85	<6	6
13	Structure 6	9.45	14.51	<6	10000
14	Structure 7E	3.0	9.37	<6	2000
15	Montejus area	27.8	142.0	<6	10000

The radiation situation at the TSF site and in the sanitary protection zone is characterized by local contamination of the soil cover, which is the source of contamination of the environment and of potential spreading of radioactivity beyond the TSF site, including the water area. Averaged results of monthly measurements of the gamma dose rate and density of contamination by alpha- and beta-active substances of the most contaminated areas of the Andreeva Bay SNF and RW TSF site outside the structures and certain areas, which were taken in 2020, are given in in Table 5.

For groundwater surveillance, 17 boreholes were initially drilled at the SNF and RW TSF site near Building 5, SRW storage areas and DSU tanks. Waters of three aquifers were found when drilling the boreholes. According to results of the measurements, in certain areas activity of water samples was as high as 2.4×10^3 Bq/kg for ^{137}Cs and 5.4×10^4 Bq/kg for ^{90}Sr, which was caused by escape of radioactivity from the SRW storage with fissure-vein water in rocky soil occurring at the depth of 1.5-1.6 m. To monitor possible migration of radionuclides with underflow from Building 153 that is a potential source of groundwater contamination, in 2017 ten more boreholes were drilled around the building as required by SPORO-2002 and OST 10517-95.

Table 5 – Data of radiation measurements taken at the site outside the structures and certain areas

#	Zone	Location of the measurement point	P_{γ}aver, μSv/h	N_{β}max, part./min·cm²
1	Controlled access zone	End wall of Building 5 facing the bay (at a distance of 4 m)	1.2	48
2	Controlled access zone	At the entrance to the DSU SP-88 No.1 (between the DSU sanitary air lock and SP-88 No.1)	0.19	<6
3	Controlled access zone	Between the DSU decontamination area and DSU-3A tank	0.22	<6
4	Controlled access zone	Entrance to the DSU-3A tank (at a distance of 2 m)	0.40	12
5	Controlled access zone	Entrance to the DSU-2A tank (at a distance of 2 m)	0.95	6
6	Controlled access zone	Entrance to the DSU-2B tank (at a distance of 2 m)	0.35	6
7	Controlled access zone	Road between decontamination area No.3 and SP-10 No.1 of Building 5 (the boundary of the DSU CAZ and Structure 1 construction site)	0.30	<6
8	Controlled access zone	Entrance to Structure 6 (at a distance of 1 m)	1.0	12
9	Controlled access zone	Halfway along the road between Structure 67A and Building 6	5.75	60
10	Controlled access zone	Gate of Structure 67 (at a distance of 3 m)	0.75	18
11	Controlled access zone	Intersection of roads from Shelter 201, Structure 67 and the road to Structure 7D	1.2	20
12	Controlled access zone	Between Structure 7D and the gate of the floating tanks area	0.37	6
13	Controlled access zone	Entrance to Structure 7V (on the side of Shelter 202)	8.45	120
14	Controlled access zone	Access way to the left gate of Shelter 202 (at a distance of 3 m)	1.35	46
15	Controlled access zone	Entrance to the Montejus area	10.55	90
16	Controlled access zone	Intersection of roads to the Montejus area, Shelter 202, Structure 67 and access way to PL-3	0.73	120

The observation boreholes are located at a distance of 5 m from the building at 30 to 40 m intervals. The maximum value of specific activity of groundwater in these 10 boreholes is 1.55 E+01 Bq/kg for cesium-137. According to results of spectrometric analysis of water taken from monitoring boreholes in the technical area in 2020, maximum values of specific activity of groundwater are 2.7 E+01 Bq/kg for cesium-137 and 1.6 E+01 Bq/kg for strontium-90. In two boreholes – No. 4092 and No.4092V – located near Building 5 maximum values of specific activity of groundwater are 1.17 E+02 Bq/kg for cesium-137 and 7.98 E+02 Bq/kg for strontium-90.

The significant reduction in the level of radioactive contamination of groundwater is a result of clean-up of contaminated areas, removal of accumulated SRW to the Saida Bay CCLS RW, removal of a large number of SFAs from the DSU-2A to PO Mayak for reprocessing, and completion of other planned remediation works during the last 5 years. Compared to radioactive contamination, chemical pollution of groundwater is more scattered in terms of locations, quantitative and qualitative factors. Cases of exceeding the MPC established for drinking water were noted for heavy metals of hazard Class II. The statement issued by Interregional Department No. 120 of FMBA of Russia characterized the radiation situation at the Andreeva Bay SNF and RW TSF site in 2018 as satisfactory, and doses to personnel as insignificant: 0.94 mSv/year for personnel of Group A, and 0.11 mSv/year for personnel of Group B (see Table 6).

Table 6 – Annual doses to the SNF and RW TSF personnel in 2017-2019

Year	Number of personnel, people	Number of personnel (people) with the individual doze in the following range, mSv/year:							Average individual dose, mSv/year	Collective dose, man-Sv/year
		0-1	1-2	2-5	5-12.5	12.5-20	20-50	>50		
Group A										
2017	65	54	9	2	-	-	-	-	0.52	0.03350
2018	71	48	10	12	1	-	-	-	0.94	0.06669
2019	78	46	14	17	1	-	-	-	1.17	0.09091
Group B										
2017	35	35	-	-	-	-	-	-	0.09	0.00312
2018	35	35	-	-	-	-	-	-	0.11	0.00374
2019	42	42	-	-	-	-	-	-	0.09	0.00386

As agreed by the Interregional Department No. 120 of FMBA of Russia, no quotas for exposure of the population of the town of Zaozyorsk from the Andreeva Bay SNF and RW TSF have been established since 2008. In view of this, radiation-hygienic passports of the Andreeva Bay SNF and RW TSF for the years from 2007 to 2019 do not contain information on annual exposure of population living in the radiation control area due to activities of the enterprise. According to data in the radiation-hygienic passports of the Andreeva Bay Division for 2017-2019 [3], average annual volume activity of radionuclides in the air within the SPZ and RCA is characterized by values given in Tables 7 and 8. The values in the tables are by several orders of magnitude less than the levels of permissible volume activity of 137Cs and 90Sr in the atmospheric air for the population specified in NRB-99/2009. The contribution of the radiation factor in contamination of the air by RNG and radioactive aerosols is negligible.

Table 7 – Average annual and maximum recorded volume activity of radionuclides in the air within the SPZ

Radionuclide	Number of samples	Atmospheric air, Bq/m^3			
		Average		Maximum	
		Bq/m^3	PVA units	Bq/m^3	PVA units
Cs137					
2017	100	<3	-	<3	-
2018	90	6.52E-04	2.42E-05	6.74E-04	2.54E-05
2019	94	7.4E-04	2.74E-05	7.6E-04	8.15E-05
Sr90					
2017	100	<1	-	<1	-
2018	90	4.2E-06	1.56E-06	5.2E-06	1.93E-06
2019	94	1.31E-03	4.22E-04	2.2E-03	8.15E-02

Table 8 – Average annual and maximum recorded volume activity of radionuclides in the air within the RCA

Radionuclide	Number of samples	Atmospheric air, Bq/m^3			
		Average		Maximum	
		Bq/m^3	PVA units	Bq/m^3	PVA units
^{137}Cs					
2017	12	<3	-	<3	-
2018	12	4.60E-06	1.70E-07	4.60E-06	1.70E-07
2019	12	1.9E-04	7.00E-06	1.9E-04	7.00E-06
^{90}Sr					
2017	12	<1	-	1	-
2018	12	1.06E-05	3.93E-06	1.06E-05	3.93E-06
2019	12	8.00E-07	2.00E-07	8.00E-07	2.00E-07

According to data in the radiation-hygienic passports of the Andreeva Bay Division for 2017-2019 [3], specific activity of radionuclides in the water of the open water bodies within the sanitary protection zone and radiation control area is characterized by values given in Tables 9 and 10.

Table 9 – Specific activity of radionuclides in the water of the open water bodies within the sanitary protection zone.

Radionuclide	Number of samples	Water of the open water bodies, Bq/l			
		Average		Maximum	
		Bq/l	Intervention level units	Bq/l	Intervention level units
Cs137					
2017	122	<3	-	<3	-
2018	141	<3	-	<3	-
2019	134	2.8	2.67E-01	6.61	6.0E-01
Sr90					
2017	122	<1	-	<1	-
2018	141	<1	-	<1	-
2019	134	1	-	1	-

Table 10 – Specific activity of radionuclides in the water of the open bodies in the radiation control area

Radionuclide	Number of samples	Water of the open water bodies, Bq/l			
		Average		Maximum	
		Bq/l	Intervention level units	Bq/l	Intervention level units
		Cs137			
2017	4	<3	-	<3	-
2018	4	<3	-	<3	-
2019	4	2.08	1.89E-01	3	-
		Sr90			
2017	4	<1	-	<1	-
2018	4	<1	-	<1	-
2019	4	1	-	1	-

Specific activity values presented in Tables 9 and 10 do not exceed respective intervention levels for these radionuclides in water specified in NRB-99/2009. According to the radiation-hygienic passports, maximum permissible emissions of radionuclides were not established for the years of 2017 and 2019. There were no actual emissions of radionuclides during these years. Recent survey results allow stating that changes in the radiation situation at the Andreeva Bay site demonstrate a positive trend of reduction in man-made radionuclides in the environment, including coastal waters.

2.3 DSU operations

The objective of works on preparation of the DSU-3A tank for retrieval of SNF is to level the BS at the design elevation of 23.255 m [6, 7, and 8]. At present (as of 01.07.2020) the initial condition of the DSU-3A tank following the IRE works is as follows [17]:

a. there is a lot of construction rubbish (concrete chips, dust, metal debris, stones, bricks, pieces of roofing felt) on the tank surface and in the cells (between plugs and caps).
b. 983 BS segments are installed on the caps without leveling devices.
c. the existing absolute elevation of the BS surface is 23.245 m [18].
d. an additional biological shielding is installed over the existing BS along the edges (along the tank wall) and in some parts.
e. the interior space of the existing enclosure building of the 3A tank is not ventilated.
f. on the outside, the tank wall is fenced with a monolithic reinforced concrete slab that serves as the floor foundation in Bay No. 2 of Building 153.
g. the gamma-radiation dose rate at any point of the surface and outside the tank does not exceed 12 μSv/hr.
h. the DSU-3A tank with the existing shelter is isolated from the environment by the outside walls and roof of Building 153.

2.4 SNF retrieval from DSU-3A

The process of retrieval and removal of SNF from the Andreeva Bay SNF and RW TSF site [9, 10, 11] shall ensure safety for personnel and population when handling the SNF at all stages of the work sequence: retrieval of SFAs from the DSU cells, loading of the SFAs into TUK-108/1 (TUK-18) casks, temporary storage, and loading of TUK-108/1 (TUK-18) casks onto the container ship for subsequent removal from the site for reprocessing.

To reduce nuclear, radiation and environmental hazards, the preferred approach to retrieval of the SNF from the storage cells is channel-by-channel retrieval of individual SFAs from canisters placed in the DSU -3A cells.

Figure 6. General view of the storage tanks at the DSU-3A in Building 153.

The mandatory condition for retrieval of a canister with SFAs from the storage cell is preliminary removal of water, if any, from the inner cavity of the canister and cell where the former is located.

Handling operations with SFAs from the DSU-3A tank cells start when the following events occur:

a. completion of the measures on preparation of the DSU-3A tank for retrieval of SFAs.
b. completion of retrieval of SFAs from the DSU-2A and DSU-2B storage cells.
c. relocation of the handling machine from the position above the DSU-2A and DSU-2B tanks in the eastern bay of Building 153 to the position above the DSU-3A tank in the western bay.

Figure 7. Process operations performed in the handling hall and TUK loading station in Building 153.

All operations of the process of channel-by-channel retrieval of SFAs from the storage cells, loading of SFAs into ChT canisters and placing the canisters with SFAs in TUK-108/1 (TUK-18) transport casks shall be performed in Building 153.

The process of retrieval of SFAs from the DSU-3A storage cells includes a number of steps:

a. retrieval of intact SFAs from intact canisters located in the tank.
b. retrieval of intact SFAs from defective canisters.
c. retrieval of defective SFAs from the remaining canisters in the tank.
d. retrieval of withdrawable canisters with stuck SFAs from the tank.

Preparations for retrieval and retrieval of SFAs from the storage cells shall be carried out by the handling machine using special equipment installed on it in accordance with the following sequence:

a. dismantling of a biological shielding section on the tank.
b. removal of a light cap from the tank cell.
c. removal of water from the opened tank cell, if any.
d. removal of any foreign objects from the canister plug.
e. fixing defects of the of the canister upper casing.
f. removal of the canister plug.
g. checking the SFA for structural integrity SFA (intact SFAs).
h. reloading of intact SFAs into “secondary” canisters.
i. fixing structural defects of defective SFAs, where possible.
j. reloading of repaired SFAs into “secondary” canisters.
k. loading of “secondary” canisters into TUK-108/1 (TUK-18).
l. removal of water from the inner cavity of a “primary” canister.
m. installation of the canister plug.
n. checking a “primary” canister with stuck SFAs for retrievability from the DSU-3A cell.
o. reloading of retrievable “primary” canisters with stuck SFAs into the modified TUK-108/1 (TUK-18) cask.

The loaded ChT canisters are transported in the transfer container for canisters (KB-651 container by the transfer trolley to the hall for preparation of TUK packages for shipment, where the canisters are to be loaded in standard TUK-108/1 (TUK-18) transport casks. The fully loaded TUK-108/1 (TUK-18) cask prepared for transportation is transferred to the transfer corridor of Building 153, installed onto a vehicle carrier by the overhead crane of lifting capacity 50 tons and transported to the accumulation pad (Building 151). In Building 151 the packages can be placed in temporary storage or reloaded onto a rail transfer trolley using the overhead crane of lifting capacity 50 tons for transportation to the fixed berth PMK-67. It is prohibited to open TUK-108/1 (TUK-18) packages in reload SFAs contained in them in Building 151. At the PMK-67 berth the TUK-108/1 (TUK-18) packages are reloaded from the transfer trolley into the cargo hold of the container ship (“Rossita” or “Serebryanka”).

Figure 8. Process operations of loading the TUK-18 cask onto the container ship.

2.5 Environmental impacts during preparation of the DSU-3A tanks: Normal Operations

During preparatory works at the DSU-3A tank, released radioactive aerosols get into the process module room and are further emitted into the atmosphere by the active exhaust ventilation system. To comply with requirements to atmospheric air quality, the exhaust ventilation of Building 153 is equipped with the system for two-stage purification of polluted air before emission to the atmosphere consisting of coarse and fine filters – FVEA-3500-2-N13 and FAST-3500-M. The purified air is emitted to the atmosphere from the shelter through a reed valve and common stack.

The FAST-3500-M high-efficiency filter is installed at the end of the exhaust duct for final purification of air from suspended solids. The filter material is made from fiberglass and polyester. The service life at the aerosol concentration at the inlet of up to 0.1 mg/m^3 is one year. The filter has a high purification factor, improved aerodynamic and mechanical characteristics. The container-type active ventilation module will be additionally installed during preparatory works at the DSU-3A tank.

The active ventilation module is a facility provided with an exhaust fan, an aerosol filter for air purification from aerosols, including those contaminated with radioactive substances (FVEA-3500-2-N13), a radiation control system and fire extinguishing system. Purified air is discharged from the active ventilation module into the existing stack of the exhaust active ventilation system V2A of Building 153 located in the area of the DSU-3A tank. The active ventilation module is equipped with built-in batteries, the autonomous operation of which in standby mode in the event of loss of power will allow sufficient time for fixing the problem.

Thus, radionuclide aerosols produced during the operations will be subjected to double purification before emitting them to the environment: on the filters of the active ventilation module to be installed in the new shelter of the DSU-3A tank, and then on the filters in Building 153. For the conservatism of further estimates we assume that the aerosol purification factor for the modular active ventilation system and for the stationary active ventilation system of Building 153 will be the same and equal to 0.01.

The main sources of radionuclide aerosols will be intermediate-level solid wastes (ILW) produced during the operations, such as:

a. reinforced concrete fragments of the upper part of the DSU-3A tank wall.
b. reinforced concrete plugs in the tank cells.
c. construction debris in the cells.
d. construction debris between the tank cells.

The volume of the SRW (ILW) generated during the preparatory works at the DSU-3A is estimated at 70 m^3.

The maximum activity of contamination of the concrete and debris is 1.3 x 10^9 Bq/kg of ^{137}Cs. Let us assume that it also contains ^{90}Sr. According to measurements taken for samples of surface water from the tank cells, activity of ^{90}Sr in them is 30 times less than activity of ^{137}Cs, and it is this water which caused contamination of the DSU surfaces. For the conservatism of the estimates we set the SRW density equal to 2 t/m^3 and assume that the dust fraction of generated SRW will be 0.01, 1% of which will go into aerosol form.

Thus, during the entire period of preparation works at the DSU-3A tank there will be produced 1.8 x 10^{10} Bq of ^{137}Cs aerosols and 6 x 10^8 Bq of ^{90}Sr aerosols. After purification in the active ventilation module and on filters of the active ventilation system of Building 153, 1.8 x 10^6 Bq of ^{137}Cs and 6 x 10^4 Bq of ^{90}Sr will be emitted to the atmosphere. The release height is 40 m (vent stack of Building 153). We will neglect the additional rise of the plume for the sake of conservatism of evaluation of radiological consequences.

The calculations were performed according to regulatory document RB-106-15 for all possible exposure routes, including:

a. external exposure from a radioactive cloud.
b. external exposure from radionuclides settled on the underlying surface.
c. internal exposure due to radionuclides that entered the body with the inhaled air (inhalation route).

The internal exposure from radionuclides that entered the body as a result of migration along the food and biological chains (oral route) are not considered since:

a. the composition of the diet for the critical group of the population mainly includes brought-in products; there is no production and consumption of local food products in the area of the organization's location.
b. drinking water supply to the enterprise and adjacent residential areas is centralized. The source of water supply is a river; water intake and conditioning to drinking quality are carried out at a water treatment plant located outside the zone of influence of radioactive emissions. Therefore, when

calculating the radiation doses to the critical group of the population, the exposure from the ingestion of radionuclides with drinking water is not considered.

To determine maximum levels of population exposure from the release, there were selected respective atmospheric stability categories for different distances from the release point, which are given in Table 11. Table 12 below gives results of dose calculations for all exposure routes for 8 directions from the site.

The maximum value is located at 200 m northeastward and is less than 4 nSv/year. Highlighted are values of annual doses for the population in the nearby localities. So, in the village of Nerpichye the additional dose will be 0.18 nSv/year, in the village of Bolshaya Lopatka – 0.125 nSv/year; and in Zaozyorsk – 0.02 nSv/year. The above values are several orders of magnitude less than the level of the minimum significant dose of 10   Sv per year. Corresponding levels of contamination of the atmosphere and land surface for performance of the DSU-3A preparation work under normal conditions are presented in Tables 13 and 14.

Table 11- Atmospheric stability categories

Category	A	A	A	A	B	C	D	D	E	F	F	F	F	F
Distance, km	0.1	0.15	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0

Table 12 – Effective dose at various distances from Building 153, nSv/year

Distance, m /Direction	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
N	5.31E-01	2.36E+00	1.74E+00	1.03E+00	4.55E-01	2.23E-01	1.91E-01	1.34E-01	8.54E-02	3.18E-02	1.47E-02	5.20E-03	2.85E-03
NE	8.49E-01	3.78E+00	2.78E+00	1.65E+00	7.27E-01	3.57E-01	3.06E-01	2.14E-01	1.37E-01	5.08E-02	2.35E-02	8.31E-03	4.56E-03
E	4.95E-01	2.21E+00	1.62E+00	9.60E-01	4.24E-01	2.08E-01	1.78E-01	1.25E-01	7.97E-02	2.96E-02	1.37E-02	4.85E-03	2.66E-03
SE	3.54E-01	1.58E+00	1.16E+00	6.86E-01	3.03E-01	1.49E-01	1.27E-01	8.92E-02	5.70E-02	2.12E-02	9.81E-03	3.46E-03	1.90E-03
S	4.24E-01	1.89E+00	1.39E+00	8.23E-01	3.64E-01	1.79E-01	1.53E-01	1.07E-01	6.84E-02	2.54E-02	1.18E-02	4.16E-03	2.28E-03
SW	3.54E-01	1.58E+00	1.16E+00	6.86E-01	3.03E-01	1.49E-01	1.27E-01	8.92E-02	5.70E-02	2.12E-02	9.81E-03	3.46E-03	1.90E-03
W	3.18E-01	1.42E+00	1.04E+00	6.17E-01	2.73E-01	1.34E-01	1.15E-01	8.03E-02	5.13E-02	1.91E-02	8.83E-03	3.12E-03	1.71E-03
NW	2.12E-01	9.46E-01	6.95E-01	4.11E-01	1.82E-01	8.93E-02	7.64E-02	5.35E-02	3.42E-02	1.27E-02	5.89E-03	2.08E-03	1.14E-03

Table 13 – Volume activity, Bq/m^3

Radionuclide	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
Cesium-137	1.18E-07	5.33E-07	3.92E-07	2.32E-07	1.03E-07	5.04E-08	4.31E-08	3.02E-08	1.93E-08	7.16E-09	3.31E-09	1.17E-09	6.40E-10
Strontium-90	3.92E-09	1.78E-08	1.31E-08	7.73E-09	3.42E-09	1.68E-09	1.44E-09	1.01E-09	6.42E-10	2.39E-10	1.10E-10	3.90E-11	2.13E-11

Table 14 – Fallout density, Bq/m^2 a year

Radionuclide	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
Cesium-137	3.03E-02	1.35E-01	9.91E-02	5.87E-02	2.59E-02	1.27E-02	1.09E-02	7.63E-03	4.87E-03	1.81E-03	8.39E-04	2.96E-04	1.63E-04
Strontium-90	1.01E-03	4.49E-03	3.30E-03	1.96E-03	8.64E-04	4.25E-04	3.63E-04	2.54E-04	1.62E-04	6.04E-05	2.80E-05	9.88E-06	5.42E-06

Thus, it is apparent that the environmental impact of radiation during preparations of the DSU-3A tank for SNF retrieval operations is negligible under normal conditions. When carrying out work under normal conditions, the expected release of pollutants into the atmosphere and the above calculations of their dispersion in the atmosphere showed that there is no danger to environmental objects in the adjacent area, for the soil and geological environment. The planned activities will not result in a significant increase of background levels.

The preparations of the DSU-3A tank for the SNF retrieval operations will be performed at the site of the operating enterprise, hence no additional usage of new land areas will be required, and, therefore, during the works there will be no additional impact on the existing flora and fauna.

Due to the absence of agricultural and fishing enterprises and organizations in the area of the Andreeva Bay SNF and RW TSF, as well as due to the unsuitability of the surrounding land for farming, there will be no additional negative impact on the flora and fauna of the area.

2.6 Forecast of environmental changes at the Andreeva Bay SNF and RW TSF caused by performance of the works on SNF retrieval from the DSU-3A tank and removal under normal conditions

All process operations on retrieval of SNF from the DSU-3A cells, loading of SFAs into canisters and loading of the canisters with SFAs into TUK-108/1 (TUK-18) transport casks shall be performed inside the shelter of the DSU-3A tank in Building 153. Subsequent handling of the SNF, including temporary storage at the accumulation pad (Building 151) and loading onto the container ship, will be carried out with TUK-108/1 (TUK-18) casks. During retrieval of SFAs from the DSU-3A cells, their reloading into canisters and loading of the canisters into the TUK-108/1 (TUK-18) casks, there are produced aerosols that contain radionuclides and shall be purified in order to prevent releases of radioactive substances to the environment in amounts exceeding the allowable limits.

For normal operation, the atmospheric impact is caused by process gas-aerosol and ventilation emissions.

The following gas-cleaning systems (GCS) will be provided in Building 153 for purification of process GRW:

a. local gas-cleaning systems for breathing blow-offs of tanks of the water removal plant (WRP) modules.
b. local gas-cleaning system of the handling machine.
c. local gas-cleaning system of SFA loading/unloading stations.

The WRP tank breathing blow-offs shall undergo two-stage cleaning from radioactive aerosols with FVEA-3500 filters to be included in the WRP modules. The purified air is removed via flexible ducts to the stationary duct, and then emitted to the atmosphere through the 40-m high vent stack. The exhaust air flow rate is up to 50 m^3/h. The volume activity of the discharged air is up to 5.3 x 10^{-2} Bq/m^3. Air removed from the working area at the DSU-3A tank with the opened horizontal shielding undergoes three-stage cleaning in filters of the filtering and ventilation unit which is part of the handling machine, and is supplied via a system of flexible ducts to a separate exhaust ventilation system where it undergoes an additional single-stage cleaning before discharge to the atmosphere through the 40-m high vent stack. The exhaust air flow rate is up to 500 m^3/h. The volume activity of the discharged air is up to 1 x 10^{-3} Bq/m^3.

Air removed from the station for loading/unloading SFAs in/from ChT canisters after cleaning in the ventilation system module is supplied to the exhaust ventilation system of the handling machine, where it also undergoes an additional single-stage cleaning before discharge to the atmosphere. The exhaust air flow rate is up to 750 m^3/h. The volume activity of the discharged air is up to 1 x 10^{-3} Bq/m^3. At normal operation of Building 153 the total annual intensity of radioactive emissions will be 1.2 x 10^4 Bq/year at the annual flow rate of discharged air no greater than 4.0 x 10^6 m^3/year.

To ensure normal operation of Building 153, there are provided the centralized supply and exhaust ventilation, local ventilation with mechanical air induction, and natural ventilation. For minimization of emission of radioactive aerosols to the environment, contaminated air from local suction and fume hoods, and air removed by the general ventilation systems from zone II room undergoes single-stage cleaning on FVEA-3500 filters and then discharged to the atmosphere through the 40-m high vent stack. The total flow rate of the ventilation air discharged through the vent stack is 71,200 m^3/h or 6.2 x 10^8 m^3/year.

Conservatively, the design annual intensity of emission of radionuclides with the ventilation air to the vent stack at the annual air rate of 6.2 x 10^8 m^3/year and filter purification factor of 10^2 will be 3.1 x 10^7 Bq/year.

The radionuclide composition of emissions is taken as follows:

a. ^{137}Cs – 50 % – 1.55 x 10^7 Bq/year.
b. ^{90}Sr – 45 % – 1.39 x 10^7 Bq/year.
c. ^{60}Co – 5 % – 1.55 x 10^6 Bq/year.

The dispersion of radionuclide emissions in the atmosphere was calculated to determine dose loads for SNF retrieval operations under normal conditions. The calculations were performed according to the procedure in regulation RB-106-15 for all possible exposure routes, including:

a. External exposure from the cloud.
b. Inhalation exposure.
c. Exposure from underlying surface.

To obtain maximum levels of radiation exposure to population from the atmospheric emission, there were chosen respective atmospheric stability categories for various distances from the release point, which are presented in Table 15. Table 16 gives results of dose calculations for all exposure routes in 8 directions. The maximum value is located at 200 m northeastward and is 43 nSv/year. Highlighted are values of annual doses for the population of nearby localities. In the village of Nerpichye the additional dose will be 2 nSv/year, in the village of Bolshaya Lopatka – 1.4 nSv/year, and in Zaozyorsk – 0.24 nSv/year. The obtained values are several orders of magnitude less than the level of the minimum significant dose of 10 Sv per year (NRB-99/2009). The levels of contamination of atmosphere and surface at normal course of operations on retrieval of SNF from the DSU-3A tank are presented in Tables 17 and 18. The calculated values of the annual effective dose to population are significantly lower than the basic dose limits established by NRB-99/2009.

Table 15 – Atmospheric stability categories

Category	A	A	A	A	B	C	D	D	E	F	F	F	F	F
Distance, km	0.1	0.15	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0

Table 16 – Effective dose at various distances from Building 153, nSv/year

Distance, m /Direction	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
N	6.02E+00	2.68E+01	1.97E+01	1.17E+01	5.16E+00	2.54E+00	2.17E+00	1.52E+00	9.70E-01	3.60E-01	1.67E-01	5.90E-02	3.24E-02
NE	9.64E+00	4.29E+01	3.16E+01	1.87E+01	8.26E+00	4.06E+00	3.47E+00	2.43E+00	1.55E+00	5.77E-01	2.67E-01	9.44E-02	5.18E-02
E	5.62E+00	2.50E+01	1.84E+01	1.09E+01	4.82E+00	2.37E+00	2.02E+00	1.42E+00	9.05E-01	3.36E-01	1.56E-01	5.51E-02	3.02E-02
SE	4.01E+00	1.79E+01	1.32E+01	7.78E+00	3.44E+00	1.69E+00	1.45E+00	1.01E+00	6.47E-01	2.40E-01	1.11E-01	3.93E-02	2.16E-02
S	4.82E+00	2.15E+01	1.58E+01	9.34E+00	4.13E+00	2.03E+00	1.73E+00	1.22E+00	7.76E-01	2.88E-01	1.34E-01	4.72E-02	2.59E-02
SW	4.01E+00	1.79E+01	1.32E+01	7.78E+00	3.44E+00	1.69E+00	1.45E+00	1.01E+00	6.47E-01	2.40E-01	1.11E-01	3.93E-02	2.16E-02
W	3.61E+00	1.61E+01	1.18E+01	7.01E+00	3.10E+00	1.52E+00	1.30E+00	9.12E-01	5.82E-01	2.16E-01	1.00E-01	3.54E-02	1.94E-02
NW	2.41E+00	1.07E+01	7.89E+00	4.67E+00	2.06E+00	1.01E+00	8.67E-01	6.08E-01	3.88E-01	1.44E-01	6.68E-02	2.36E-02	1.29E-02

Table 17– Volume activity, Bq/m³

Radionuclide	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
Cesium-137	1.01E-06	1.01E-06	3.93E-06	4.59E-06	3.38E-06	2.00E-06	8.83E-07	4.34E-07	3.71E-07	2.60E-07	1.66E-07	6.16E-08	2.85E-08
Strontium-90	9.15E-07	9.15E-07	3.55E-06	4.15E-06	3.05E-06	1.80E-06	7.98E-07	3.92E-07	3.35E-07	2.35E-07	1.50E-07	5.57E-08	2.58E-08
Cobalt-60	1.01E-07	1.01E-07	3.93E-07	4.59E-07	3.38E-07	2.00E-07	8.83E-08	4.34E-08	3.71E-08	2.60E-08	1.66E-08	6.16E-09	2.85E-09

Table 18– Fallout density, Bq/m² a year

Radionuclide	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
Cesium-137	9.94E-03	2.61E-01	9.95E-01	1.16E+00	8.54E-01	5.05E-01	2.23E-01	1.10E-01	9.38E-02	6.57E-02	4.20E-02	1.56E-02	7.23E-03
Strontium-90	8.98E-03	2.35E-01	8.99E-01	1.05E+00	7.71E-01	4.56E-01	2.02E-01	9.91E-02	8.47E-02	5.94E-02	3.79E-02	1.41E-02	6.53E-03
Cobalt-60	9.94E-04	2.61E-02	9.95E-02	1.16E-01	8.54E-02	5.05E-02	2.23E-02	1.10E-02	9.38E-03	6.57E-03	4.20E-03	1.56E-03	7.23E-04

2.7 Impact of radioactive waste, production, and consumption waste

It is expected that wastes of categories SRW, LRW and GRW of various activities will be generated when performing the works on preparation of the DSU-3A tank, retrieval of SFAs from the tank cells and their transportation onto the container ship in accordance with the Operating Procedure [9]. Generation of various types of solid radioactive wastes is expected during the operations on retrieval of SNF from the DSU-3A tank cells and its loading into shielding casks in Building 153. The following SRW management scheme is envisaged for operations in Building 153:

a. SRW collection in points of origin and initial sorting by waste type and activity.
b. placing the SRW in a primary package.
c. placing the primary package in a returnable collection container for on-site transportation.
d. transfer of the SRW to Building 203 for further management.

A special area provided with lifting mechanisms, radiation control system and decontamination devices is allocated in Building 153 for collection of SRW, outgoing control (radiation control, weight checking) and decontamination of outer surfaces of collection containers. The anticipated types, characteristics, and quantities of SRW produced in Building 153 during retrieval of SNF from the DSU-3A tank cells are presented in Table 19. Quantities and types of solid radioactive waste generated from decontamination of equipment are shown Table 20. Containers with SRW will be transported to the RW management complex.

New liquid radioactive wastes (LRW) will be generated in Building 153 when handling SNF from the DSU-3A tank in accordance with the Operating Procedure [9] and HTF [19] in addition to the wastes accumulated during the long-term storage. The expected LRW types include:

a. intermediate-level (ILW) low-salt LRW (accumulated in the storage tank cells and canisters with SFAs);
b. low-level (LLW) high-salt LRW from decontamination of zone II rooms, vehicles, TUK-108/1 (TUK-18) casks, collection containers with SRW and other equipment;
c. low-salt LRW (LLW) generated in the air locks;
d. liquid wastes produced during decontamination of special vehicles and zone III rooms, and those removed from the TUK-108/1, (TUK-18) casks.

Water samples taken from the tank cells in 2004 show that the water is mostly LRW (ILW) the activity of which in certain cells is in the range from 10^7 to 10^9 Bq/l. The specific activity of water on the surface is almost completely defined by ^{137}Cs. An increase of specific activity for ^{137}Cs and especially for ^{90}Sr with increasing depth is observed for all cells. Alpha-emitters were found. This strongly indicates that there is contact between the fuel and water, and not just fission products but actinoids (^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, ^{235}U) as well pass into the water. There are no reliable data on characteristic of LRW inside the canisters, since surveys that would involve opening of canisters in the DSU-3A cells and taking water samples from them were not conducted. Based on the available data we can assume that radionuclide composition of LRW in the canisters will be close to that of water in the cells, but the specific activity may be significantly higher due to the development of corrosion cracking of the material of the outer cladding of fuel elements. Thus, the expected specific activity of water in canisters, which directly contacts the fuel composition through leaks in the fuel element cladding, may reach 7.4×10^{10} Bq/l. Chemical composition of water in canisters with intact membranes may also differ significantly from water in a cell. The estimated amount of water contained in one DSU-3A cell up to the canister head may be approximately from 50 to 120 l depending on the cell sizes and canister type. The amount of water contained in one cell from the canister head to the bottom is approximately from 20 to 100 l. According to the estimates, the volume of water to be removed from the DSU-3A tank cells and canister is ~ 145 m^3.

Table 19 – Description, characteristics, and quantities of SRW generated during retrieval of SNF from DSU-3A cells

List of SRW	Radiation characterization	Quantity per year	Total quantity	Note
1. Rubbish, foreign objects	LLW -ILW	M = 0.007 t/year V = 0.13 m^3/year	V = 0.78 m^3	
2. Plugs from old canisters	ILW	500 pcs	3000 pcs	
3. Gas-cleaning system filters PA	ILW	1st stage – 4 pcs 2nd stage – 2 pcs 3rd stage – 2 pcs	1st stage – 24 pcs 2nd stage – 6 pcs 3rd stage – 6 pcs	
4. Vacuum cleaner filters	ILW	1 pc	6 pcs	
5. Vacuum cleaner collector	ILW	1 pc	6 pcs	
6. Filters of local gas-cleaning systems of the WRP	LLW up to 106 Bq/kg	1st stage – 4 pcs 2nd stage – 2 pcs	1st stage – 24 pcs 2nd stage – 12 pcs	
7. Mechanical filters of the WRP	ILW up to 109 Bq/kg	12 – 16	100 pcs (20% with NFM)	To be confirmed by the WRP developer
8. Container filters with selective sorbent	ILW 2.2×109 Bq/kg	11 pcs (average annual)	120 pcs	
9. Filters of ventilation systems for cleaning air in zone II rooms	LLW up to 106 Bq/kg	16 pcs	96 pcs	
10. Filters of ventilation systems of the 3rd step of air cleaning for PA, and of SFA loading/unloading stations	LLW up to 106 Bq/kg	2 pcs	12 pcs	
11. Filters of the local ventilation system (HPO cabinet)	LLW up to 106 Bq/kg	1 pcs	6 pcs	
12. Equipment, tools	LLW 104 - 105 Bq/kg	2 t/year (1 m^3/year)	6 m^3	5 drums BN-0.2
13. Cleaning rags	LLW 103 - 105 Bq/kg	0.25 t/year (2.5 m^3/year)	15 m^3	15 drums BN-0.2
14 PPE	LLW 103 - 105 Bq/kg	1.5 t/year (15 m^3/year)	90 m^3	70 drums BN-0.2
TOTAL for Building 153	HLW ILW LLW	0.01 m^3/year 15 m^3/year 25 m^3/year	0.06 m^3 90 m^3 150 m^3	

Table 20– Quantities and types of solid radioactive waste generated from decontamination of equipment

#	Description	Waste quantity, kg	Specific activity (beta-emitting radionuclides), Bq·103 /kg
1	Cleaning rags	100	<103 (LLW)
2	Personal protection equipment	50	(LLW)
3	Tools	20	(LLW)

It is planned to use a special modular water removal plant (WRP) for pumping LRW out of the cells and canisters. The WRP shall provide cleaning of LRW from suspended solids, corrosion products and fuel spills with mechanical filters and reduction of the LRW activity to the level of low-level waste with selective filters. After checking for specific activity and salt content, the LRW will be further transferred as low-salt LRW (LLW) to accumulation tanks and then to the Serebryanka ship for removal for processing. LRW produced during decontamination of TUK casks, containers, process equipment, as well as from the zone II rooms and sanitary air lock will be transferred to accumulation tanks and further delivered by a road tanker to the Serebryanka ship for removal for processing. Water removed from transport packages as well as water arising from decontamination of special vehicles, vehicle entries and zone III rooms will be transferred to control tanks of the active sewage system wherefrom, depending on the value of specific activity, the water shall be removed to the household sewage system or to accumulation tanks and then to the Serebryanka ship for removal for processing. No additional generation of inert waste is expected during the works. Waste generation standards and disposal limits established for the Andreeva Bay SNF and RW TSF will not be exceeded.

3 Forecast of environmental impact of possible accidents during preparations of the DSU-3A tank for SNF retrieval operations

3.1 Results of calculations of design basis accidents during the DSU-3A preparation works

Calculations of propagation and dose loads were performed in accordance with the Russian standard methodology MPA-96.

3.1.1 Drop of a container with SRW

Drop of a container occurs outside the DSU-3A tank shelter. For conservatism of the estimates, we set the SRW density equal to 2 t/m^3. The dust fraction of the SRW will be 0.01, 1% of which will pass into aerosol form. At the KRAD container volume of 1.3 m^3 and maximum estimated SRW activity of $1.3 \cdot 10^9$ Bq/kg we obtain that $3.4 \cdot 10^8$ Bq of ^{137}Cs aerosols and $1.1 \cdot 10^7$ Bq of ^{90}Sr aerosols will get to the active ventilation system of Building 153. After being cleaned on filters of the active ventilation system of Building 153, $3.4 \cdot 10^6$ Bq of ^{137}Cs aerosols and $1.1 \cdot 10^5$ Bq of ^{90}Sr aerosols will be released into the atmosphere. The release height is 40 m. For conservatism of the estimates, minimum wind velocities were set for different categories of the atmosphere (see Table 21).

Table 21 – Wind velocities for different atmospheric stability categories

Category	A	B	C	D	E	F	G
Wind velocity, m/s	1	1.5	3	4	2	1.5	1

To obtain maximum levels of dose exposure to the population from the atmospheric release, respective atmospheric stability categories were chosen for different distances from the release point as shown in Table 22.

Table 23 shows total doses for all exposure routes at different distances from the release point. In the village of Nerpichye the dose from the emergency release will be less than 0.1 nSv, in the village of Bolshaya Lopatka – 0.24 nSv, and in Zaozyorsk – 1.65 nSv. The maximum value of 15 nSv will be observed at 300 m from the release point. The above values are several orders of magnitude less than the level of the minimum significant dose of 10 μSv per year.The levels of contamination of atmosphere and land surface for the accident during preparation of the DSU-3A tank are presented in Tables 24 and 25.

Table 22 – Atmospheric stability categories

Category	A	A	A	A	E	E	G	G	G	G	G	G	G	G
Distance, km	0.1	0.15	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0

Table 23 – Effective dose at different distances from Building 153, nSv.

Distance, km	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, nSv	8.52E-01	1.44E+01	1.50E+01	3.60E+00	3.43E+00	9.91E-02	1.33E-01	2.42E-01	4.83E-01	1.65E+00	1.73E+00	6.17E-01	1.83E-01

Table 24 – Time integral of volume activity, Bq/m^3

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	9.49E+00	2.43E+02	2.55E+02	6.08E+01	5.82E+01	7.81E-01	1.41E+00	3.34E+00	7.55E+00	2.76E+01	2.91E+01	1.03E+01	2.91E+00
Strontium-90	3.07E-01	7.85E+00	8.24E+00	1.97E+00	1.88E+00	2.53E-02	4.57E-02	1.08E-01	2.44E-01	8.94E-01	9.42E-01	3.32E-01	9.42E-02

Table 25 – Fallout density, Bq/m^2

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	1.17E-01	1.96E+00	2.05E+00	4.92E-01	4.69E-01	1.37E-02	1.84E-02	3.32E-02	6.61E-02	2.25E-01	2.36E-01	8.44E-02	2.51E-02
Strontium-90	3.80E-03	6.35E-02	6.64E-02	1.59E-02	1.52E-02	4.45E-04	5.95E-04	1.07E-03	2.14E-03	7.28E-03	7.64E-03	2.73E-03	8.11E-04

3.1.2 Fall of the overhead crane

Fall of the overhead crane in Building 153 may lead to destruction of the shelter and appearance of aerosols containing radionuclides from the impact of structural fragments on construction debris on the DSU-3A tank surface between the cells. For conservatism of the estimates, we set the SRW density equal to 2 t/m^3. The dust fraction of the SRW will be 0.01, 1% of which will pass into aerosol form. At the volume of debris between the cell of 5 m^3 and maximum estimated SRW activity of $1.3 \cdot 10^9$ Bq/kg we obtain that $1.3 \cdot 10^9$ Bq of ^{137}Cs aerosols and $4 \cdot 10^7$ Bq of ^{90}Sr aerosols will get to the active ventilation system of Building 153. After being cleaned on filters of the active ventilation system of Building 153, $1.3 \cdot 10^7$ Bq of ^{137}Cs aerosols and $4 \cdot 10^5$ Bq of ^{90}Sr aerosols will be released into the atmosphere. The release height is 40 m.

Wind velocities and stability categories are similar to those specified for the accident with the container drop. Table 26 shows total doses for all exposure routes at different distances from the release point. Highlighted are values of annual doses for the population of nearby villages. In the village of Nerpichye the dose from the emergency release will be 0.38 nSv, in the village of Bolshaya Lopatka – 0.92 nSv, and in Zaozyorsk – 6.3 nSv. The maximum dose is located at a distance of 300 m from the emergency release point, and its value is 57 nSv. The above values are several orders of magnitude less than the level of the minimum significant dose of 10 μSv per year.

Levels of contamination of the atmosphere and land surface due to the accident during preparation of the DSU-3A tank are presented in Tables 27 and 28.

Table 26 – Effective dose at different distances from Building 153, nSv.

Distance,	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, nSv	3.26E+00	5.49E+01	5.74E+01	1.38E+01	1.31E+01	3.79E-01	5.09E-01	9.24E-01	1.85E+00	6.30E+00	6.61E+00	2.36E+00	7.00E-01

Table 27 – Time integral of volume activity, Bq/m^3

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	3.63E+01	9.28E+02	9.74E+02	2.32E+02	2.22E+02	2.99E+00	5.40E+00	1.28E+01	2.89E+01	1.06E+02	1.11E+02	3.93E+01	1.11E+01
Strontium-90	1.12E+00	2.86E+01	3.00E+01	7.15E+00	6.84E+00	9.19E-02	1.66E-01	3.93E-01	8.89E-01	3.25E+00	3.43E+00	1.21E+00	3.43E-01

Table 28 – Fallout density, Bq/m^2

Radionuclide	0.05	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	3.18E-01	4.49E-01	7.51E+00	7.85	1.88	1.79E	5.25E-02	7.03E-02	1.27E-01	2.53E-01	8.61E-01	9.03E-01	3.23E-01	9.58E-02
Strontium-90	9.77E-03	1.38E-02	2.31E-01	2.41E-01	5.79E-02	5.51E-02	1.62E-03	2.16E-03	3.90E-03	7.78E-03	2.65E-02	2.78E-02	9.92E-03	2.95E-03

3.2 Results of calculation of the beyond design basis accident during the DSU-3A preparation works

In the event of a beyond design basis accident as a result of earthquake of intensity 7 on the MSK-64 scale, there will occur a partial destruction of the Building 153 roof, destruction of the DSU-3A shelter, collapse of the DSU-3A tank structures and fall of the overhead crane onto the tank surface. The active ventilation system will also fail.

Fall of the overhead crane on the DSU-3A tank may lead to appearance of aerosols containing radionuclides from the impact of crane components and structural fragments on construction debris on the DSU-3A tank surface between the cells. For conservatism of the estimates, we set the SRW density equal to 2 t/m^3. The dust fraction of the SRW will be 0.01, 1% of which will pass into aerosol form. At the volume of debris between the cell of 5 m^3 and maximum estimated SRW activity of $1.3 \cdot 10^9$ Bq/kg we obtain that $1.3 \cdot 10^9$ Bq of ^{137}Cs aerosols and $4 \cdot 10^7$ Bq of ^{90}Sr aerosols will be released. The release height corresponds to the Building 153 roof. To obtain maximum levels of dose exposure to the population from the atmospheric release, the following atmospheric stability categories were chosen for different distances from the release point (see Table 29).

Table 30 shows total doses for all exposure routes at different distances from the release point. The maximum dose value will be 15 μSv; it is located at 50 m from the epicenter of the emergency release. This value is much less than 1 mSv per year specified by population in NRB-99/2009. In the village of Nerpichye the dose from the emergency release will be 2.1 μSv, in the village of Bolshaya Lopatka – 1.8 μSv, and in Zaozyorsk – 1.5 μSv. The above values are several orders of magnitude less than the level of the minimum significant dose of 10 μSv per year. The levels of contamination of the atmosphere and surface due to the beyond design basis accident during preparations of the DSU-3A tank are presented in Tables 31 and 32. The environmental impact of radiation from possible accidents during the works on preparation of the DSU-3A tank for SNF retrieval operations is negligible.

Table 29 – Atmospheric stability categories

Category	A	A	A	A	A	E	F	F	F	G	G	G	G	G	F
Distance, m	50	100	150	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000

Table 30 – Effective dose at different distances from Building 153, μSv

Distance, km	0.05	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, μSv	1.52E+01	1.25E+01	7.63	4.88	3.13	2.75	2.12	1.97	1.84	2.03	1.48	6.42E-01	8.90E-02	3.12E-02

Table 31 – Time integral of volume activity, Bq/m^3

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	2.12E+05	1.30E+05	8.29E+04	5.32E+04	4.67E+04	3.60E+04	3.34E+04	3.11E+04	3.44E+04	2.50E+04	1.08E+04	1.42E+03	4.94E+02
Strontium-90	6.54E+03	3.99E+03	2.55E+03	1.64E+03	1.44E+03	1.11E+03	1.03E+03	9.57E+02	1.06E+03	7.70E+02	3.33E+02	4.36E+01	1.52E+01

Table 32 – Fallout density, Bq/m^2

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	1.71E+03	1.04E+03	6.67E+02	4.28E+02	3.75E+02	2.89E+02	2.69E+02	2.51E+02	2.77E+02	2.02E+02	8.77E+01	1.22E+01	4.27E+00
Strontium-90	5.25E+01	3.21E+01	2.05E+01	1.32E+01	1.15E+01	8.91E+00	8.27E+00	7.73E+00	8.53E+00	6.20E+00	2.70E+00	3.75E-01	1.31E-01

4 Forecast of environmental impact of possible accidents during operations on retrieval of SNF from the DSU-3A tank and further removal

4.1 Environmental impact of radiation at accidents during retrieval of SNF from the DSU-3A tank and further removal

4.1.1 Drop of the guiding device onto a TUK package in Building 153

When loading canisters with SFAs into TUK-108/1 (TUK-18) casks in room 113, the guiding device falls into the TUK with the lid removed. In the worst case this may lead to damage of three canisters and all SFAs contained in them. Thus, the drop of the guiding device results in a force impact on 21 SFAs. Consequences of the force impact on the SFAs may include formation of SNF spills in the canister and release of volatile radioactive substances from the TUK cask to the room air. Let us set the dust fraction of the SRW to 0.01, 1% of which will pass into aerosol form. The spread of radioactive substances outside the room is prevented by the ventilation system. Room 113 will be provided with general ventilation system. Before being released into the atmosphere, the air is subjected to the single-stage cleaning (the decontamination factor is 0.01) and then discharged into the atmosphere through the 40-m high vent stack. The expected release of radionuclides to the environment at the drop of the guiding device onto TUK 108/1 (TUK-18) casks is shown in Table 33.

Table 33 – Release of radionuclides to the environment, MBq

Nuclide	Release from Building 153, MBq
^{137}Cs	1.62E+01
^{90}Sr	1.43E+01
^{238}Pu	2.31E-01
^{239}Pu	1.87E-02
^{240}Pu	2.10E-02
^{241}Pu	1.22E+00
^{241}Am	6.72E-02

To obtain maximum levels of radiation exposure to the population from the emergency release, there were chosen respective atmospheric stability categories for various distances from the release point, which are presented in Table 34. Table 35 shows expected total doses for all exposure routes at different distances from the point of release resulting from the design basis accident with the drop of the guiding device on the TUK cask and depressurization of three canisters containing 21 submarine SFAs.

Highlighted are values of annual doses for the population of nearby villages. In the village of Nerpichye the dose from the emergency release will be 67.5 nSv, in the village of Bolshaya Lopatka – 71.5 nSv, and in Zaozyorsk – 45.5 nSv. The maximum value of 0.42 μSv will be observed at 300 m from the release point. The obtained values are lower than the level of the minimum significant dose of 10 μSv per year. The levels of contamination of the atmosphere and land surface for this accident are presented in Tables 36 and 37.

Table 34 – Atmospheric stability categories

Category	A	A	A	A	E	F	F	F	F	G	G	G	G
Distance,	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000

Table 35 – Effective dose at different distances from Building 153, nSv

Distance, m	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, nSv	1.72E+01	3.99E+02	4.18E+02	2.33E+02	9.54E+01	6.75E+01	6.99E+01	7.15E+01	6.89E+01	4.55E+01	4.79E+01	1.69E+01	4.84E+00

Table 36 – Time integral of volume activity, Bq/m^3

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	4.51E+01	1.15E+03	1.21E+03	6.76E+02	2.77E+02	1.95E+02	2.03E+02	2.07E+02	2.00E+02	1.31E+02	1.39E+02	4.89E+01	1.38E+01
Strontium-90	3.98E+01	1.02E+03	1.07E+03	5.97E+02	2.44E+02	1.73E+02	1.79E+02	1.83E+02	1.76E+02	1.16E+02	1.22E+02	4.31E+01	1.22E+01
Plutonium-238	6.44E-01	1.65E+01	1.73E+01	9.65E+00	3.95E+00	2.79E+00	2.89E+00	2.96E+00	2.85E+00	1.88E+00	1.98E+00	6.98E-01	1.98E-01
Plutonium-239	5.21E-02	1.33E+00	1.40E+00	7.81E-01	3.20E-01	2.26E-01	2.34E-01	2.39E-01	2.31E-01	1.52E-01	1.60E-01	5.65E-02	1.60E-02
Plutonium-240	5.86E-02	1.50E+00	1.57E+00	8.78E-01	3.59E-01	2.54E-01	2.63E-01	2.69E-01	2.59E-01	1.71E-01	1.80E-01	6.34E-02	1.80E-02
Plutonium-241	3.40E+00	8.70E+01	9.13E+01	5.09E+01	2.08E+01	1.47E+01	1.53E+01	1.56E+01	1.50E+01	9.90E+00	1.04E+01	3.68E+00	1.04E+00
Americium-241	1.87E-01	4.80E+00	5.03E+00	2.81E+00	1.15E+00	8.12E-01	8.42E-01	8.60E-01	8.30E-01	5.46E-01	5.76E-01	2.03E-01	5.75E-02

Table 37 – Fallout density, Bq/m^2

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	5.59E-01	9.34E+00	9.76E+00	5.45E+00	2.23E+00	1.58E+00	1.64E+00	1.67E+00	1.61E+00	1.07E+00	1.12E+00	4.01E-01	1.19E-01
Strontium-90	4.93E-01	8.25E+00	8.62E+00	4.81E+00	1.97E+00	1.40E+00	1.45E+00	1.48E+00	1.42E+00	9.46E-01	9.92E-01	3.54E-01	1.05E-01
Plutonium-238	7.98E-03	1.33E-01	1.39E-01	7.78E-02	3.18E-02	2.26E-02	2.34E-02	2.39E-02	2.30E-02	1.53E-02	1.60E-02	5.73E-03	1.70E-03
Plutonium-239	6.46E-04	1.08E-02	1.13E-02	6.29E-03	2.58E-03	1.83E-03	1.89E-03	1.93E-03	1.86E-03	1.24E-03	1.30E-03	4.64E-04	1.38E-04
Plutonium-240	7.26E-04	1.21E-02	1.27E-02	7.07E-03	2.89E-03	2.05E-03	2.13E-03	2.17E-03	2.09E-03	1.39E-03	1.46E-03	5.21E-04	1.55E-04
Plutonium-241	4.21E-02	7.03E-01	7.35E-01	4.10E-01	1.68E-01	1.19E-01	1.23E-01	1.26E-01	1.21E-01	8.07E-02	8.46E-02	3.02E-02	8.98E-03
Americium-241	2.32E-03	3.88E-02	4.06E-02	2.26E-02	9.26E-03	6.57E-03	6.80E-03	6.94E-03	6.70E-03	4.45E-03	4.67E-03	1.67E-03	4.95E-04

4.1.2 Drop of the guiding device onto a TUK cask in Building 151

For the design basis accident with the drop of the guiding device onto a TUK cask in Building 151, there were considered scenarios with depressurization of the TUK cask, partial destruction of SFAs, and discharge of air from Building 151 by the ventilation system without cleaning through the louvers at the height of 12 meters. The release of radionuclides to the environment at a drop of the guiding device onto a TUK cask is shown in Table 38.

Table 38 – Release of radionuclides to the environment at a drop of the guiding device onto a TUK cask, MBq.

Nuclide	Release from Building 151, MBq
^{137}Cs	5.39E+02
^{90}Sr	4.76E+02
^{238}Pu	7.70E+00
^{239}Pu	6.23E-01
^{240}Pu	7.00E-01
^{241}Pu	4.06E+01
^{241}Am	2.24E+00

Respective atmospheric stability categories for different distances from the release point selected such as to ensure conservatism of the calculations are given in Table 39.

Table 40 shows expected exposure doses to the population as a result of the design basis accident with a drop of the guiding device onto a TUK cask in Building 151.

In the village of Nerpichye the dose from the emergency release will be 18 μSv, in the village of Bolshaya Lopatka – 13 μSv, and in Zaozyorsk – 2.2 μSv. The maximum expected emergency dose at the worst weather conditions will be 0.14 mSv (at 100 m from the release point) for the first year after the accident, which is less than the dose limit for the population of 1 mSv (NRB-99/2009). The levels of contamination of the atmosphere and land surface for this accident are presented in Tables 41 and 42.

Table 39– Atmospheric stability categories for different distances from the release point.

Category	A	A	A	A	F	F	G	G	G	G	G	G	F	F
Distance,	0.05	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0

Table 40 – Effective dose at different distances from Building 151, μSv.

Distance, km	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, μSv	1.42E+02	5.26E+01	3.70E+01	2.73E+01	2.52E+01	1.77E+01	1.58E+01	1.26E+01	9.06E+00	2.18E+00	5.27E-01	1.30E-01	5.47E-02

Table 41 – Time integral of volume activity, Bq/m$^{3.}$

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	4.11E+05	1.52E+05	1.07E+05	7.91E+04	7.32E+04	5.14E+04	4.59E+04	3.66E+04	2.63E+04	6.31E+03	1.52E+03	3.74E+02	1.57E+02
Strontium-90	3.63E+05	1.35E+05	9.47E+04	6.99E+04	6.46E+04	4.54E+04	4.06E+04	3.24E+04	2.32E+04	5.57E+03	1.35E+03	3.30E+02	1.39E+02
Plutonium-238	5.87E+03	2.18E+03	1.53E+03	1.13E+03	1.05E+03	7.34E+02	6.56E+02	5.23E+02	3.75E+02	9.02E+01	2.18E+01	5.34E+00	2.24E+00
Plutonium-239	4.75E+02	1.76E+02	1.24E+02	9.15E+01	8.46E+01	5.94E+01	5.31E+01	4.23E+01	3.04E+01	7.29E+00	1.76E+00	4.32E-01	1.82E-01
Plutonium-240	5.34E+02	1.98E+02	1.39E+02	1.03E+02	9.51E+01	6.67E+01	5.96E+01	4.76E+01	3.41E+01	8.20E+00	1.98E+00	4.86E-01	2.04E-01
Plutonium-241	3.10E+04	1.15E+04	8.08E+03	5.96E+03	5.51E+03	3.87E+03	3.46E+03	2.76E+03	1.98E+03	4.75E+02	1.15E+02	2.82E+01	1.18E+01
Americium-241	1.71E+03	6.34E+02	4.46E+02	3.29E+02	3.04E+02	2.13E+02	1.91E+02	1.52E+02	1.09E+02	2.62E+01	6.33E+00	1.55E+00	6.53E-01

Table 42 – Fallout density, Bq/m^2.

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	3.30E+03	1.22E+03	8.60E+02	6.35E+02	5.87E+02	4.12E+02	3.69E+02	2.94E+02	2.11E+02	5.11E+01	1.24E+01	3.15E+00	1.33E+00
Strontium-90	2.91E+03	1.08E+03	7.60E+02	5.60E+02	5.19E+02	3.64E+02	3.25E+02	2.60E+02	1.86E+02	4.51E+01	1.10E+01	2.79E+00	1.17E+00
Plutonium-238	4.71E+01	1.75E+01	1.23E+01	9.06E+00	8.39E+00	5.89E+00	5.27E+00	4.20E+00	3.02E+00	7.30E-01	1.77E-01	4.51E-02	1.90E-02
Plutonium-239	3.81E+00	1.41E+00	9.94E-01	7.33E-01	6.79E-01	4.76E-01	4.26E-01	3.40E-01	2.44E-01	5.91E-02	1.44E-02	3.65E-03	1.53E-03
Plutonium-240	4.28E+00	1.59E+00	1.12E+00	8.24E-01	7.63E-01	5.35E-01	4.79E-01	3.82E-01	2.74E-01	6.64E-02	1.61E-02	4.10E-03	1.72E-03
Plutonium-241	2.48E+02	9.21E+01	6.48E+01	4.78E+01	4.42E+01	3.10E+01	2.78E+01	2.22E+01	1.59E+01	3.85E+00	9.35E-01	2.38E-01	1.00E-01
Americium-241	1.37E+01	5.08E+00	3.57E+00	2.64E+00	2.44E+00	1.71E+00	1.53E+00	1.22E+00	8.77E-01	2.12E-01	5.16E-02	1.31E-02	5.52E-03

4.1.3 Fire affecting a TUK-108/1 (TUK-18) package

As a design basis accident, there is considered a fire of a vehicle with a TUK-108/1 (TUK-18) cask containing SFAs during transportation from Building 153 to Building 151 and to the berth. The calculations were performed for a scenario with the TUK-108/1 (TUK-18) package staying in the fire for 1 hour. As a result of actions taken by the personnel, the fire is extinguished. After that the package cools down for 3 hours. During the fire the heated air rises to a height of about 50 m due to the action of aerodynamic forces. A conservative estimate of the release of radionuclides to the environment at such a fire is given in Table 43.

Table 43 – Release of radionuclides to the environment, MBq.

Nuclide	Release from Building 151, MBq
^{137}Cs	7.15E+02
^{90}Sr	1.08E+02
^{238}Pu	1.31E+00
^{239}Pu	1.06E-01
^{240}Pu	1.19E-01
^{241}Pu	6.92E+00
^{241}Am	3.82E-01

Respective atmospheric stability categories for different distances from the release point selected such as to ensure conservatism of the calculations are given in Table 44.

Table 45 shows expected exposure doses to the population as a result of the design basis accident with the fire affecting the TUK-18 cask. In the village of Nerpichye the dose from the emergency release will be 2.4 μSv, in the village of Bolshaya Lopatka – 5.3 μSv, and in Zaozyorsk – 4.6 μSv. The maximum expected emergency dose will be 35 μSv (at 200 m from the release point) for the first year after the accident, which is less than the dose limit for the population of 1 mSv (NRB-99/2009). The levels of contamination of the atmosphere and land surface for this accident are presented in Tables 46 and 47.

The radiation impact of possible design basis accidents during the SNF retrieval operations does not exceed the basic dose limits for personnel and population established by regulatory documents. The impact on the environment is minimal.

Table 44 – Atmospheric stability categories for different distances from the release point

Category	A	A	A	A	A	A	A	E	F	F	G	G	G
Distance, km	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0

Table 45 – Effective dose at different distances from the accident site, μSv

Distance, km	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, μSv	3.50E+01	2.51E+01	8.47E+00	2.87E+00	2.36E+00	5.16E+00	5.25E+00	4.57E+00	3.54E+00	2.48E+00	1.02E+00	6.96E-01

Table 46 – Time integral of volume activity, Bq/m^3

Radionuclide	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
Cesium-137	6.16E+02	2.13E+05	3.64E+05	2.61E+05	8.79E+04	2.96E+04	2.43E+04	5.37E+04	5.44E+04	4.75E+04	3.66E+04	2.56E+04	1.04E+04
Strontium-90	9.33E+01	3.22E+04	5.50E+04	3.95E+04	1.33E+04	4.49E+03	3.68E+03	8.13E+03	8.24E+03	7.20E+03	5.53E+03	3.88E+03	1.57E+03
Plutonium-238	1.13E+00	3.91E+02	6.68E+02	4.80E+02	1.61E+02	5.44E+01	4.46E+01	9.87E+01	1.00E+02	8.73E+01	6.71E+01	4.70E+01	1.91E+01
Plutonium-239	9.15E-02	3.16E+01	5.40E+01	3.88E+01	1.31E+01	4.40E+00	3.61E+00	7.98E+00	8.09E+00	7.06E+00	5.43E+00	3.80E+00	1.54E+00
Plutonium-240	1.03E-01	3.55E+01	6.07E+01	4.36E+01	1.47E+01	4.95E+00	4.06E+00	8.97E+00	9.09E+00	7.94E+00	6.10E+00	4.28E+00	1.73E+00
Plutonium-241	5.97E+00	2.06E+03	3.52E+03	2.53E+03	8.51E+02	2.87E+02	2.35E+02	5.20E+02	5.27E+02	4.60E+02	3.54E+02	2.48E+02	1.00E+02
Americium-241	3.29E-01	1.14E+02	1.94E+02	1.40E+02	4.69E+01	1.58E+01	1.30E+01	2.87E+01	2.91E+01	2.54E+01	1.95E+01	1.37E+01	5.54E+00

Table 47 – Fallout density, Bq/m²

Radionuclide	100	200	300	500	1000	1800	2000	2400	3000	6000	10000	20000	30000
Cesium-137	9.24E+01	1.75E+03	2.94E+03	2.11E+03	7.12E+02	2.42E+02	1.99E+02	4.34E+02	4.41E+02	3.84E+02	2.99E+02	2.09E+02	8.67E+01
Strontium-90	1.40E+01	2.64E+02	4.45E+02	3.19E+02	1.08E+02	3.67E+01	3.01E+01	6.56E+01	6.68E+01	5.82E+01	4.53E+01	3.17E+01	1.31E+01
Plutonium-238	1.70E-01	3.21E+00	5.40E+00	3.87E+00	1.31E+00	4.45E-01	3.66E-01	7.96E-01	8.11E-01	7.06E-01	5.49E-01	3.85E-01	1.59E-01
Plutonium-239	1.37E-02	2.60E-01	4.37E-01	3.13E-01	1.06E-01	3.60E-02	2.96E-02	6.44E-02	6.56E-02	5.71E-02	4.44E-02	3.11E-02	1.29E-02
Plutonium-240	1.54E-02	2.92E-01	4.91E-01	3.52E-01	1.19E-01	4.05E-02	3.32E-02	7.24E-02	7.37E-02	6.42E-02	4.99E-02	3.50E-02	1.45E-02
Plutonium-241	8.95E-01	1.69E+01	2.85E+01	2.04E+01	6.89E+00	2.35E+00	1.93E+00	4.20E+00	4.27E+00	3.72E+00	2.90E+00	2.03E+00	8.40E-01
Americium-241	4.94E-02	9.34E-01	1.57E+00	1.13E+00	3.80E-01	1.29E-01	1.06E-01	2.32E-01	2.36E-01	2.05E-01	1.60E-01	1.12E-01	4.63E-02

4.2 Consequences of beyond design basis accidents

The following two scenarios were considered as beyond design basis accidents with the worst radiation consequences for the population:

a. an aircraft (A/C) crash on a TUK-108/1 (TUK-18) cask being loaded with canisters containing SFAs in the handling hall (room 113) of Building 153.
b. fall of heavy process equipment (cranes and their components) and building structures onto a TUK-108/1 (TUK-18) cask in Building 151 as a result of natural and man-induced impacts.

4.2.1 Accident with an A/C crash into Building 153

The following takes place at an A/C crash:

a. partial destruction of the Building 153 roof.
b. fuel getting into the loaded TUK cask and fire.
c. heating and loss of sealing of SFAs in the TUK cask (49 SFAs).
d. release of radionuclides to the atmosphere.

Release of radionuclides from SFAs in case of fire can be estimated by way of comparison with the Chernobyl accident. In Chernobyl, burning of fire lasted 12 days. The dynamics of the release of radioactive substances from the damaged reactor of the Chernobyl NPP showed that the values of daily releases were approximately equal during the first 12 days. The release in the first 24 hours was formed by the energy of the thermal explosion and fire with graphite burning, while releases in the next 11 days were only due to a fire. According to domestic data, the relative values in the total release are as follows: (10-14)% for $^{134, 137}$Cs; 4% for ^{90}Sr and 3% for Pu(α). Assuming that the fire will last about 6 hours after the A/C crash, the release of radionuclides as a result of such an accident can be conservatively taken as 0.02 % for ^{137}Cs, 0.007% for ^{90}Sr and 0.005% for ^{241}Am and Pu (^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Pu) (due to the storage for a long time, SFAs do not contain radioactive gases).

The expected release of radionuclides to the environment at an A/C crash on Building 153 is given in Table 48.

Table 48 – Release of radionuclides to the environment at an A/C crash into Building 153, MBq

Nuclide	Release from Building 153, MBq
^{137}Cs	8.58E+05
^{90}Sr	1.30E+05
^{238}Pu	1.58E+03
^{239}Pu	1.27E+02
^{240}Pu	1.43E+02
^{241}Pu	8.30E+03
^{241}Am	4.58E+02

Atmospheric stability categories for different distances from the release point selected such as to ensure conservatism of the calculations are given in Table 49.

Table 50 shows expected values of exposure doses to the population as a result of the beyond design basis accident with an A/C crash onto Building 153. In the village of Nerpichye the dose from the emergency release will be 2.3 mSv, in the village of Bolshaya Lopatka – 2 mSv, and in Zaozyorsk – 1.6 mSv. The maximum expected emergency dose will be 16.3 mSv (at 50 m from the release point), which is lower than the dose limit for Group A personnel (20 mSv in a year as per NRB-99/2009), but higher than dose limits for the population and on-site personnel of Group B. According to NRB-99/2009, level A of the criterion for making a decision on limitation of consumption of contaminated food and drinking water (5 mSv per year) is not exceeded, and certainly this is true for level A of the criterion for making a decision on resettlement (50 mSv per year). If the exposure level prevented by a protective measure does not exceed level A, then there is no need to take protective measures associated with disruption of the normal life of the population, as well as the economic and social functioning of territories of the nearby localities of Nerpichye, Bolshaya Lopatka and Zaozyorsk. The levels of contamination of atmosphere and surface due to an A/C crash on Building 153 are presented in Tables 51 and 52.

The radiation impact of the beyond design basis accident during the SNF retrieval operations will not require implementing protective measures associated with disruption of the normal life of the population, as well as the economic and social functioning of territories of the nearby localities. The impact on the environment and ecosystem of the region will not lead to its change.

Table 49 – Atmospheric stability categories for different distances from the release point.

Category	A	A	A	E	F	F	F	G	G	G	G	G	F	E
Distance, km	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0	40.0

Table 50 – Effective dose at different distances from Building 153, mSv

Distance ,km	0.05	0.1	0.2	0.3	0.5	1.0	1.8	2.4	3.0	6.0	10.0	20.0	30.0	40.0
Dose, mSv	1.63E+01	1.34E+01	8.20	5.25	3.37	2.95	2.28	1.97	2.18	1.58	6.87E-01	9.34E-02	3.27E-02	1.64E-02

Table 51 – Time integral of volume activity, Bq/m^3

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.4	3.0	6.0	10.0	20.0	30.0	40.0
Cesium-137	1.40E+08	8.55E+07	5.47E+07	3.51E+07	3.08E+07	2.38E+07	2.21E+07	2.05E+07	2.27E+07	1.65E+07	7.13E+06	9.36E+05	3.26E+05
Strontium-90	2.12E+07	1.29E+07	8.28E+06	5.32E+06	4.66E+06	3.60E+06	3.34E+06	3.11E+06	3.43E+06	2.50E+06	1.08E+06	1.42E+05	4.94E+04
Plutonium-238	2.57E+05	1.57E+05	1.00E+05	6.45E+04	5.65E+04	4.36E+04	4.05E+04	3.77E+04	4.17E+04	3.03E+04	1.31E+04	1.72E+03	5.99E+02
Plutonium-239	2.08E+04	1.27E+04	8.13E+03	5.22E+03	4.57E+03	3.53E+03	3.28E+03	3.05E+03	3.37E+03	2.45E+03	1.06E+03	1.39E+02	4.85E+01
Plutonium-240	2.34E+04	1.43E+04	9.14E+03	5.86E+03	5.14E+03	3.97E+03	3.68E+03	3.43E+03	3.79E+03	2.75E+03	1.19E+03	1.56E+02	5.44E+01
Plutonium-241	1.36E+06	8.28E+05	5.30E+05	3.40E+05	2.98E+05	2.30E+05	2.14E+05	1.99E+05	2.20E+05	1.60E+05	6.91E+04	9.06E+03	3.16E+03
Americium-241	7.49E+04	4.57E+04	2.92E+04	1.88E+04	1.64E+04	1.27E+04	1.18E+04	1.10E+04	1.21E+04	8.82E+03	3.81E+03	5.00E+02	1.74E+02

Table 52 – Fallout density, Bq/m²

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.4	3.0	6.0	10.0	20.0	30.0	40.0
Cesium-137	1.13E+06	6.87E+05	4.40E+05	2.82E+05	2.47E+05	1.91E+05	1.66E+05	1.83E+05	1.33E+05	5.78E+04	8.03E+03	2.82E+03	1.41E+03
Strontium-90	1.70E+05	1.04E+05	6.66E+04	4.27E+04	3.75E+04	2.89E+04	2.51E+04	2.77E+04	2.01E+04	8.75E+03	1.22E+03	4.27E+02	2.13E+02
Plutonium-238	2.07E+03	1.26E+03	8.08E+02	5.18E+02	4.55E+02	3.51E+02	3.04E+02	3.36E+02	2.44E+02	1.06E+02	1.48E+01	5.18E+00	2.59E+00
Plutonium-239	1.67E+02	1.02E+02	6.54E+01	4.19E+01	3.68E+01	2.84E+01	2.46E+01	2.72E+01	1.98E+01	8.59E+00	1.19E+00	4.19E-01	2.10E-01
Plutonium-240	1.88E+02	1.15E+02	7.35E+01	4.71E+01	4.13E+01	3.19E+01	2.77E+01	3.05E+01	2.22E+01	9.66E+00	1.34E+00	4.71E-01	2.35E-01
Plutonium-241	1.09E+04	6.66E+03	4.26E+03	2.73E+03	2.40E+03	1.85E+03	1.60E+03	1.77E+03	1.29E+03	5.60E+02	7.78E+01	2.73E+01	1.37E+01
Americium-241	6.02E+02	3.67E+02	2.35E+02	1.51E+02	1.32E+02	1.02E+02	8.85E+01	9.77E+01	7.11E+01	3.09E+01	4.29E+00	1.51E+00	7.53E-01

4.2.2 Accident with a fall of process equipment onto the TUK-108/1 (TUK-18) package in Building 151

A fall of heavy process equipment (cranes and their components) and building structures onto a TUK-108/1 (TUK-18) package in Building 151 may occur due to natural and man-induced impacts. In the worst case in terms of radiation consequences this may lead to destruction of the package and 49 SFAs contained in it.

The release of radionuclides to the environment at a fall of process equipment onto a TUK-108/1 (TUK-18) package in Building 151 is presented in Table 53

Table 53 – Release of radionuclides to the environment at a fall of process equipment onto a TUK-108/1 (TUK-18) package in Building 151, MBq

Nuclide	Release from Building151, MBq
^{137}Cs	3.77E+03
^{90}Sr	3.33E+03
^{238}Pu	5.39E+01
^{239}Pu	4.36E+00
^{240}Pu	4.90E+00
^{241}Pu	2.84E+02
^{241}Am	1.57E+01

The release occurs at the level of the building roof. Atmospheric stability categories for various distances from the release point shows expected exposure doses to the population as a result of the beyond design basis accident with a fall of equipment in Building 151.

Effective dose at different distances from the release site are presented in Table 54. In the village of Nerpichye the dose from the emergency release will be 0.12 mSv, in the village of Bolshaya Lopatka – 0.09 mSv, and in Zaozyorsk – 15 μSv. The maximum expected emergency dose at the worst weather conditions will be 0.99 mSv (at 100 m from the release point) for the first year after the accident, i.e. it will be at the level of the limit dose for the population of 1 mSv per year (NRB-99/2009). The levels of contamination of atmosphere and land surface for this accident are presented in Tables 55 and 56.

Table 54 – Effective dose at different distances from Building 151, μSv

Distance, km	0.1	0.20	0.30	0.50	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Dose, μSv	9.92E+02	3.68E+02	2.59E+02	1.91E+02	1.77E+02	1.24E+02	1.11E+02	8.84E+01	6.34E+01	1.53E+01	3.69E+00	9.11E-01	3.83E-01

Table 55 – Time integral of volume activity, Bq/m^3

Radionuclide	0.1	0.20	0.30	0.50	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	2.88E+06	1.07E+06	7.51E+05	5.54E+05	5.12E+05	3.60E+05	3.22E+05	2.56E+05	1.84E+05	4.42E+04	1.07E+04	2.62E+03	1.10E+03
Strontium-90	2.54E+06	9.43E+05	6.63E+05	4.89E+05	4.53E+05	3.18E+05	2.84E+05	2.26E+05	1.62E+05	3.90E+04	9.42E+03	2.31E+03	9.71E+02
Plutonium-238	4.11E+04	1.52E+04	1.07E+04	7.91E+03	7.32E+03	5.14E+03	4.59E+03	3.66E+03	2.63E+03	6.31E+02	1.52E+02	3.74E+01	1.57E+01
Plutonium-239	3.33E+03	1.23E+03	8.68E+02	6.40E+02	5.92E+02	4.16E+02	3.72E+02	2.96E+02	2.13E+02	5.11E+01	1.23E+01	3.03E+00	1.27E+00
Plutonium-240	3.74E+03	1.39E+03	9.75E+02	7.20E+02	6.66E+02	4.67E+02	4.18E+02	3.33E+02	2.39E+02	5.74E+01	1.38E+01	3.40E+00	1.43E+00
Plutonium-241	2.17E+05	8.04E+04	5.66E+04	4.17E+04	3.86E+04	2.71E+04	2.42E+04	1.93E+04	1.39E+04	3.33E+03	8.03E+02	1.97E+02	8.29E+01
Americium-241	1.20E+04	4.44E+03	3.12E+03	2.30E+03	2.13E+03	1.49E+03	1.34E+03	1.07E+03	7.64E+02	1.84E+02	4.43E+01	1.09E+01	4.57E+00

Table 56 – Fallout density, Bq/m^2

Radionuclide	0.1	0.20	0.30	0.50	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0
Cesium-137	2.31E+04	8.56E+03	6.02E+03	4.44E+03	4.11E+03	2.88E+03	2.58E+03	2.06E+03	1.48E+03	3.58E+02	8.69E+01	2.21E+01	9.29E+00
Strontium-90	2.04E+04	7.56E+03	5.32E+03	3.92E+03	3.63E+03	2.55E+03	2.28E+03	1.82E+03	1.31E+03	3.16E+02	7.68E+01	1.95E+01	8.21E+00
Plutonium-238	3.30E+02	1.22E+02	8.60E+01	6.35E+01	5.87E+01	4.12E+01	3.69E+01	2.94E+01	2.11E+01	5.11E+00	1.24E+00	3.15E-01	1.33E-01
Plutonium-239	2.67E+01	9.90E+00	6.96E+00	5.13E+00	4.75E+00	3.33E+00	2.98E+00	2.38E+00	1.71E+00	4.14E-01	1.00E-01	2.55E-02	1.07E-02
Plutonium-240	3.00E+01	1.11E+01	7.82E+00	5.77E+00	5.34E+00	3.75E+00	3.35E+00	2.67E+00	1.92E+00	4.65E-01	1.13E-01	2.87E-02	1.21E-02
Plutonium-241	1.74E+03	6.45E+02	4.54E+02	3.35E+02	3.10E+02	2.17E+02	1.94E+02	1.55E+02	1.11E+02	2.70E+01	6.55E+00	1.66E+00	7.00E-01
Americium-241	9.59E+01	3.56E+01	2.50E+01	1.85E+01	1.71E+01	1.20E+01	1.07E+01	8.56E+00	6.14E+00	1.49E+00	3.61E-01	9.18E-02	3.86E-02

5 Environment protection measures at the Andreeva Bay SNF and RW TSF site

5.1 Measures for prevention and/or mitigation of possible negative impact of the planned activities on the environment and population

Measures to prevent negative impact on the environment and population during the preparation of the DSU-3A tank for retrieval of SFAs and further handling are as follows:

a. assurance of nuclear and radiation safety during preparatory works, retrieval of SFAs, their transportation in TUK casks to the berth and loading onto the ship.
b. prevention of the spread of radioactive substances into process areas of buildings and into the environment.
c. application of ALARA principles (as low radiation exposure of personnel, population and environment as technically achievable and economically reasonable).
d. the use of a system physical barriers to the spread of ionizing radiation and radioactive substances into the environment (the defense-in-depth principle).
e. application of various control measures.
f. optimization of handling, transport, and transfer operations during the management of the SNF and arising RW.
g. minimization of generation of secondary RW.
h. ensuring physical protection at all stages of SNF management; accounting and control of nuclear materials and radioactive substances at all stages of SNF and RW management.

5.2 Atmospheric air protection measures

The following measures are envisaged for minimization of radiation and chemical impact on the atmospheric air during preparatory, dismantling, and SNF retrieval and transportation operations:

a. the use of the highly efficient three-stage system for cleaning the exhaust air contaminated with radioactive aerosols.
b. ensuring the dispersion of radioactive releases in the atmosphere: the use of the 40-m high vent stack prevents the exhaust air from getting into the air shadow of the building, and also ensures a reduction in the dose load on the population from exposure to a possible release of radioactive substances to values several orders of magnitude below the dose limit for the population prescribed by NRB-99;
c. control over exact observance of the Operating Procedure.
d. health monitoring of process equipment and filtration systems being used with timely repair and replacement of equipment.
e. the use of the vacuum debris collection system for dust reduction in the working area.
f. the use of electric construction mechanisms and tools that do not pollute the atmospheric air while maintaining the functionality and power capacity of the units.
g. strict adherence to instructions for handling radioactive substances.

h. prohibition of incineration of generated waste on the site.
i. the use of special and construction equipment with minimum pollution of the atmospheric air without deterioration of functional capacities of the units.
j. development of an environmental monitoring program for the duration of the works.
k. prohibition of work during unfavorable meteorological conditions.
l. timely removal of wastes from the site.
m. monitoring of the natural environment.

5.3 Surface water and groundwater protection measures

The following recommendations and measures should be observed in order to prevent contamination of surface and ground waters when performing the works:

a. discharge of wastewater to the Andreeva Bay of the Zapadnaya Litsa Bay of the Motovsky Gulf in the Barents Sea on the basis of the Decision on Granting the Water Body for Use No. 00-02.01.00.006-M-RSVH-T-2018-02115/00 of 27.06.2018 issued by the Dvinsko-Pechersky Basin Water Directorate for the period until 31.12.2022.
b. observance of established allowable levels of discharge of substances through the organized wastewater outlet No.1 after the sewage treatment units of the Andreeva Bay SNF and RW TSF site to the Andreeva Bay of the Zapadnaya Litsa Bay of the Motovsky Gulf in the Barents Sea.
c. ensuring quality control of wastewater discharge into the surface water body – Andreeva Bay of the Zapadnaya Litsa Bay of the Motovsky Gulf in the Barents Sea – at the outlet of treatment units UKOS-BIO-F-20.
d. control of operating efficiency of UKOS-BIO-F-20 treatment units for household wastewaters and industrial wastewaters of similar composition discharged into the surface water body – Andreeva Bay of the Zapadnaya Litsa Bay of the Motovsky Gulf in the Barents Sea.
e. control of radioactive contamination of wastewater after decontamination of vehicles; in case when the specified standards (control levels) are exceeded, the wastewater shall be pumped into a special road tanker and further removed onboard the Serebryanka ship for processing.
f. collection of wastewaters from cleaning of zone II rooms, from the TUK decontamination area, SRW container decontamination area in a drainage pit with its further pumping into a special road tanker and removal onboard the Serebryanka ship for processing.
g. control of groundwater pollution and level with water sampling from observation boreholes around Building 153.
h. prevention of the spillage of waste liquids on soil and subsoil and of wastewater discharges onto the terrain.
i. equipment of a special place for storage of the generated waste in conditions that exclude contacts of the stored waste with ground and surface waters, timely removal of waste.
j. the use of paved roads for machinery.
k. regular cleaning of the site with maximum mechanization of the cleaning work.
l. monitoring of the sewage working state, prohibition to use failed systems.
m. mandatory visual control over the state of the natural environment.

5.4 Mitigation measures for impact on the soil, flora, and fauna

The protection of soil, flora and fauna will in the first place consist in compliance with the environmental legislation, and minimization of impact on the atmospheric air, soli, surface and ground waters, which will indirectly reduce the level of impact of the facility on the surrounding biota.

For the duration of the works, the following measures are envisaged to prevent pollution of the soil:

a. conducting the works strictly within the allotted land boundaries.
b. the use of vehicles that are in good technical condition, which excludes leaks from fuel equipment.
c. organization of traffic only on existing driveways or roads or those specially organized for the period of dismantling operations.
d. collection of generated wastes in specially designated areas and their further timely removal to authorized sites for recycling or final disposal.
e. regular cleaning of construction debris.
f. The following measures are recommended to prevent the death of objects of the animal world (living in conditions of natural freedom) due to changes in the habitat.
g. prevent destruction or deterioration of the habitat of wildlife objects.
h. prohibit burning of vegetation.
i. prohibit the use of chemical reagents without taking measures to ensure the prevention of deterioration of the habitat.

5.5 Mitigation measures for environmental impact of generated radioactive waste, production and consumption waste

Measures to minimize the environmental impact of radioactive waste, production and consumption waste during performance of the works include:

a. availability of the sanitary and epidemiological conclusion on the compliance of working conditions when handling solid radioactive waste, liquid radioactive waste and conducting radiation situation monitoring at the RW storage area with sanitary rules, No. SEZ- 51.SN.34.000.M.000050.12.16 (valid unit 01.12.2021);
b. availability of the operating RW management complex at the Andreeva Bay SNF and RW TSF.
c. availability of the enclosure building over the existing storage tanks and SRW storage areas designed to protect the SRW from atmospheric precipitation, ensure safe retrieval of SRW from storage places throughout a year, and minimize the release of radioactive substances into the environment.
d. collection of RW in points of origin and transportation to the complex for further management of the RW.
e. preparation of accumulated SRW in accordance of acceptance criteria and removal to the Saida Bay CCLS RW for conditioning and placement in storage until final disposal.
f. strict adherence to the "Instructions for the management of liquid and solid radioactive waste" in force on the territory of the enterprise.
g. provision of a specially designated area at the construction site for accumulation of construction debris.
h. availability of contracts with specialized licensed organizations for the removal of construction debris household waste, scrap of ferrous metals, transfer of materials for recycling, treatment of wastewater.
i. selective collection of wastes, adherence to the rules for organizing waste accumulation areas.

j. accounting of the movement of wastes and control of frequency of their removal.
k. development of an environmental control program for the management of construction debris.
l. mandatory visual control over the state of the natural environment.

6 Information about the quantity and condition of radioactive materials to be removed, SNF handling methods during retrieval, evaluation of possible accident scenarios, radiation doses to the population, biota (flora and fauna), and description of ways of avoiding the accidents

Assessment of types, characteristics and quantities of SRW produced in the DSU-3A tank during preparations for retrieval and in the course of retrieval of SFAs shows that there will be large quantities of SRW (LLW and ILW). SRW (ILW) generated mostly during dismantling of concrete structures and other parts of the DSU-3A tank at the stage of preparatory works before the retrieval of SNF will be the main sources of suspended dust and radionuclide aerosols. The volume of SRW (ILW) anticipated at this stage is about 70 m^3. The total estimated volume of SRW (ILW) at the DSU-3A preparation and SNF retrieval stages will be about 160 m^3.The estimate presented earlier shows that the volume of LRW removed from the DSU-3A tank cells and canisters is ~ 145 m^3. Water samples taken from the tank cells in 2004 show that the water is mostly LRW (ILW), the activity of which in certain cells is in the range from 10^7 to 10^9 Bq/l. The specific activity of water on the surface is almost completely defined by ^{137}Cs. An increase of specific activity for ^{137}Cs and especially for ^{90}Sr with increasing depth is observed for all cells. Alpha-emitters were found. This strongly indicates that there is contact between the fuel and water, and not just fission products but actinoids (^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, ^{235}U) as well pass into the water. There are no reliable data on characteristic of LRW inside the canisters, since surveys that would involve opening of canisters in the DSU-3A cells and taking water samples from them were not conducted. Based on the available data we can assume that radionuclide composition of LRW in the canisters will be close to that of water in the cells, but the specific activity may be significantly higher due to the development of corrosion cracking of the material of the outer cladding of fuel elements. Thus, the expected specific activity of water in canisters, which directly contacts the fuel composition through leaks in the fuel element cladding, may reach $7.4 \cdot 10^{10}$ Bq/l.

LRW removed from the DSU-3A tank cells and canisters are subject to mechanical cleaning from corrosion products and possible spills of the fuel composition, and to cleaning from radionuclides with the modular water removal plant filters for reduction of activity to the level of low-level waste. Low-level LRW will be transferred to accumulation tanks and further to the Serebryanka ship for removal for processing. Air removed from the space under the horizontal shielding, storage cells and canisters at the DSU-3A tank undergoes three-stage cleaning in filters of the filtering and ventilation unit being part of the handling machine, and is supplied via a system of flexible ducts to a general ventilation system where it undergoes an additional single-stage cleaning before discharge into the atmosphere through the 40-m high vent stack. In Building 153 all gaseous waste and the air removed by general ventilation systems from zone II rooms after cleaning on filters is emitted into the atmosphere through a high vent stack. The selected height of the stack (40 m) prevents the exhaust air from getting into the air shadow of the building, and also provides a reduction in the volume activity of radioactive substances at the plume landing site to levels that ensure that the permissible exposure limits are not exceeded.

6.1 About SNF handling methods during retrieval

The design documentation for retrieval of SNF from the cells of storage tanks DSU-2A, 2B and 3A substantiates channel-by-channel retrieval of individual SFAs from canisters located in DSU-3A cells in such a manner as to ensure nuclear, radiation and environmental safety [9, 10, 11, 19, 27]. The method of retrieving SFAs by canisters was considered, but it proved to be less preferred compared to the channel-by-channel retrieval. Main disadvantages of retrieval by canisters are described in Section 12.

The chosen channel-by-channel method of retrieving SFAs from the DSU-3A storage tank cells includes a number of steps:

a. retrieval of intact SFAs from intact canisters located in the tank.
b. retrieval of intact SFAs from defective canisters.
c. retrieval of defective SFAs from the remaining canisters in the tank.
d. retrieval of withdrawable canisters with stuck SFAs from the tank.

The process operations of retrieval of SFAs from the storage cells will be performed remotely by the handling machine using special equipment and devices installed on the HM. To date, about 5,000 SFAs have been retrieved from the DSU-2A tank storage cells.

6.2 Evaluation of possible accident scenarios, possible emissions resulting from the accidents, and radiation exposure of the population

The following events were used as initiating events for consideration and analysis of design basis accidents:

a. External impacts of natural origin, characteristic of the area where the Andreeva Bay SNF and RW TSF is located (seismic impact with intensity up to 7 points on the MSK-64 scale, floods, hurricanes, lightning strike, etc.).
b. Air blast caused by an explosion at the facility.
c. Complete power loss.
d. Fire at the facility or of the vehicle transporting a TUK cask with SFAs within the site. Drop of an SFA, a canister with SFAs, transfer containers or a TUK-108/1 (TUK-18) cask during handling and transport operations.
e. Failures of equipment of SFA storage handling systems.
f. Human errors.

The list of initiating events for consideration and analysis of beyond design basis accidents:

a. Emergence of SSCR for various reasons.
b. Fall of process equipment (cranes) and building structures on the covering of SNF storage compartments.
c. Crash of a light aircraft.
d. Air blast caused by an explosion at a nearby facility, passing transport, etc.

Accidents with the worst radiation consequences for the population were identified based on the detailed analysis of the above initiating events, accident development scenarios and consequences, and assessment of the levels of man-made impact at all stages of handling SFAs from the DSU-3A tank. Assessments of consequences of design basis and beyond design basis accidents presented in Sections 7 and 8 have shown that the environmental impact of radiation from possible accidents during preparation of the DSU-3A tank for retrieval of SNF is negligible. So, in the village of Nerpichye the dose from the emergency release will be 2.1 μSv, in the village of

Bolshaya Lopatka – 1.8 μSv, and in Zaozyorsk – 1.5 μSv, which is lower than the minimum significant dose level of 10 μSv per year.

Exposure doses for the population outside the SPZ of the Andreeva Bay SNF and RW TSF for the maximum design basis accident (fall of process equipment on a TUK 108/1(TUK-18) package containing SFAs) do not exceed the dose limit for the population of 1 mSv per year specified in NRB-99/2009. In the village of Nerpichye the dose from the emergency release will be 18 μSv, in the village of Bolshaya Lopatka –13 μSv, and in Zaozyorsk – 2.2 μSv.

Exposure doses for the population outside the SPZ of the Andreeva Bay SNF and RW TSF for the maximum beyond design basis accident (aircraft crash on a TUK 108/1 or TUK-18 package containing SFAs) during the first year will be very close to 5 mSv. In the village of Nerpichye the effective dose for the population from the emergency release will be 2.3 mSv, in the village of Bolshaya Lopatka – 2 mSv, and in Zaozyorsk – 1.6 mSv.

According to NRB-99/2009, level A of the criterion for making a decision on limitation of consumption of contaminated food and drinking water (5 mSv per year) is not exceeded, and certainly this is true for level A of the criterion for making a decision on resettlement (50 mSv per year). If the exposure level prevented by a protective measure does not exceed level A, then there is no need to take protective measures associated with disruption of the normal life of the population, as well as of the economic and social functioning of the territory.

Release of aerosols contaminated with radionuclides outside the DSU-3A tank is unlikely in the event of a fire at the facility or on-site vehicles during preparations for retrieval of SFAs. The most fire-hazardous operation when handling SNF during retrieval and transportation of SFAs is the transport of packaging is transportation of a TUK-108/1 (TUK-18) package by a special vehicle from Building 153 to Building 151. Failure of the special vehicle elements may become a fire source. Table 45 gives the estimated release of radionuclides to the environment. The maximum expected emergency exposure dose will be 35 μSv (at 200 m from the release point) for the first year after the accident, which is less than the dose limit for the population of 1 mSv (NRB-99/2009). To minimize the time of a fire from a burning vehicle, the vehicle shall be filled with fuel per trip.

6.3 Estimation of dose rates for the biota (flora and fauna)

Let us consider the radiation load on aquatic ecosystems formed under the influence of natural radionuclides. As a rule, the following natural radionuclides have the highest values of average specific activity in the waters of the World Ocean: ^{40}K – 12 Bq/kg; ^{87}Rb – 0.14 Bq/kg; ^{14}C – 0.52 Bq/kg; ^{234}U – 0.037 Bq/kg; ^{210}Po – 0.002 Bq/kg; ^{226}Ra – 0.001 Bq/kg [28]. The first three of the listed radionuclides are β-active, and the last three are α-active. The total β-activity of seawater is almost completely defined by ^{40}K, and α-activity – by two natural radionuclides: ^{210}Po and ^{226}Ra, with the characteristic α-activity of seawater being about 2 orders of magnitude less than β-activity. Among γ-emitters in seawater, ^{40}K makes the greatest contribution; against its background, the fraction of U and Th isotopes is negligible. Specific activity of 40K in the marine environment directly depends on the degree of the water salinity and usually varies within the range from 9 to 13 Bq/l.

There may be roughly identified three sources of radiation exposure of aquatic organisms from natural or man-made radionuclides:

a. Radionuclides incorporated in a hydrobiont organism, which form a source of internal radiation.

b. Radionuclides dissolved or suspended in surrounding aquatic environment, which in fact represent an infinite volume radiation source with a uniform (in the first approximation) activity distribution density.
c. Radionuclides contained in bottom sediments, which can be represented as a volume semi-infinite radiation source with a uniform or variable (depending on the approximation used) activity distribution density.

Tables 57 – 59 give estimated contributions of incorporated natural radionuclides, radionuclides dissolved in water and contained in bottom sediments.

The procedure recommended by IAEA [29] was used hereinafter for evaluation of the impact of natural or man-made radionuclides contained in the marine environment on the change in the radiation load on aquatic ecosystems. This procedure is described in detail in Appendix 1 and allows obtaining an adequate estimate of dose loads on various classes of hydrobionts based on the concentrations of radionuclides in the aquatic environment.

Table 57 – Estimated dose rates received by marine hydrobionts from natural radionuclides in the layer of bottom sediments [29], μSv/h

Radionuclide	Phytoplankton	Zooplankton	Mollusks, crustaceans, fish
^{235}U + daughter radionuclides (in radiation equilibrium)	0.3 - 4	0.3 - 4	0.6 - 7
^{232}Th + daughter radionuclides (in radiation equilibrium)	0.7 - 6	0.3 - 2	0.5 - 5
^{40}K	0.5 - 6	1 - 15	3 - 30

As can be seen from the data presented in Tables 57 – 59, in the marine environment, most of the background dose rate for phytoplankton, zooplankton and pelagic fish is determined by the action of incorporated radionuclides, mainly α-emitters, with the main source of radiation being ^{210}Po. In the second place by significance is the most abundant in marine environment natural radionuclide – ^{40}K. For benthic organisms, i.e. mollusks, crustaceans and demersal fish, an equally significant source of radiation is γ-radiation of the seabed. In fact, of all radionuclides present in the marine environment, only ^{40}K makes a significant contribution to the total dose rate from external exposure.

Another source that makes a noticeable contribution to the formation of the natural exposure dose for marine organisms is cosmic radiation. This factor is quite important for biota living in the surface layers of the sea, because the dose from cosmic radiation on the surface is on average 0.04 μSv/h. However, already at a depth of 20 m this value decreases to 0.005 μSv/h, and at depths of about 100 m it becomes negligible [29].

The estimated partial contributions and total dose rate received by marine organisms from natural radiation sources are given in Table 60. As can be seen from the data presented, the most significant contribution to the dose rate was from the incorporated radionuclides and due to external exposure from the layer of bottom sediments for benthic (demersal) organisms. For fish, it makes sense to consider the latter component only for demersal species, in other cases (i.e., for pelagic species) its contribution should be assumed to be zero.

Table 58 – Estimated dose rates received by marine hydrobionts from incorporated radionuclides of natural origin [29], μSv/h

Radionuclide	Phytoplankton	Zooplankton	Mollusks	Crustaceans	Fish
^{3}H	$(0.6\text{-}3.4) \times 10^{-7}$	$(0.6\text{-}3.5) \times 10^{-7}$	$(0.6\text{-}3.5) \times 10^{-7}$	$(0.6\text{-}3.5) \times 10^{-7}$	$(0.6\text{-}3.5) \times 10^{-7}$
^{14}C	1.1×10^{-4}	3.4×10^{-4}	5.6×10^{-4}	6.8×10^{-4}	4.5×10^{-4}
^{40}K	2.4×10^{-4}	1.4×10^{-2}	2.8×10^{-2}	2.5×10^{-2}	2.5×10^{-2}
^{87}Rb	-	-	-	7.8×10^{-5}	4.9×10^{-5}
^{238}U	1.2×10^{-3}	$(0.9\text{-}1.8) \times 10^{-3}$	-	-	$(0.6\text{-}270) \times 10^{-5}$
^{234}U	1.4×10^{-3}	$(1.0\text{-}2.0) \times 10^{-3}$	-	-	$(0.8\text{-}350) \times 10^{-3}$
^{226}Ra	6.1×10^{-4}	2.0×10^{-3}	-	-	$(0.2\text{-}5.2) \times 10^{-2}$
$^{210}Pb + ^{210}Bi$	$(2.6\text{-}18) \times 10^{-5}$	$(0.6\text{-}14) \times 10^{-4}$	$(4.2\text{-}8.5) \times 10^{-5}$	$(3.4\text{-}5.9) \times 10^{-4}$	$(1.7\text{-}20) \times 10^{-6}$
^{210}Po	$1.4\text{-}5.8 \times 10^{-2}$	$0.6\text{-}12 \times 10^{-2}$	$4.5\text{-}12 \times 10^{-2}$	$4.5\text{-}18 \times 10^{-2}$	$5\times10^{-5} - 1.5\times10^{-2}$
^{228}Th	$(2.4\text{-}19) \times 10^{-4}$	$(2.3\text{-}25) \times 10^{-4}$	-	-	-
$^{228}Th + ^{224}Ra + ^{220}Rn + ^{216}Po + ^{212}Pb + ^{212}Bi + ^{212}Po + ^{208}Tl$	$(1.4\text{-}11) \times 10^{-3}$	$(1.4\text{-}15) \times 10^{-3}$	-	-	-
^{235}U	5.6×10^{-5}	5.6×10^{-5}	-	-	$(0.03\text{-}13) \times 10^{-5}$

Table 59 – Estimated dose rates received by marine hydrobionts from natural radionuclides dissolved in seawater [29], μSv/h

Radionuclide	Phytoplankton	Zooplankton	Mollusks, crustaceans, fish
^{3}H	$(1.5\text{-}7.7) \times 10^{-9}$	-	-
^{14}C	1.5×10^{-7}	-	-
^{40}K	4.1×10^{-3}	2.4×10^{-3}	4.1×10^{-3}
^{87}Rb	4.9×10^{-6}	-	-
$^{238}U + ^{234}Th + ^{234m}Pa$	9.7×10^{-5}	1.5×10^{-5}	1.3×10^{-5} -
^{234}U	9.2×10^{-5}	-	-
^{230}Th	$(0.4\text{-}9.7) \times 10^{-8}$		
^{226}Ra	$(2.8\text{-}3.2) \times 10^{-6}$	-	-
$^{222}Rn + ^{218}Po + ^{214}Pb + ^{214}Bi + ^{214}Po$	6.8×10^{-6}	9.3×10^{-7}	7.9×10^{-7}
$^{210}Pb + ^{210}Bi$	$(0.8\text{-}5.6) \times 10^{-7}$	$(0.3\text{-}2.0) \times 10^{-7}$	-
^{210}Po	$(0.5\text{-}3.3) \times 10^{-6}$	-	-
^{232}Th	$(0.6\text{-}47) \times 10^{-9}$	-	-
$^{228}Ra + ^{228}Ac$	$(0.3\text{-}34) \times 10^{-7}$	$(0.3\text{-}28) \times 10^{-7}$	$(0.3\text{-}25) \times 10^{-7}$
$^{228}Th + ^{224}Ra + ^{220}Rn + ^{216}Po + ^{212}Pb + ^{212}Bi + ^{212}Po + ^{208}Tl$	$(0.1\text{-}1.6) \times 10^{-6}$	$(0.9\text{-}14) \times 10^{-8}$	$(0.8\text{-}12) \times 10^{-8}$
^{235}U	3.5×10^{-6}	2.0×10^{-7}	2.0×10^{-7}

Table 60 – Dose rate received by marine biota from natural radiation sources [29], μSv/h

Natural radiation source	Phytoplankton	Zooplankton	Mollusks	Crustaceans	Fish
Cosmic radiation*)	5×10^{-3}	5×10^{-3}	5×10^{-3}	5×10^{-3}	5×10^{-3}
Incorporated radionuclides	$(1.9\text{-}7.3) \times 10^{-2}$	$(2.6\text{-}15.7) \times 10^{-2}$	$(7.4\text{-}14.9) \times 10^{-2}$	$(7.9\text{-}21.4) \times 10^{-2}$	$(2.7\text{-}4.2) \times 10^{-2}$
External radiation of the environment	4×10^{-3}	2×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}
External radiation from the layer of bottom sediments contribution of β-radiation contribution of γ-radiation	-	-	$(1.5\text{-}16.0) \times 10^{-2}$ $(1.6\text{-}21.0) \times 10^{-2}$	$(1.5\text{-}16.0) \times 10^{-2}$ $(1.6\text{-}21.0) \times 10^{-2}$	$(1.5\text{-}16.0) \times 10^{-2}$ **) $(1.6\text{-}21.0) \times 10^{-2}$ **)
TOTAL	$(2.8\text{-}8.2) \times 10^{-2}$	$(3.3\text{-}16.4) \times 10^{-2}$	$(9.5\text{-}31.5) \times 10^{-2}$	$(10.0\text{-}38.0) \times 10^{-2}$	$(4.8\text{-}20.8) \times 10^{-2}$

*) the estimated contribution of cosmic radiation is given for a 20-m deep water body

**) only for demersal (bottom) species, in other cases (i.e. for pelagic species) the contribution is 0.

The issue of the impact of the temporary storage facility for radioactive waste in Andreeva Bay on the ecological state of the marine environment and biota in the adjacent waters was studied in detail in the work described in publication [30]. The objective of the work was to study ecosystems with a chronic source of contamination by man-made isotopes and analyze the impact of the Andreeva Bay SNF and RW TSF on the ecological state of the seawater and biota in the Zapadnaya Litsa Bay of the Motovsky Gulf, Andreeva Bay, Malaya Andreeva Bay, and in the coastal area of the Kola Peninsula. The procedure used in the work consisted in taking samples of seawater and bottom sediments and subsequent processing of the samples. The activity of γ-emitting radionuclides in the samples was measured with the InSpector-2000 γ-spectrometer (Canberra, USA) with detector made of pure germanium. The analysis of the specific activity of ^{90}Sr in the samples was carried out by the radiochemical method, followed by measurement of the activity of equilibrium ^{90}Y in the samples using the LS-6500 measuring system (Beckman Instruments Inc., USA). Results of the volume activity measurements for man-made radionuclides in the seawater in bottom sediments are presented in Figures 9 and 10, respectively.

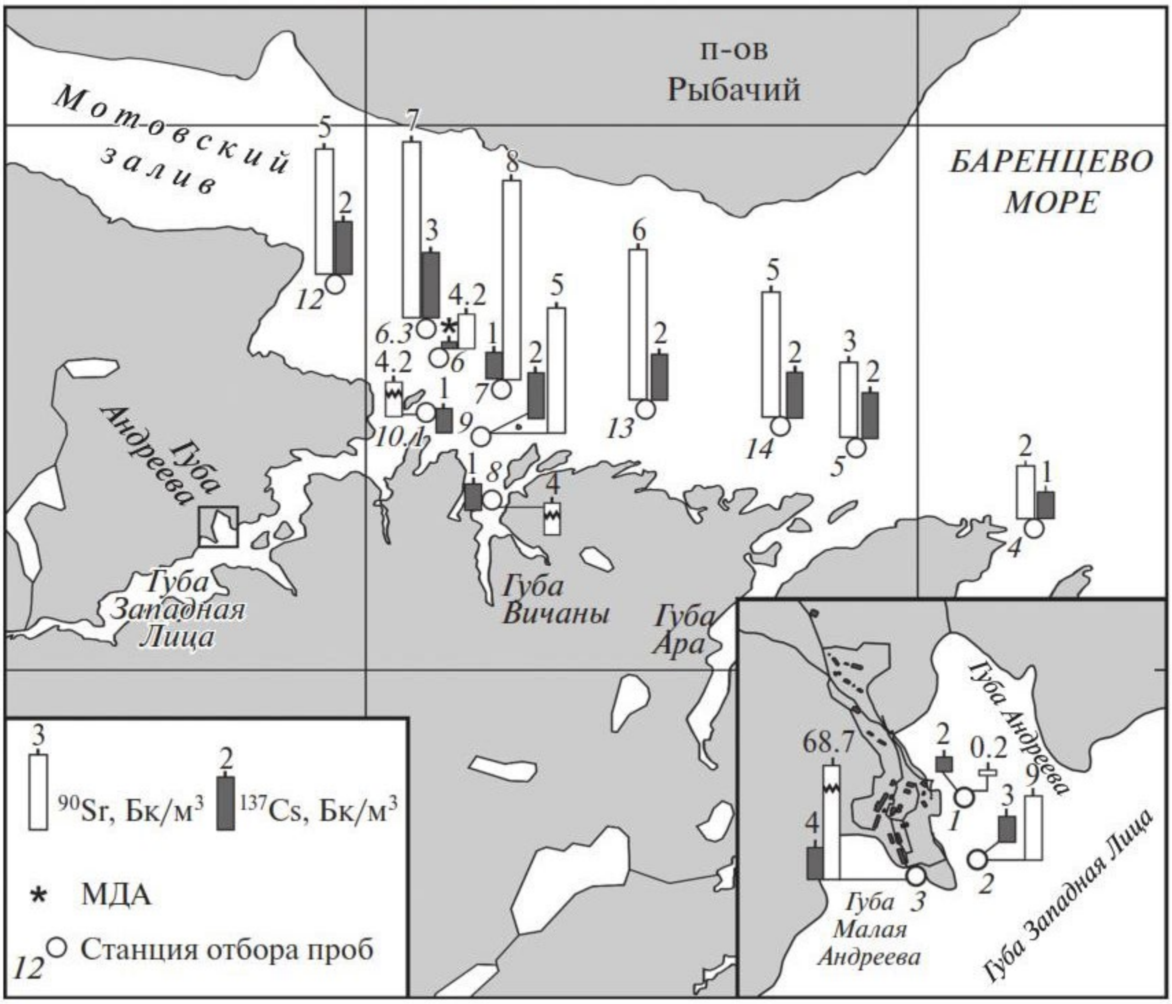

*Figure 9 – Volume activity of ^{137}Cs and ^{90}Sr in seawater [30]. * MDA — minimum detectable activity of the radionuclide*

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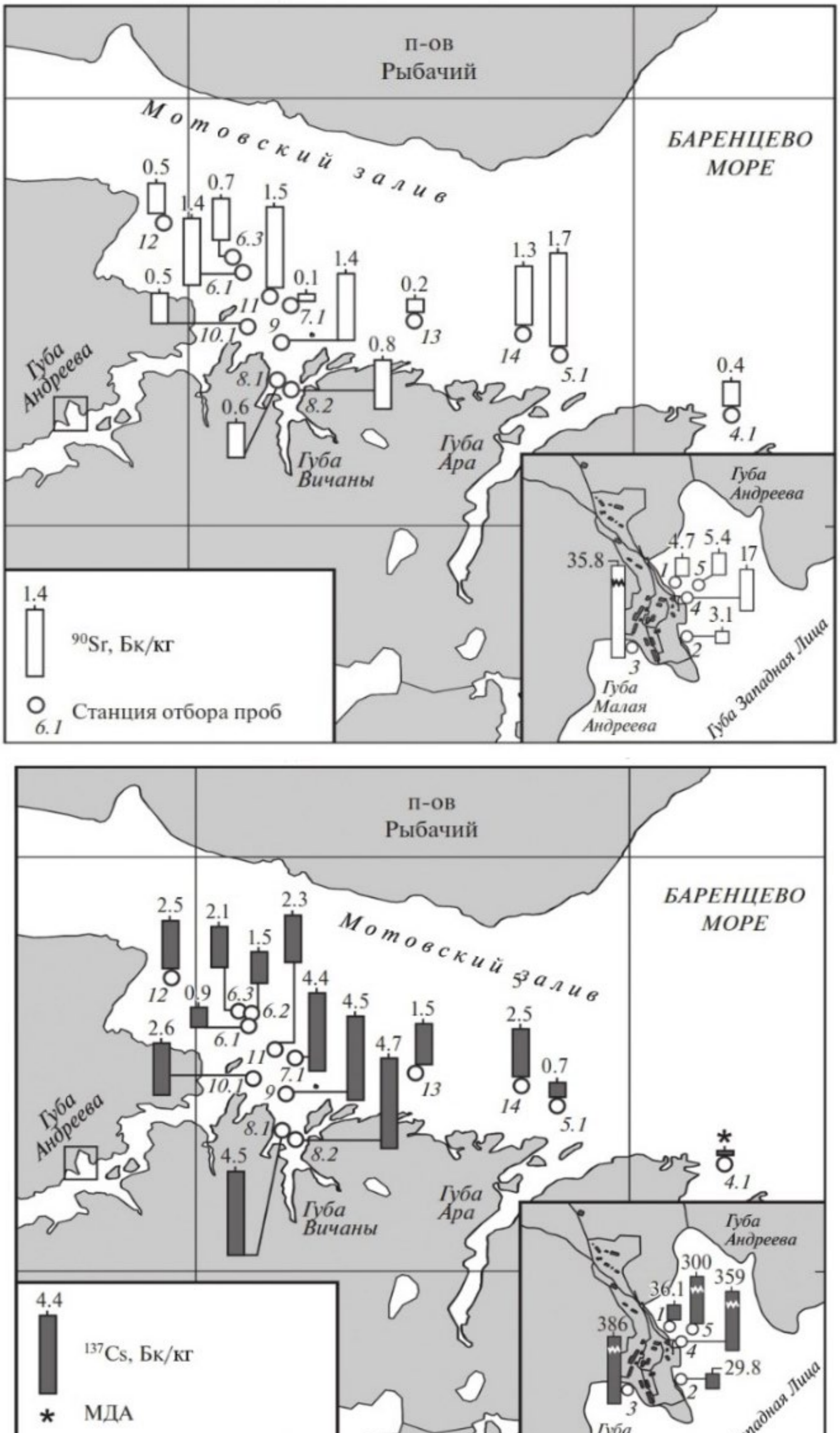

*Figure 10. Specific activity of ^{137}Cs and ^{90}Sr in bottom sediments [30]. * MDA — minimum detectable activity of the radionuclide*

From the data presented in Figure 9 it follows that the average (for three sampling stations) volume activity of ^{137}Cs and ^{90}Sr in the seawater in immediate proximity to the Andreeva Bay SNF and RW TSF is 3 and 26 Bq/m^3, respectively. Also, from the data presented in Figure 10 it follows that the average (for five sampling stations) specific activity of ^{137}Cs and ^{90}Sr in the bottom sediments in immediate proximity to the Andreeva Bay SNF and RW TSF is 222.2 and 13.2 Bq/m^3, respectively. Thus, the results of measurements of the γ- and β-activity of environmental samples allow estimating the additional dose load on aquatic organisms due to the production activity of the Andreeva Bay SNF and RW TSF. The estimates obtained according to the methodology described in Appendix 1 are given in Table 61.

Table 61 – Additional radiation loads on aquatic organisms resulting from production activities of the Andreeva Bay SNF and RW TSF, μSv/h

Radiation source	Phyto-plankton	Zooplankton	Mollusks	Crustaceans	Fish
$^{137}Cs + ^{137m}Ba$	1.90×10^{-5}	$1,91 \times 10^{-5}$	1.98×10^{-5}	2.10×10^{-5}	2.98×10^{-5}
$^{90}Sr + ^{90}Y$	2.11×10^{-2}	3.26×10^{-2}	2.08×10^{-2}	2.08×10^{-2}	2.08×10^{-2}
TOTAL	2.11×10^{-2}	3.27×10^{-2}	2.09×10^{-2}	2.09×10^{-2}	2.09×10^{-2}
% of the dose due to natural radionuclides (see Table 11.4.1.4)	25 - 75	20 - 99	6.6 - 22	5.5 – 20.9	10 – 43.5

Comparison with the data in Table 60 shows that the additional dose load on aquatic organisms in the water areas of the Andreeva and Malaya Andreeva Bays, caused by the influence of man-made radionuclides during normal operation of the enterprise, does not exceed the natural radiation background and cannot have a negative effect on marine organisms. These estimates are confirmed by the conclusion made in the previous study [30] about the small impact of weak chronic contamination of the above water areas on local ecosystems.

Radiation loads on aquatic organisms caused by the maximum beyond design basis accident

Let us consider the change in the dose load on aquatic organisms due to a beyond design basis accident with the worst radiation consequences. Such a beyond design basis accident is the scenario considered in Section 8.2.1, i.e. an accident with the aircraft crash, which causes partial destruction of the Building 153 roof, fire, depressurization of SFAs and the release of radionuclides into the atmosphere.

Results of the calculations of the man-made radionuclides fallout density for such a scenario, given in Table 50, allow assessing the change in the radiation situation in the water area adjacent to the Andreeva Bay SNF and RW TSF. The water area corresponds to a circle with a radius of 4.2 km around the center of the hypothetical accident (Building 153), which bounds the area with the highest fallout density (Building 153). The area of water inside the circle is 14.51 km^2 at an average depth of the water body of 90 m. Table 62 gives the data on specific activity in the part of the water area that will experience the largest impact as a results of the beyond design basis accident.

Table 62 – Specific activity in the part of the water area that will be maximally exposed to radiation as a result of the beyond design basis accident, Bq/m^3.

Radionuclide	Average fallout density (for R = 0 ÷ 4200 m), Bq/m^2	Specific activity, Bq/m^3
$^{137}Cs + ^{137m}Ba$	$4.27 \times 10^{+4}$	$4.7 \times 10^{+2}$
$^{90}Sr + ^{90}Y$	$4.27 \times 10^{+3}$	$4.7 \times 10^{+1}$
^{238}Pu	$7.55 \times 10^{+1}$	8.4×10^{-1}
^{239}Pu	6.10	6.8×10^{-2}
^{240}Pu	6.89	7.7×10^{-2}
^{241}Pu	$8.19 \times 10^{+2}$	9.1
^{241}Am	$2.20 \times 10^{+1}$	2.4×10^{-1}

The data in Table 62 allow estimating an additional dose load on aquatic organisms resulting from the beyond design basis accidents with aircraft crash. The estimates obtained according to the methodology described in Appendix 1 are given in Table 63. The calculations were performed with the use of the coefficients of distribution of radionuclides between water and bottom sediments in marine water bodies, recommended by the Ministry of Natural Resources and Ecology of the Russian Federation [31].

Table 63 – Additional radiation load on aquatic organisms as a results of the beyond design basis accident, μSv/h

Radionuclide	Phyto-plankton	Zooplankton	Mollusks	Crustaceans	Fish
$^{137}Cs + ^{137m}Ba$	1.5×10^{-1}	1.5×10^{-1}	1.5×10^{-1}	1.5×10^{-1}	1.6×10^{-1}
$^{90}Sr + ^{90}Y$	3.8×10^{-2}	6.0×10^{-2}	3.8×10^{-2}	3.8×10^{-2}	7.8×10^{-4}
^{238}Pu	1.6	5.4	1.6×10^{-1}	1.6×10^{-2}	2.2×10^{-3}
^{239}Pu	1.2×10^{-1}	4.1×10^{-1}	1.2×10^{-2}	1.2×10^{-3}	1.6×10^{-4}
^{240}Pu	1.4×10^{-1}	4.6×10^{-1}	1.4×10^{-2}	1.4×10^{-3}	1.8×10^{-4}
^{241}Pu	3.8×10^{-4}	1.3×10^{-3}	3.8×10^{-5}	3.8×10^{-6}	5.1×10^{-7}
^{241}Am	9.4×10^{-1}	3.1	3.1×10^{-1}	7.8×10^{-3}	7.8×10^{-4}
TOTAL	3.0	9.6	6.9×10^{-1}	2.2×10^{-1}	1.6×10^{-1}
Lethal radiation levels for various classes of marine organisms at acute irradiation, Sv (lethal radiation level types) [28, 32]	30 – 1200 (LD_{50})	50 - 6000 (LD_{50})	200 – 1090 ($LD_{50/30}$)	15 – 566 ($LD_{50/30}$)	11 – 56 ($LD_{50/30}$)

The results of the calculations show that as a result of the beyond design basis accident with aircraft crash the additional dose load on hydrobionts in the adjacent water area, including the Andreeva Bay and Malaya Andreeva Bay, will temporarily exceed the natural background by 1-2 orders of magnitude.

Nevertheless, the daily radiation dose to marine organisms after the maximum beyond design basis accident will be by 2-4 orders of magnitude less than the lower threshold of the fifty percent lethal exposure level for the population [28, 32] (see Table 63). Thus, there is no accident development scenario that would lead to failure of local marine ecosystems in the water area of the Andreeva Bay SNF and RW TSF.

7 Results of consideration of alternative options of achieving the goal, planned economic and other activities, and “zero option”

7.1 Alternative option of retrieving SFAs from DSU-3A

To reduce the risk to nuclear, radiation and environmental safety, the scheme for retrieving SNF from storage cells is channel-by-channel retrieval of individual SFAs from canisters located in the DSU-3A cells [9]. The adopted retrieval scheme corresponds to the standard fuel reprocessing technology used at the PO Mayak.

As an alternative option, there was considered retrieval by canisters rather than the channel-by-channel retrieval of SFAs, when a canister with all SFAs contained in it is retrieved. The option of retrieving SFAs by canisters has an advantage over the channel-by-channel option, associated with a reduction in the total time to empty the DSU-3A tank from fuel and remove the fuel from the Andreeva Bay SNF and RW TSF. This would allow in the foreseeable future to name the Andreeva Bay SNF and RW TSF site another zone in the Northwest Russia free from nuclear fuel. The site of the Gremikha Division of NWC “SevRAO” – Branch of FSUE “FEO” became the first zone free from nuclear fuel of water-cooled submarine reactors in 2012.

Main disadvantages of the option of retrieving the SFAs by canisters:

a) In this option, in spite of the fact that water is removed from the cell before the retrieval operation, it may remain in the canister itself. According to the estimates, in the presence of damaged SFA and fuel spills in the canister there is a possibility of the formation of a critical system in the canister with SFA and, accordingly, of the occurrence of SSCR.

b) PO Mayak does not have a technology for reprocessing of nuclear submarine fuel as part of canister.

c) Nuclear legacy elimination work will be transferred to another region of Russia. It will be necessary to create a similar SNF management complex at the site of PO Mayak for channel-by-channel retrieval of SFAs.

7.1.1 Consequences of occurrence of the SSCR in a canister with SFAs

During a short burst, a mixture of SNF, water, water vapor and air heated to a high temperature will be thrown into the premises of Building 153, along with debris of SFAs and the canister, which will destroy the structures of the Building 153 shelter and roof. The burst leads to the termination of the nuclear fission process. We assume that the SSCR burst intensity will be about 10^{18} fissions of ^{235}U nuclei. Short-lived isotopes resulting from the SSCR, in particular inert gases with their daughter nuclides, should only be taken into account when assessing the exposure of personnel in Building 153 and in the immediate vicinity of the accident site, and there the levels will not exceed 1-2 mSv. Therefore, to assess the impact of an accident with SSCR on the population and personnel of the Andreeva Bay SNF and RW TSF, we consider the release of long-lived fission products accumulated in the SNF. We estimate the aerosol release as 10% of ^{137}Cs, 2% of ^{90}Sr and 2% of Pu(α) from 7 SFA contained in the DSU cell canister.

The expected release of radionuclides into the environment is shown Table 64. The release height corresponds to the height of the Building 153 roof.

Table 64 – Release of radionuclides to the environment at SSCR in Building 153, MBq

Nuclide	Release from Building153, MBq
^{137}Cs	5.39E+06
^{90}Sr	9.52E+05
^{238}Pu	1.54E+04
^{239}Pu	1.25E+03
^{240}Pu	1.40E+03
^{241}Pu	8.12E+04
^{241}Am	4.48E+03

Atmospheric stability categories for different distances from the release point were taken in accordance with Table 65.

Table 65 – Atmospheric stability categories

Category	A	A	A	E	F	F	F	G	G	G	G	G	F	E
Distance, km	0.1	0.2	0.3	0.5	1.0	1.8	2.0	2.4	3.0	6.0	10.0	20.0	30.0	40.0

Table 66 shows expected exposure doses to the population as a result of the accident with the SSCR.

In the village of Nerpichye the dose from emergency release will be 17 mSv, in the village of Bolshaya Lopatka – 15 mSv, in Zaozyorsk – 12 mSv, and in Vidyaevo – 0.12 mSv. The maximum expected exposure dose at the accident with SSCR is 124 mSv, which is more than 6 time higher than the dose limit for Group A personnel.

The obtained values show that the level A of the criterion for making a decision on the protection of the population in nearby settlements is exceeded (NRB-99/2009), hence it is possible that the local administration imposes restrictions on the consumption of contaminated food and drinking water.

The levels of contamination of atmosphere and land surface for the SSCR accident are presented in Tables 67 and 68.

Table 66 – Effective dose at various distances from Building 153, mSv.

Distance, km	0.1	0.2	0.3	0.5	1.0	1.8	2.4	3.0	6.0	10.0	20.0	30.0	40.0
Dose, mSv	1.02E+02	6.21E+01	3.97E+01	2.55E+01	2.23E+01	1.72E+01	1.49E+01	1.65E+01	1.20E+01	5.20E+00	7.02E-01	2.46E-01	1.23E-01

Table 67 – Time integral of volume activity, Bq/m³

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.4	3.0	6.0	10.0	20.0	30.0	40.0
Cesium-137	8.81E+08	5.37E+08	3.44E+08	2.21E+08	1.93E+08	1.49E+08	1.39E+08	1.29E+08	1.43E+08	1.04E+08	4.48E+07	5.88E+06	2.05E+06
Strontium-90	1.56E+08	9.49E+07	6.07E+07	3.90E+07	3.42E+07	2.64E+07	2.45E+07	2.28E+07	2.52E+07	1.83E+07	7.92E+06	1.04E+06	3.62E+05
Plutonium-238	2.52E+06	1.54E+06	9.83E+05	6.31E+05	5.53E+05	4.27E+05	3.96E+05	3.68E+05	4.07E+05	2.96E+05	1.28E+05	1.68E+04	5.86E+03
Plutonium-239	2.04E+05	1.24E+05	7.95E+04	5.10E+04	4.47E+04	3.45E+04	3.21E+04	2.98E+04	3.30E+04	2.40E+04	1.04E+04	1.36E+03	4.74E+02
Plutonium-240	2.29E+05	1.40E+05	8.93E+04	5.73E+04	5.03E+04	3.88E+04	3.60E+04	3.35E+04	3.70E+04	2.69E+04	1.16E+04	1.53E+03	5.32E+02
Plutonium-241	1.33E+07	8.10E+06	5.18E+06	3.33E+06	2.91E+06	2.25E+06	2.09E+06	1.94E+06	2.15E+06	1.56E+06	6.75E+05	8.86E+04	3.09E+04
Americium-241	7.32E+05	4.47E+05	2.86E+05	1.83E+05	1.61E+05	1.24E+05	1.15E+05	1.07E+05	1.19E+05	8.62E+04	3.73E+04	4.89E+03	1.70E+03

Table 68 – Fallout density, Bq/m^2

Radionuclide	0.1	0.2	0.3	0.5	1.0	1.8	2.4	3.0	6.0	10.0	20.0	30.0	40.0
Cesium-137	7.08E+06	4.32E+06	2.77E+06	1.77E+06	1.56E+06	1.20E+06	1.11E+06	1.04E+06	1.15E+06	8.36E+05	3.64E+05	5.05E+04	1.77E+04
Strontium-90	1.25E+06	7.63E+05	4.89E+05	3.13E+05	2.75E+05	2.12E+05	1.97E+05	1.84E+05	2.03E+05	1.48E+05	6.42E+04	8.92E+03	3.13E+03
Plutonium-238	2.02E+04	1.23E+04	7.91E+03	5.07E+03	4.44E+03	3.43E+03	3.18E+03	2.98E+03	3.28E+03	2.39E+03	1.04E+03	1.44E+02	5.06E+01
Plutonium-239	1.64E+03	9.99E+02	6.40E+02	4.10E+02	3.60E+02	2.77E+02	2.58E+02	2.41E+02	2.66E+02	1.93E+02	8.40E+01	1.17E+01	4.09E+00
Plutonium-240	1.84E+03	1.12E+03	7.19E+02	4.61E+02	4.04E+02	3.12E+02	2.89E+02	2.71E+02	2.99E+02	2.17E+02	9.44E+01	1.31E+01	4.60E+00
Plutonium-241	1.07E+05	6.51E+04	4.17E+04	2.67E+04	2.34E+04	1.81E+04	1.68E+04	1.57E+04	1.73E+04	1.26E+04	5.48E+03	7.60E+02	2.67E+02
Americium-241	5.88E+03	3.59E+03	2.30E+03	1.47E+03	1.29E+03	9.98E+02	9.26E+02	8.66E+02	9.56E+02	6.95E+02	3.02E+02	4.20E+01	1.47E+01

7.2 Zero option (do nothing)

If SNF is not removed from the DSU-3A storage tank, SFA will remain in the storage cells, while the long-term storage of the SFAs, the presence of defective SFAs among them, the presence of water in the DSU-3A cells – all this will lead to degradation of materials and failure of the fuel composition in the SFAs. As a result, cells with a critical value of fuel spills in the cells may appear in the DSU-3A tank. The most significant from the point of view of nuclear hazard will be the formation of a water-fuel mixture, which will lead to SSCR. The initiating event of such an accident can be both natural and technogenic external impact of a seismic nature.

The likelihood of such an incident will only increase over time due to the corrosive destruction of canisters, SFAs and the fuel composition in the DSU-3A cells containing SNF. The consequences of this event in case of the "zero option" are similar to those discussed in section 7.1.1 for the SSCR at the alternative option of retrieving SNF from the DSU-3A tank.

7.3 Substantiation of the choice of an alternative option

The following options are considered as alternatives:

a. Implementation of the planned activities according to the process described in the Operating Procedure [9].
b. Implementation of the planned activities according to the process other than that described in the Operating Procedure [9].
c. Zero option (do nothing).

7.3.1 Zero option

The long-term storage of SNF in the DSU-3A tank will promote corrosive destruction of canisters, SFAs and fuel composition in the DSU-3A cells containing SNF, and will lead for the formation of a water-fuel mixture, which will cause the SSCR. Results of calculations of the expected exposure doses for the population in the event of SSCR show that the level A of the criterion for making a decision on the protection of the population in nearby settlements will be exceeded (NRB-99/2009). This option is unacceptable.

7.3.2 Implementation of planned activities in accordance with technology other than the technology described in the Operating Procedure [9]

When using the technology of retrieving SFAs by canisters, there is a possibility of the formation of a critical system in the canister with SFAs and, accordingly, of the occurrence of SSCR. Results of calculations of the expected exposure doses for the population in the event of SSCR show that the level A of the criterion for making a decision on the protection of the population in nearby settlements will be exceeded (NRB-99/2009).

It will be necessary to create a similar complex for SNF management in another region of Russia for channel-by-channel retrieval of SFAs to fit the standard fuel reprocessing technology at PO Mayak, which will lead to the search for additional financial resources and a general increase in the time to eliminate the nuclear legacy accumulated at the Andreeva Bay SNF and RW TSF. This option is unacceptable.

7.3.3 Implementation of planned activities in accordance with the technology described in the Operating Procedure [9].

The implementation of alternative options is not advisable; the selected solution for the implementation of channel-by-channel retrieval of SFAs is the most acceptable option from the economic, social, political and environmental points of view.

8. CONCLUSION

a. The EIA materials developed for operations on preparation of the DSU-3A tank for retrieval of SFAs from the DSU-3A tank cells, loading the SFAs into new canisters, loading of canisters with SFAs into TUK-108/1 (TUK-18) casks, putting the TUK casks with SFAs in temporary storage at the TUK accumulation pad, and loading of TUK casks with SFAs onto the container ship show that the channel-by-channel method of retrieving the SFAs ensures nuclear, radiation and environmental safety.

b. To implement the process operations at the DSU-3A tank, there will be used the SNF and RW management complex provided with unique remotely operated equipment, which was put in operation in 2016 and is currently used for retrieval of SFAs from the DSU-2A tank. It allows minimizing personnel exposure during retrieval of SFAs from the DSU-3A tank cells.

c. The EIA materials give the structure and description of the constructed SNF and RW management complex, describes main process operations and radiation situation in the complex structures and at the territory of the SPZ of the Andreeva Bay SNF and RW TSF.

d. The EIA was developed using data on natural and climatic conditions; it characterizes the current state of the ecological system and anthropogenic loads on environmental objects in the RCA of the Andreeva Bay SNF and RW TSF.

e. Analysis of the impact of emissions of harmful chemical and radioactive substances on the population and environmental objects showed that:

f. Emissions of chemical pollutants during performance of planned activities at the Andreeva Bay SNF and RW TSF site will not lead to negative impact on the population living in the area. Results of calculations of dispersion of pollutants during the works on preparation of the DSU-3A tank, retrieval and removal of SNF from the Andreeva Bay SNF and RW TSF site taking into account existing similar discharged ingredients showed that the nearest settlements in the Nerpichya Bay, Bolshaya Lopatka Bay and Zaozyorsk do not get into the zone of influence of emissions, the radius of which, according to calculations, is about 750 m. Maximum surface concentrations for all pollutants in these settlements do not exceed 0.05 MPC.

g. The maximum value of the effective dose of exposure of the population for operations at the Andreeva Bay TSF under normal conditions will be 0.009 μSv/year.

h. The planned measures for the protection of surface, underground water bodies and soil are aimed at minimizing the negative impact and will ensure, during the planned activities, the absence of excessive impact on the environment and the nearest residential area.

i. The radiation impact of possible design basis accidents during the SNF retrieval operations does not exceed the basic dose limits for personnel and population established by regulatory documents. The impact on the environment is minimal.

j. The radiation impact of the beyond design basis accident during the SNF retrieval operations will not require the introduction of protective measures associated with disruption of the normal life of the population, and of the economic and social functioning of the territory of nearby settlement. The impact on the environment and ecosystem of the region will not lead to its change.

k. Calculations performed in accordance with the procedure recommended by IAEA (see Appendix 1) showed that during the normal operation of the enterprise the additional dose load on aquatic organisms in water areas of the Andreeva Bay and Malaya Andreeva Bay due to the influence of man-made radionuclides does not exceed natural background radiation and cannot have a negative impact on marine organisms. These estimates are confirmed by the conclusion about small effect of weak chronic pollution of indicated water areas on local ecosystems, which was made in the publication [30] based on the results of the two-year cycle of field studies.

l. Analysis of accident scenarios showed that as a result of the maximum beyond design basis accident with aircraft crash there will be formed an additional dose load on hydrobionts living in the adjacent water area (including the Andreeva Bay and Malaya Andreeva Bay), which will temporarily exceed the natural background by 1-2 orders of magnitude. According to the calculations, the highest daily radiation dose to marine organisms due to the maximum beyond design basis accident will be by 2-4 orders of magnitude less than the lower threshold of the fifty percent lethal exposure level for various types of marine biota. Thus, even under the most severe scenario of the development of the radiation accident the temporary increase in the levels of exposure of hydrobionts will not lead to failure of local marine ecosystems in the adjacent water area.

m. The Program of Industrial Environmental Control was developed for the site of NWC “SevRAO” – Branch of FSUE “FEO” and approved by Director of NWC “SevRAO” – Branch of FSUE “RosRAO” V.V. Eremenko on August 15, 2019. According to the Program, the environmental control covers the atmospheric air, water bodies and soil.

n. The EIA materials meet all the necessary requirements of sanitary, hygienic, environmental and regulatory acts. The implementation of all environment protection measures planned during the work, proposed and considered in these materials will ensure compliance with the environmental legislation, reduce the environmental impact and eliminate in the long term the impact of the Andreeva Bay TSF on the environment.

LIST OF ABBREVIATIONS

A/C	aircraft
AAS	anion-active surfactants
ADER	ambient equivalent dose rate
ARSMS	Automated Radiation Situation Monitoring System
BOD	biological oxygen demand
BS	biological shielding
CAZ	controlled access zone
CMB	Coastal Maintenance Base
COD	chemical oxygen demand
DSU	Dry Storage Unit
DWGSWDL	Draft Waste Generation Standards and Waste Disposal Limits
EHC	extremely high contamination
EIA	environmental impact assessment
ER	emergency response
FE	fuel element
FEO	Federal Environmental Operator
FNM	fissile nuclear materials
FSUE	Federal State Unitary Enterprise
GCS	gas-cleaning system
GRW	gaseous radioactive waste
HC	high contamination
HCS	harmful chemical substances
HLW	high-level waste

ILW	intermediate level waste
IRD of FMBA	Interregional Department of the Federal Medical-Biological Agency
IRE	improvement of the radiological environment
LLW	low-level waste
LRW	liquid radioactive waste
MDRF	Ministry of Defense of the Russian Federation
MPC	maximum permissible concentration
NF	nuclear facility
NPI	nuclear power installation
NPS	nuclear-powered submarine
NRHF	nuclear- and radiation-hazardous facility
RCA	radiation control area
RIG	radioactive inert gases
RM	radiation monitoring
RCS	Radiation Control System
RN	radioactive nuclides
RS	radiation safety
RW	radioactive waste
SAS	surface-active substances
SFA	spent fuel assembly
SNF	spent nuclear fuel
SPZ	sanitary protection zone
SRW	solid radioactive waste
SSCR	self-supporting chain reaction

SSESC	State Sanitary and Epidemiological Supervision Center
TSEL	tentative safe exposure level
HM	handling machine
TSF	temporary storage facility
TUK	transport package
WRP	water removal plant

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APPENDIX 1. Evaluation of the dose rate for aquatic organisms

Description of the computational model

Data on concentrations of radionuclides in the aquatic biota relate to organisms of all geometries, and in most cases the geometry of such biological objects is not known, even approximately. Therefore, to estimate the radiation dose rate absorbed by a bio object, it is necessary to use an idealized computation model with simplified description of the real situation. For this reason, we used the calculation procedure recommended by IAEA [1] for estimation of the effect of man-made radionuclides released during the works on removal of SNF from the Andreeva Bay SNF and RW TSF site on the change in the radiation load on aquatic ecosystems of adjoining water bodies. Let us consider three routes of exposure of aquatic organisms to natural and man-made radionuclides.

1. Dose rate from incorporated radionuclides

Phytoplankton. The computational model used for these organisms represented a sphere of unit density tissue-equivalent material with the diameter of 50 μm. This size is considered typical for the most common species of marine phytoplankton. Though sizes of certain phytoplankton species vary from less than 10 to (presumably) 200 μm, and the strictly spherical shape is rarely encountered [2], the adopted computational model provides a simple way of estimating the absorbed dose rate for organisms in this size range. It was also assumed that the computational model would be suitable for freshwater phytoplankton, though typical size of these organisms is usually somewhat less than that of their marine analogs, and sizes and shapes of various species vary. In our computational model we assume that radioactivity accumulated in these organisms is uniformly distributed over the entire volume. Due to small size of these bio objects, a considerable portion of energy radiated by incorporated radionuclides is scattered and absorbed in the surrounding water environment.

Let us take the mean path of α-particles equal to 60 μm, which corresponds to the path of an α-particle with energy 6 MeV in water [3] at constant value of linear energy transfer (LET), then the distribution of possible path lengths of the α-particle within the bio object is such that about 30% of the energy radiated by the α-particle is absorbed inside the volume of the sphere circumscribing the bio object [1], i.e.

$D_\alpha \approx 0.3 \cdot D_\alpha(\infty)$,

where $D_\alpha(\infty) = 2.13 \cdot \bar{E}_\alpha \cdot C$, and

$D_\alpha(\infty)$ is the dose rate in the infinite volume uniformly contaminated with a radionuclide at concentration C, which in one decay emits α-particles with mean energy $\bar{E}_\alpha$.

Since for β-radiation the mean path in tissue-equivalent unit density material is 2 cm, the most part of the β-particle radiated energy with the exception of the lowest energy part of the spectrum is absorbed beyond the bio object. Figure 1 presents the average dose rate of β-radiation inside spheres of different radii, Dsph(r), as a function of maximum β-spectrum energy in fractions of $D_\beta(\infty)$, which is determined similarly to $D_\alpha(\infty)$ above. The calculated curves were taken from the IAEA document [1].

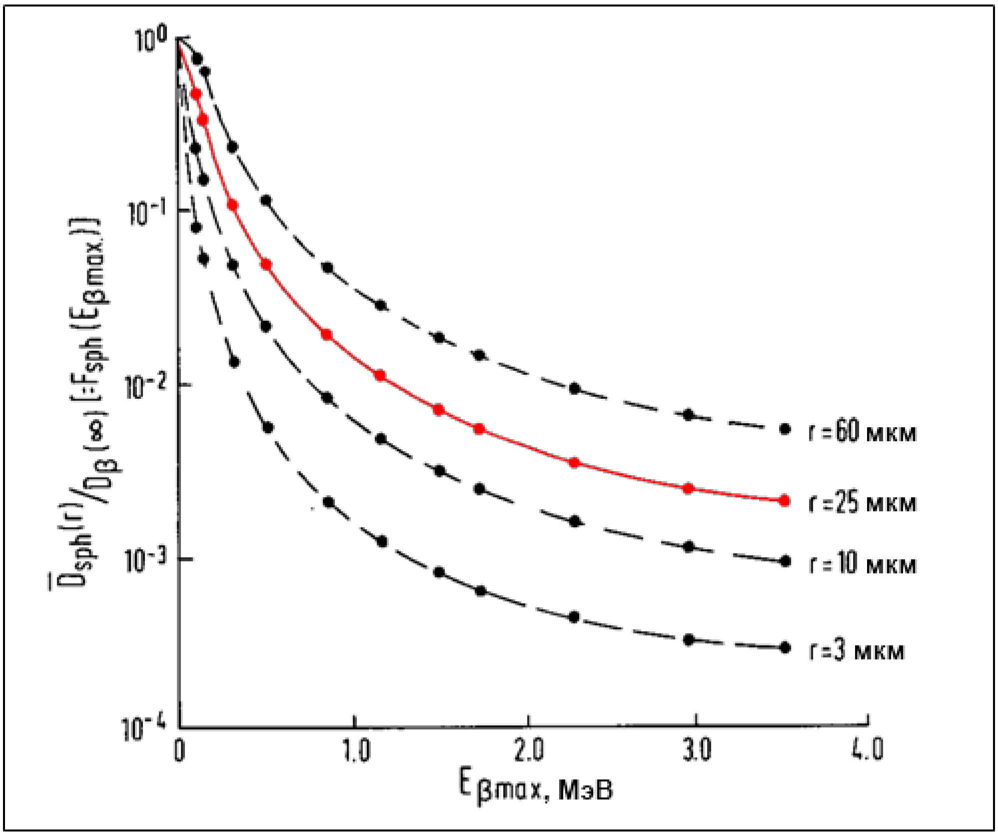

Figure 1.1 – Calculated curves of the average dose rate of β-radiation in spheres of tissue-equivalent unit density material with uniform distribution of β-radiation sources [1]. The solid red curve corresponds to the accepted computational model.

The γ-radiation absorption coefficient is so small that it is safe to assume that γ-radiation from radionuclides incorporated by phytoplankton makes an insignificant contribution to the total dose rate received by the bio object. However, in cases of very high density of phytoplankton (> 1 μg in 1 g of water) and high concentration coefficients (> 2×104), which are very rare for northern seas, radioactivity associated with plankton may constitute a significant fraction of the total activity of the water environment. In such instances individual organisms may receive a dose of both β- and γ-radiation from radionuclides incorporated by other organisms.

For phytoplankton species the typical sizes of which are less or greater than the diameter of 50 μm used in the computational model, the dose rate from incorporated α- and β-emitters at the same concentration of radionuclides will be, respectively, less or greater than the values calculated with the dosimetric model used.

Zooplankton. In the accepted computational model these organisms were approximated by a cylinder of unit density tissue-equivalent material with the length of 0.5 cm and diameter of 0.2 cm. This size is considered typical for organisms constituting zooplankton in the northern seas [2]. Similar to phytoplankton, various zooplankton species vary wildly in size and shape, hence the accepted computational model is only used as a means of deriving estimates of the absorbed dose rate for organisms in this size range based on available data on radionuclide concentrations in the water medium. The computational model used is considered as the sufficient approximation for freshwater zooplankton as well. In the same way as for phytoplankton, the incorporated radionuclides are assumed to be uniformly distributed over the entire volume of the bio object.

In case of α-radiation, the volume of organisms of this class appears to be sufficiently large compared to the particle path, therefore it can be assumed that the average absorbed dose rate approximately corresponds to $D\alpha(\infty)$.

For β-radiation, the typical size of zooplankton is of the same order or less than the mean path of β-particles in a tissue-equivalent material. Thus, a certain fraction of the radiated energy is not absorbed and leaves the volume corresponding to the bio object. In Figure 2 the β-radiation dose rate in the center of cylinders with the constant length-to-diameter ratio, $D\beta(P)$, is presented in units of $D\beta(\infty)$ as a function of the maximum β-radiation energy. The computational curves were taken from the IAEA document [1]. The solid red curve corresponds to the accepted computational mode.

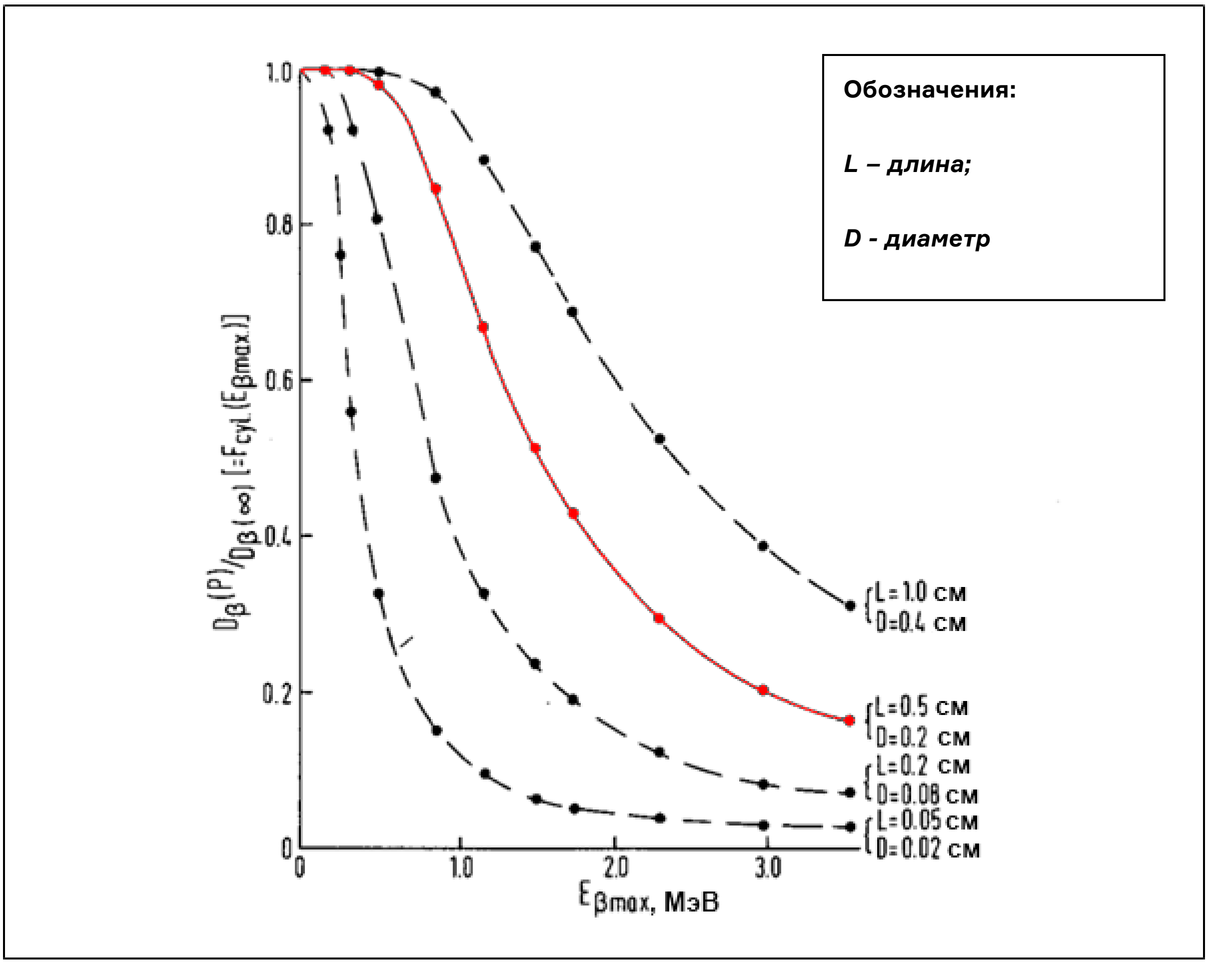

Figure 1.2 – Calculated curves of the β-radiation dose rate in the center of cylinders of tissue-equivalent unit density material with uniform distribution of β-radiation sources [1].

The solid red curve corresponds to the accepted computational model.

Calculation of the absorbed γ-radiation dose rate within the volume of a bio object containing incorporated radionuclides at a concentration C also requires consideration of geometric factors [4]; in this case the average γ-radiation dose rate is defined by the following expression:

$D\gamma = 10\text{-}3 \cdot G \cdot C \cdot \rho \cdot \bar{g}$, where

G – gamma-ray constant,

C – radionuclide concentration,

ρ – density of the bio object (in our case it is set equal to unity),

$\bar{g}$ – mean geometric factor (for zooplankton it is set equal to unity).

For the zooplankton species with typical sizes less or greater than the sizes used in the computational model (i.e. the length of 0.5 cm and the diameter of 0.2 cm), the dose rate from incorporated α- and β-emitting radionuclides at the same concentration will be, respectively, less or greater than the values calculated with the dosimetric model used.

Mollusks, crustaceans and fish. According to the computational model, sizes used to represent each of these groups of animals are such that it may be assumed that dose rates from α- and β-radiation closely approach come very close to the values of $D_\alpha(\infty)$ and $D_\beta(\infty)$, respectively. The average γ-radiation dose rate was calculated using the following typical sizes and geometric factors as recommended by IAEA [1]:

mollusks: a cylinder with the length of 1 cm and diameter of 4 cm; $\bar{g}$ = 10 cm;

crustaceans: a cylinder with the length of 15 cm and diameter of 6 cm; $\bar{g}$ = 25 cm;

fish: a cylinder with the length of 50 cm and diameter of 10 cm; $\bar{g}$ = 41 cm.

It is assumed for each of the considered classes of bio objects that their density is equal to unity and radionuclides are uniformly distributed throughout the volume. For fish, as being the largest of aquatic organisms considered, the average dose rate from γ-radiation approximately corresponds to absorption in the animal of 10% of the total energy of the incorporated γ-emitting radionuclides.

2. Dose rate from radionuclides contained in water

Estimation of the dose rate from radionuclides that are contained in water also requires considering the geometry of bio objects, especially in case of α- and β-radiation.

Phytoplankton. Since the dose rate from α-particles emitted inside the organism is about $0.3 \cdot D_\alpha(\infty)$, the dose rate from external α-particles is about $0.7 \cdot D_\alpha(\infty)$, where $D_\alpha(\infty)$ is calculated from the concentration of α-emitting radionuclides in the surrounding water (marine) environment.

Likewise, the average dose rate due to β-radiation of seawater is defined by the expression:

$\overline{D_\beta} = D_\beta(\infty) - \overline{D_{sph}}$ (r = 25 μm),

where the values of $D_\beta(\infty)$ and $\overline{D_\beta}$ (r = 25 μm) are calculated from the concentration of β-emitting radionuclides in the water environment and calculated data presented in Figure 1.

The dose rate of external γ-radiation for phytoplankton is virtually equal to $D_\gamma(\infty)$ in the marine environment.

Zooplankton. We assume that the dose rate from external α-radiation is negligible. For external β-radiation, the dose rate is defined by the following expression:

$D_\beta = D_\beta(\infty) - D_\beta(P)$,

that is estimated based on data on concentrations of radionuclides in the marine environment and calculated curves presented in Figure 1.2

The dose rate of external γ-radiation for zooplankton is taken equal to Dγ(∞) in the marine environment.

Mollusks, crustaceans and fish. It is assumed that external α- and β-radiation from radionuclides contained in the seawater makes an insignificant contribution to the total dose rate for these classes of marine organisms.

The dose rate of external γ-radiation is also taken equal to Dγ(∞) in the marine environment.

3. Dose rate from radionuclides in bottom sediments

If we consider the effect of natural radionuclides, the seabed can be presented as a half-space, i.e. an infinitely thick plane source with uniformly distributed activity. It is assumed that each radionuclide – representative of the uranium-thorium series is in equilibrium. Hence, the dose rate on the boundary between water and bottom sediments is ½·Dβ(∞) and ½·Dγ(∞) for β- and γ-radiation, respectively. Within the sedimentary layer the β-radiation dose rate increases to Dβ(∞) already at the depth of about 1 cm [5].

The dose rate from radionuclides in bottom sediments was calculated taking into account the variations in specific activity depending on the depth [6]. To consider this effect, it was assumed that the γ-radiation dose rate above the sediment layer is approximately equal to 0.25·Dγ(∞).

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