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Environmental Impact Assessment Of The Removal of Spent Nuclear Fuel (SNF) From Andreeva Bay

Reference:
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Key words:
Andreeva, spent nuclear fuel, risk assessment.

Abstract:
This report was written on the initiative of Norwegian authorities as a part of the bilateral collaboration between Russia and Norway. The report is concerned with an evaluation of possible consequences for both man and the environment on removal of the spent fuel stored at Andreeva Bay. The report is based upon potential accidents and provides estimates of the dispersion of radioactive materials should such accidents occur during the removal operations.

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Emneord:
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Resymé:
Denne rapporten er laget på initiativ fra norske myndigheter som en del av det bilaterale samarbeidet mellom Russland og Norge. Den handler om en vurdering av mulige konsekvenser for mennesker og miljø ved fjerning av det brukte brenselet lagret i Andreevabukta. Rapporten tar utgangspunkt i potensielle ulykker og gir estimater på spredning av radioaktivt materiale om slike ulykker inntreffer under fjerningsarbeidet.

Approved:

Per Strand, director, Department of Emergency Preparedness and Environmental Radioactivity

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Environmental Impact Assessment Of The Removal of Spent Nuclear Fuel (SNF) From Andreeva Bay

Transfer To Canisters And Transport Casks, Loading At The Pier In Andreeva Bay, Transport To The Pier Of FSUE Atomflot In Murmansk And Unloading At The Pier Of FSUE Atomflot

Statens strålevern

Norwegian Radiation Protection Authority
Østerås, 2017

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Sammendrag

Denne rapporten er laget på initiativ fra norske myndigheter som en del av det bilaterale samarbeidet mellom Russland og Norge. Rapporten gir en vurdering av mulige konsekvenser for mennesker og miljø ved fjerning av det brukte brenselet som er lagret i Andrejevbukta. Rapporten tar utgangspunkt i potensielle ulykker og gir estimater på spredning av radioaktivt materiale om slike ulykker inntreffer under fjerningsarbeidet. Arbeidet med rapporten er finansiert gjennom Regjeringens atomhandlingsplan for atomvirksomhet og miljø i nordområdene. Fylkesmannen i Finnmark (FMFI) har mottatt tilskudd fra Statens strålevern for å igangsette arbeidet i dialog med russiske SevRAO. FMFI og Andreeva SevRAO undertegnet en kontrakt 16. mai 2014 for å utarbeide miljøkonsekvensanalysen. «Atomprosjekt» skrev analysen. Sjefingeniør Per-Einar Fiskebeck (FMFI) var norsk prosjektleder. Miljøkonsekvensanalysen er godkjent av russiske tilsynsmyndigheter.

Flere russiske eksperter har forfattet originalrapporten og originalspråket er russisk. Rapporten ble oversatt til engelsk av språkkyndige russiske kolleger og har deretter blitt redigert av Statens strålevern. Strålevernet har gjennomgått utkast til denne rapporten i dialog med russisk part. Strålevernet er dermed sikker på at innholdet gir en korrekt presentasjon av de russiske konsekvensvurderingene og gjengir rapporten på engelsk i overbevisning om at vurderingene er basert på riktig og relevant informasjon. Norsk og internasjonal innsats har sammen med betydelig russisk egeninnsats lagt til rette for at fjerning av brukt brensel kan bli gjort på en sikker måte med så lav risiko som mulig. Det er et russisk ansvar å gjennomføre arbeidet. Det er gjennomført hypotetiske konsekvensanalyser av å gjennomføre flytting av brukt brensel både for «verst-tenkelige» ulykker som betegnes som (A) innenfor «design-based accidents» og (B) «beyond-design-basis accidents»:

Risikoanalyse for (A) type ulykker:

- Naturlige forhold som er typiske for området Andrejevbukta ligger i (jordskjelv, flom, orkaner, lynnedslag, etc.).
- Lufttrykksbølge som følge av en eksplosjon på stedet.
- Fullstendig tap av elektrisk kraft.
- Brann på stedet eller i et kjøretøy med brukt brensel.
- Å miste brukt brensel, brukt brenselutstyr, overføringsskuffer, beholdere under håndtering.
- Feil ved det brukte brenselets lagrings- og håndteringssystemer.
- Menneskelig feil.

Risikoanalyse for (B) type ulykker:

- Kritikalitet på grunn av ulike årsaker.
- Å miste utstyr (kraner) og konstruksjonselementer på taket hvor brukt brensel oppbevares.
- Krasj av et lett fly inn i anlegget for brukt brensel.
- Lufttrykksbølge som følge av en eksplosjon på stedet.

Ved å gjennomføre konsekvensvurderinger vil man være bedre i stand til å planlegge arbeidet og redusere risikoen for ulykker. Rapporten indikerer at de radiologiske konsekvensene utenfor anlegget i Andrejevbukta som følge av hypotetiske ulykker generelt er svært små.

Executive Summary

This NRPA 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 removing the used nuclear fuel stored at the Andreeva Bay facility. The report considers potential accidents and provides estimates of the spread of radioactive material if such accidents occur during removal operations. The work on the report was funded through the Ministry of Foreign Affairs Atomic Action Plan. The county governor of Finnmark (FMFI) received funds from the Norwegian Radiation Protection Authority to initiate work in dialogue with Andreeva SevRAO. FMFI and Andreeva SevRAO signed a contract 16.5.2014 to prepare the environmental impact assessment. «Atomprojekt» completed the analysis. Chief Engineer Per-Einar Fiskebeck (FMFI) was Norwegian project manager. The 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 the Norwegian Radiation Protection Authority. Edited extracts from this translation regarding radiological consequences that potentially could arise due to hypothetical accidents are presented in this NRPA report. The Norwegian Radiation Protection Authority has completed this report in dialogue with Russian colleagues. The Norwegian Radiation Protection Authority is satisfied that the reports contents are a true and faithful representation of the Russian consequence analysis and release the report in good faith that the report is based upon accurate and appropriate information. Norwegian and international efforts together with a significant Russian effort have meant that the fuel can be removed in a safe and secure manner with as a low a risk as possible. It is Russia's responsibility to conduct the work. Russia has conducted a hypothetical consequence analysis for the fuel removal in relation to a "worst case" accident scenario for both (A) design based accidents and (B) beyond design based accidents.

The risk analysis for type (A) accidents includes:

- Natural conditions typical for Andreeva Bay (earthquakes, floods, hurricanes, lightning strikes etc.)
- Air pressure waves as a result of explosions at the site
- Complete loss of electrical power
- Fire at the site or on a vehicle with spent fuel
- Fall to the ground of spent fuel, handling equipment, transfer casks, fuel containers during handling
- Faults in the spent fuel storage and handling systems
- Human errors.

The risk analysis for type (B) accidents includes:

- Criticaility due to a number of causes
- Equipment or construction failures on the roof over the spent fuel storage
- Impact of a light plane with the spent fuel site
- Air pressure waves as a result of an explosion at the site

Conducting a consequence analysis leads to better work planning such that the risk for an accident may be reduced. The work indicates that, in general, the offsite radiological consequences offsite following hypothetical accidents are very small.

1 Introduction

Potential sources of anthropogenic radionuclides in the Arctic environment include spent nuclear fuel (SNF) and radioactive wastes; much of this located in northwest Russia. Ongoing international efforts, working together with relevant Russian authorities to reduce the risk to human health and the Arctic environment, are focusing on managing and decommissioning sites such as in Andreeva Bay. Andreeva Bay, on the Kola Peninsula, held a service port for the soviet fleet of nuclear submarines. After this activity ended in the 1990s, the site became a Site of Temporary Storage (STS) for spent nuclear fuel and radioactive waste. Since 2000, maintenance work at the site has been inadequate and the facilities have rapidly deteriorated in the harsh, coastal, Arctic conditions.

At Andreeva Bay STS, most of the SNF and radioactive waste is still on-site, totalling some 21,000 spent nuclear fuel assemblies and about 12,000 cubic meters of radioactive waste [31]. A limited trial recovery and transport of SNF from the site in 2010 used the vessel Serebryanka to transport some material to the Atomflot enterprise near Murmansk. The degraded state of the SNF at Andreeva Bay, previous failures of containment barriers and the overall poor condition of facilities have previously been recognized as requiring increased attention [32].

The Russian Federation has operated a program of site rehabilitation at Andreeva Bay STS with international collaborators over several years. Shandala et al. [33] and Roudak et al. [34] account the scale of progress from a safety and regulatory perspective, as well as presenting data on the radioactive source terms and other relevant information about the Andreeva Bay site.

Before any full-scale removal of SNF can occur, it is important to make a thorough environmental impact assessment of the possible consequences of such activities. This report gives an account of such a study completed by ROSATOM under funding from the Norwegian Nuclear Safety and Security program (Atomhandlingsplanen.no).

It is important to remember that environmental radiological monitoring in and around the site is important during decommissioning, particularly during critical phases of preparing and removing SNF and radioactive waste. Monitoring also helps identify radioactivity leakages after decommissioning.

1.1 The Andreeva Bay and ATOMFLOT Facilities: Geographic and Climatic Context

The Andreeva Bay branch of the Northwestern Centre for Radioactive Waste Management 'SevRAO' (69°27'9"N 32°21'54"E) and FSUE Atomflot are located on the Kola Peninsula. Andreeva Bay is located on the northwestern shore of the Kola Peninsula, 45 km from the Russian-Norwegian border, and is part of the Zapadnaya Litsa Bay of the Motovskiy Bay of the Barents Sea (Figure 1). The Motovskiy Bay extends inland south of the Rybachy Peninsula between Cape Sharapov and Cape Vys-Navolok, 15.7 km to the south-south-east. The southern shore of the Motovskiy Bay is crenelated, with long bays and inlets, the largest of them being Titovka Bay, Zapadnaya Litsa and Vichany Bay. The northern shoreline (from Cape Sharapov to Motka Bay) is less crenelated. The area of the Andreeva Bay facility stretches in a north – south direction, occupying an entire peninsula on the western shore of the Zapadnaya Lista Bay. The rugged terrain is largely comprised of low hills at elevations of 25-60 m. Rocky ridges with steep and sharp slopes are the predominant features of the landscape. The nearest settlements to the facility are Bolshaya Lopatka (2.4 km), Nerpichie (1.8 km), the city of Zaozersk (6 km south-east) and the settlement of Vidyaevo (45 km southeast). The nearest railhead is Pechenga station, 60 km to the west of the facility. The nearest seaport is 80 km southeast of the facility, in Murmansk. The administration of the Andreeva Bay branch of NWC SevRAO is located in the nearest large settlement (Zaozersk) which constitutes a closed administrative territorial entity (ZATO). The population of Zaozersk was 11,255 persons in 2014. On average, 20% of the workforce is engaged in labour activities due largely the specific character of a ZATO, whilst the majority of the population (68%) are service personnel and their families seeing as there are no other large industrial or agricultural activities in the area. The land is not suited to any arable purpose.

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

FSUE Atomflot (69° 2.627'N, 33° 4.374'E) is located in the Kola Bay (Figure 2), which is some 57 km long and 1 to 7 km wide with an approximate depth at its entrance of 200 m. The city of Murmansk (population 300000) is the administrative centre and the largest city in the region. FSUE Atomflot is situated on the northern periphery of Murmansk, other populated centres in the area arethe city of Severomorsk (13 km north-east, population 50100), Roslyakovo (5.8 km north-east, population 8700) and the settlement of Safonovo (8 km north-east, population 7300). Murmansk is an ice-fee seaport. The entire region occupies an area of 114,900 km^2, with a population of 766,000, 90% of whom are urban dwelling. Major industries in the region include the processing of apaptite-nepheline ores (Khibiny), dressing and processing of copper and nickel ores (Pechenga) and ferrous oxides (Olenegorsk and Kovdor), non-ferrous metallurgy (production of brass, cobalt, nickel and rare earths concentrates). In addition, fisheries, fish processing, maritime transport and ship repair are significant contributors to the regional economy. There are hydropower plants on the Niva, Tuloma, Paz, Kovda and Voronya Rivers and there is a tidal power plant in the Kislaya fjord. There is also a nuclear power plant (Poliarnie Zori). Major agricultural activities are reindeer herding and dairy farming. Large enterprises in the vicinity of Murmansk include Shipyard 35 (a branch of the OAO Ship-repairing centre), Zvyozdochka, located 1 km from FSUE Atomflot, the OAO Murmansk marine fleet ship-repairing plant located 6 km from FSUE Atomflot and the Murmansk sea commercial port and Murmansk fishing port, also located 6 km from the Atomflot facility. The nearest airfield (Severomorsk-1) is located 11 km from FSUE Atomflot. The airway exit corridor at the Severomorsk-1 airfield is 15 km away. The piloting zone over the Kola Bay (Severomorsk-1 airfield) is 1.5 km away. In accordance with paragraph 38 of the 'Federal regulations of the use of the RF airspace', the distance from danger zones to flight patterns around airfields and limits of airways and local air lines is 10 km.

1.1.1 *Climate*

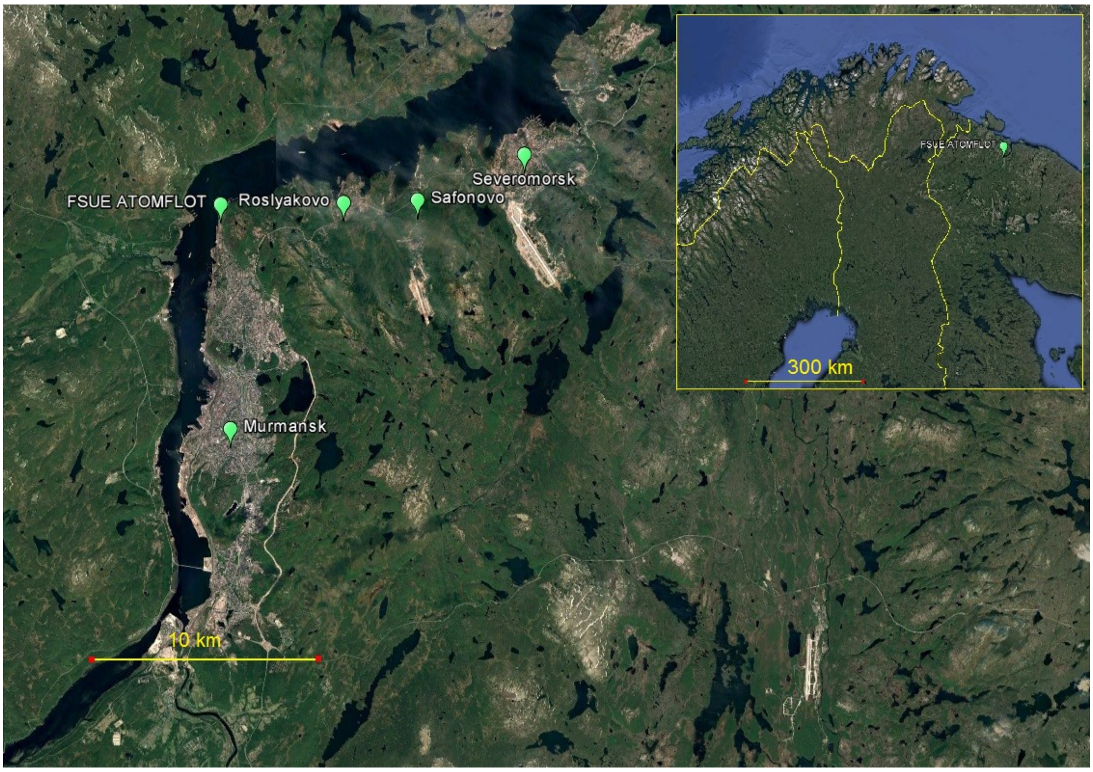

Figure 2. Location of FSUE ATOMFLOT (Source: Google Earth).

The climate of the Kola Peninsula is affected by its location north of the Arctic Circle and its proximity to the warm water streams of the Atlantic Ocean. The region's climate is classified as being as sub-humid and maritime with some areas possibly being classified as humid zones. The climate is tempered by the warm North Cape current in the Barents Sea along the northern coast of the peninsula. Prevalent winds are south-westerly, southerly and westerly. The annual distribution of wind frequencies for the Murmansk and Andreeva Bay areas are provided in Table 1.

Table 1. – Frequency of wind directions (%) for the Murmansk and Andreeva Bay areas.

	Direction							
	N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Murmansk	14	8	3	4	36	20	6	9
Andreeva Bay	12	10	9	6	15	24	14	10

The mean annual wind speed is 5.3 m/s for Murmansk and 6.6 m/s for Andreeva Bay, highest wind speeds being observed in the winter, late autumn and early spring. The average number of days with winds in excess of 15 m/s is 68 days at Andreeva Bay and 38 in Murmansk although days with strong winds may occur all year round. Annual relative humidity is 75-85 per cent, the lowest relative humidity being observed in May-June, the highest (up to 86 percent) being during the months of February and August (November in Murmansk.

Annual precipitation is typically about 500 mm/yr, half of all precipitation falling as rain and half falling as solid or mixed precipitation. Precipitation is spread unevenly through the year, being highest (63 mm) in the autumn (August-October) and lowest in April (28 mm). On average, there are about 200 days with precipitation per year, days with traces of precipitation (≤0.1 mm) being 50-70 per year. The mean annual air temperature is + 0.2 °C in Murmansk and +1.2 ºC in Andreeva Bay. February is the coldest month (- 6-10 ºC) while July is the warmest (10-12 ºC). Normal annual atmospheric pressure at sea level is 1011 hPa with insignificant monthly variations (8-10 hPa).

1.1.2 Geology and hydrogeology

The Andreeva Bay facility is situated on a peninsula stretching northwest to southeast with an overburden of technogenic soils and marine deposits. A concrete pier on the shore of the bay serves as the eastern limit of the site. The terrain in the north-west and centre of the facility is flat and covered with concrete slabs. The north eastern part of the site has difficult access with the entire surface being covered with mounds and pits up to 0.5 m deep and by slopes of 1.0-3.0 m. The area has a simple geology. The shore section has virtually no sand-clay deposits, the shore bedrock is mainly composed of Precambrian granite-gneiss and, to a lesser extent, gabbro-diabase. The near shore sea bottom is largely rocky with a prevalence of silt and sand in some areas. Silt prevails in the middle of the bay. The area has a seismic rating of 7 as per Map S OSR-97. The Andreeva Bay projects into the north-western shore of the Zapadnaya Litsa Bay some 40 km from its head. The depth at the mouth of the bay is some 90 m and rises steeply towards the head and shores. The tidal zone in the south of the bay is 5-10 m wide expanding up to 150 m along the northern part of the shore. The surface temperature is 0.8 °C in the winter and up to 17 °C in the summer. Semidiurnal tidal effects play a major role in the sea level regime. The average tide is 240 cm and the fall and rise intervals are virtually equal. Meteorological factors (atmospheric pressure and wind) have a substantial influence on the levels, changing atmospheric pressure may decrease the sea level by 30 cm or increase it by 45 cm. Wind influences both the height of tide and the time of high and low water. Riverine runoff has little influence. Tidal and constant currents play a major role in the flow regime of the bay. During the tide, the current flows towards the head of the Zapadnaya Litsa Bay and away from the bay during the ebb. The velocity of the constant current from the head of the bay is no more than 2 knots (1.01 m/s). The average velocity of summary currents is 2-2.5 knots. Maximum velocity is 3 knots (1.54 m/s).

FSUE Atomflot is situated on the steep eastern shore of the Kola Bay north of Murmansk. Hills in the area are up to 180 m high. The shore plunges rapidly down into the bay – the 10-m isobath is 15-25 m from the shoreline while the 20 m isobath is 100-120 m away. 150 m away the depth is 25 m. At depth, the bottom is primarily silt with silty sand and sand closer to the shore with occasional rocks. The facility itself adjoins a steep bedrock slope to a glacial plateau with elevations from 0 to 39 m and occupies the offshore strip of the bay, the lower sea-shore terrace and a part of the slope of the adjoining hill. The facility sits on a man-made embankment (4.4 m deep) filled with sandy soils and some pebble/boulder mixed soils. There are occasional bedrock outcrops. Underlying the man-made soil are marine sandstone and morainic deposits overlying the parent bedrock. In terms of hydrogeology, the site has ground water in the quaternary deposits and fractured bedrock zone. The free groundwater, recharged by rainwater and melt water infiltration, has a strong hydraulic link to the water in the bay, influencing both its level and chemical composition. Groundwater depth varies widely depending on the bedrock depth, composition of the aqueous soil and surface topography. During boring, the groundwater was registered at depths from 1 to 4.1 m from the surface. Chemically, the groundwater and seawater are of sodium-chloride and calcium-hydrocarbonate type.

2 The Andreeva Bay Facility

The onshore service base in Andreeva Bay was built and commissioned in 1961-1963 and was used as a service base for nuclear submarines for 25 years. The base received and temporarily stored spent nuclear fuel (SNF) and was engaged in its preparation for shipping as well as for the reception of, treatment and temporary storage of solid and liquid radioactive waste (SRW and LRW). The base stopped taking in spent nuclear fuel and radioactive waste in 1989. Currently, the temporary SNF and RW storage facility at Andreeva Bay is managed by the Northwestern Centre for radioactive waste management SevRAO, branch of FSUE RosRAO (NWC SevRAO - branch of FSUE RosRAO) as the Andreeva Bay branch. The facility stores a large amount of SNF (approximate 21000 spent fuel elements) and solid and radioactive waste. SNF is in the dry storage unit) and in 20 shielded casks of an old design in conditions that fail to meet current nuclear and radiation safety requirements. According to the 'Concept of environmental rehabilitation of onshore technical bases of the Northern region of Russia' the Andreeva Bay facility is to be decommissioned, the most important phase of the decommissioning being the removal of SNF from its current storage and its transport for processing. No life extension or conversion of the facility is envisioned. Currently, the facility hosts the following major facilities/sites of the SNF handling and transport system:

1. Tanks 2A, 2B, 3A – SNF Dry storage unit;
2. Building 151 –pad for transport shielded casks;
3. PMK-67 pier;
4. Building 121 – storage of old shielded casks with SNF;
5. Building 154 – storage and maintenance of auxiliary equipment;
6. Building 5 – decommissioned SNF storage facility;
7. Building 6 - LRW and SRW storage;
8. Building 67 – SRW storage;
9. Building 67A - SRW storage;
10. Building 201 – Enclosure No. 1 over SRW storages 7 and 7A;
11. Building 202 – Enclosure No. 2 over SRW storages 7B, 7B1, 7G, 7G1;
12. Building 50 – Laboratory facility;
13. Building 160 – fixed sanitary pass before the DSU controlled access zone;
14. Building 210 – modular sanitary pass at the SRW storage pad;
15. Building 209 – carwash at the SRW pad.

The layout of the SNF and RW handling and transport complex at Andreeva Bay is shown in Figure 3.

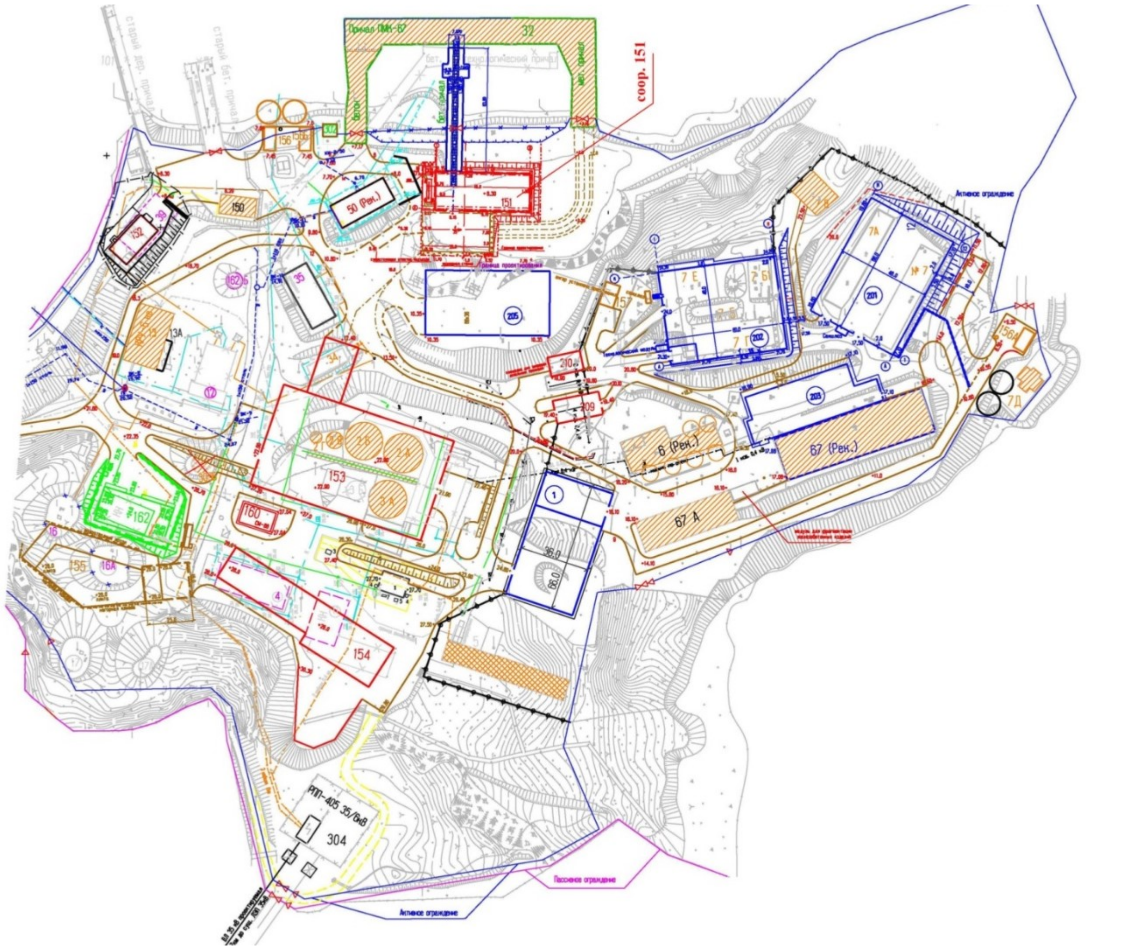

Figure 3. Layout of the SNF and RW handling and transport complex at the Andreeva Bay.

As per Russian sanitary regulations [25], a sanitary protection zone (SPZ), coinciding with the facility fence line (physical protection perimeter), has been imposed around the Andreeva Bay facility. An observation zone (OZ) within a circle of radius 10 km around the area has also been established. The delineation of the SPZ and OZ was verified by OAO Lead Institute VNIPIET in 2012 [26, 27]. The limits of the existing sanitary protection zone and observation zone in the Andreeva Bay are shown in Figure 4. The SNF dry storage unit (DSU) was established after an accident at the storage pool (Building 5) in 1982 resulted in a leak from cooling ponds within the building. The DSU is comprised of three separate storages: 3A, 2A and 2B, which were established in the three 1000 m^3 tanks of the unused special water treatment facility. The tanks are partially buried and made of cast, reinforced concrete. The bottom of the tanks is 0.9 m thick and the walls are 0.7 m thick. Tank 2A has a stainless steel lining and tanks 3A and 2B have a 25 mm layer of shotcrete containing sodium aluminate.

Tanks 2A, 2B and 3A were built in 1965 and designed by VNIPIET for the reception and storage of LRW but were never used for the original purpose. In 1983-1985, these tanks were rebuilt for the temporary storage of spent fuel assemblies (SFAs) by fitting them with vertically oriented metal tubes for storage of canisters with SFAs. The tubes are made of St.20 carbon steel. The cell depth at 2A and 2B is 4,000 mm and 4,100 mm, respectively. The inner diameter of the cells in 2B is 310-313 mm (1000 mm height) at the top and about 260 mm at the bottom. Cells in 2A are of uniform diameter along their length. Sizes are 313 mm and 260 mm. Cells in 3A have a similar geometry to those in 2B: 310-313 mm at the top (1000 mm height) and about 260 mm at the bottom. Depth is 4050 mm (figures obtained from measuring two cells). According to random measurements, the maximum vertical deviation of tubes in DSU cells is thought to be 1.5–2 degrees. Currently, almost all cells are full with the exception of cells where structural defects prevented the placement of SFA canisters. The DSU cells house canisters with SFAs from nuclear-powered icebreakers and first and second-generation nuclear-powered submarines. The three DSU tanks house over 3000 canisters with SFAs of different types.

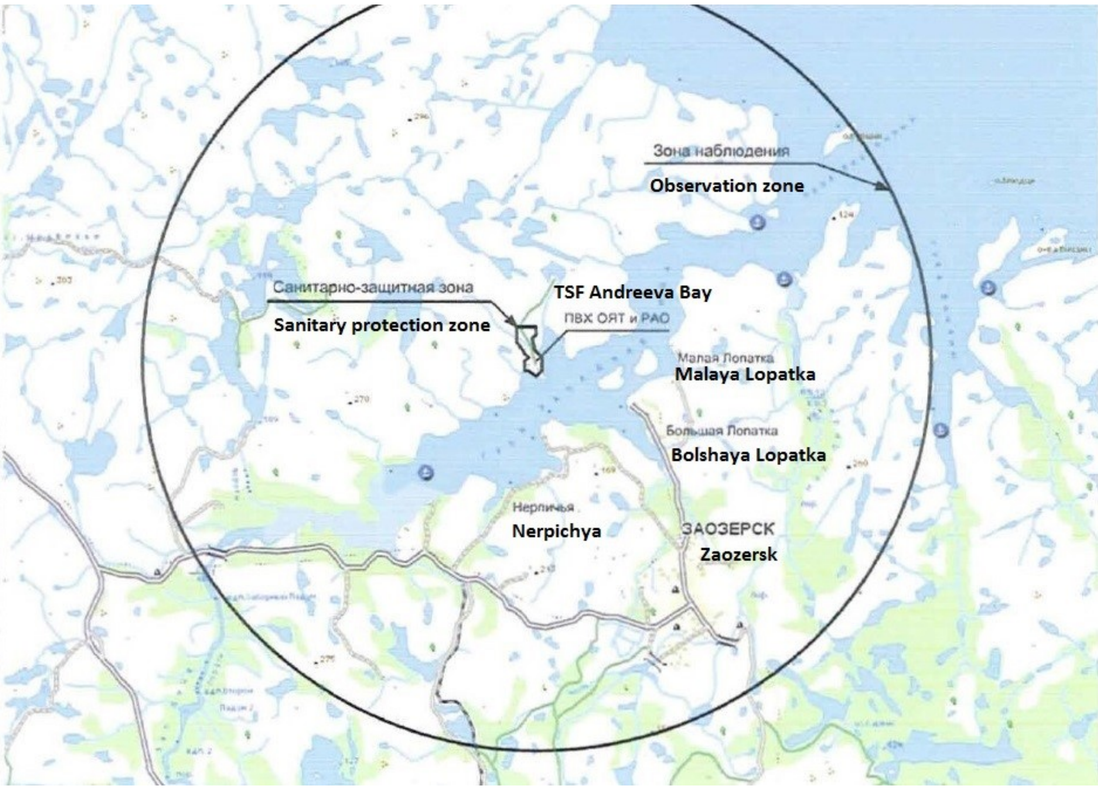

Figure 4. Sanitary protection zone (SPZ) and observation zone (OZ) of the Andreeva Bay facility.

In 2010-2012, efforts were made to improve the radiological environment in all three DSU tanks, including the installation of additional horizontal shielding on top of the DSU to reduce irradiation to acceptable levels and facilitate access to the tanks for construction or other activities. As the DSU tanks have different gamma radiation levels at their surfaces, the steel shielding elements (cross pieces and inserts) installed on the tanks are of different thickness - 75 mm on DSU 2A, 120 mm on 2B and 150 mm on 3A. The radiological environment over the DSU tanks after the installation of the horizontal shielding meets the design requirements. To allow for SNF removal, a sector of horizontal shielding (1600×1600 mm) will be cut out above the respective cells. Accordingly, once the shielding is removed the radiological environment above the worksite will deteriorate. Special equipment and a local ventilation system must be used to protect the personnel and reduce releases of volatile radionuclides to the environment.

The purpose of the DSU enclosure (Building 153) is to ensure a safe working environment during SNF retrieval from the DSU cells, transferal of SFAs to ChT canisters and the filling of TUK-108/1 (TUK-18) packages. Furthermore, the DSU enclosure facilitates the operation of the retrieval machine, bridge cranes, transfer cars and special-purpose equipment for the operations mentioned above. The enclosure also serves to prevent ingress of precipitation to the DSU, casks and canisters and limits the release of radioactive substances and ionizing radiation to the environment under normal operating conditions and in the event of an accident. The status as of December 2016 for B153 is that the structure is in place with the crane installed and work is underway to finish installing ventilation and electrical systems. The plan is to commission B153 during the first half of 2017. The DSU Enclosure is a heated two-aisle structure over the DSU tanks with an annex on the eastern side of the building. The purpose of this annex is for the transfer of canisters with SFAs to the TUK-108/1 (TK-18) transport shielded casks and preparation of packages for transport. The ground floor plan of Building 153 is shown in Figure 5 and the location of Building 153 within the Andreeva Bay facility is shown in Figure 3.

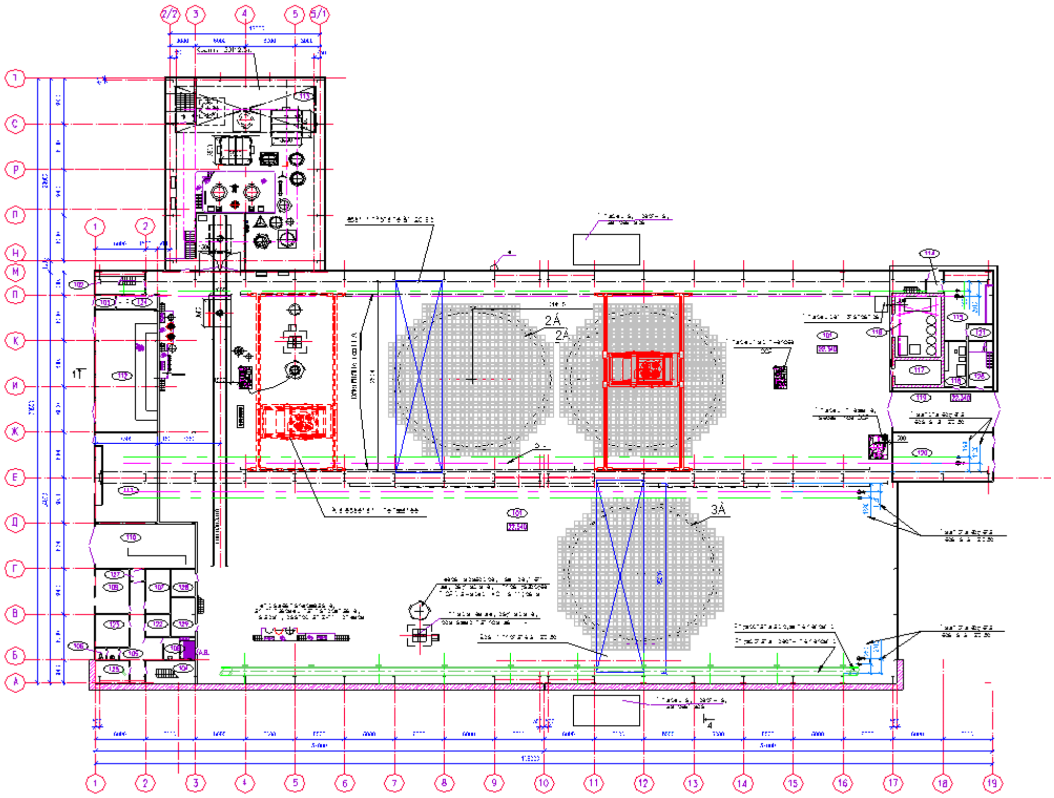

Figure 5. Building 153 layout.

The following areas, rooms and stations are to be found within Building 153:

1. Two-aisle transport process hall;
2. TUK preparation hall (in the annex);
3. Auxiliary services section with a vehicle airlock in the first (eastern) aisle of Building 153 (southern part of the building);
4. Auxiliary services section with a vehicle airlock (northern part of the building).

The building is designated according to Russian regulations as a class 1 potential hazard. Class 1 operations will be performed in the building and a three-zone concept was therefore chosen for the building. This concept is an element of the radiation safety assurance system, protecting the personnel and the environment from radiation and potential contamination both under normal operating conditions and in case of remediation after potential radiological accidents. The three zones are as follows:

1. Zone 1 – unmanned areas which are the main source of radiation and contamination;
2. Zone 2 – periodically manned areas designated for SFA retrieval, maintenance of RW collection and handling equipment;
3. Zone 3 – continuously manned areas throughout the shift.

All rooms of Building 153, except for common ventilation and switchboard rooms, are controlled access areas. Zone 3 is accessed via a gallery connecting the existing sanitary pass (Building 160) and Building 153. A fixed sanitary airlock is planned between Zone 3 and 2. A centralized supply and exhaust ventilation, local ventilation with mechanical activation and natural ventilation are employed in Building 153. Airflows are directed from rooms with lower radioactive contamination towards rooms with potentially higher radioactive contamination. To reduce contamination of the main air ducts, the filters are installed in dedicated rooms in immediate proximity to the source of contamination. To minimize emissions of radioactive aerosols to the environment, contaminated air from local suction and exhaust hoods, as well as air removed by general ventilation from Zone 2, is discharged to the atmosphere via a high stack. The selected stack height (40 m) ensures that the plume stays out of the air shadow of the building and reduces the volumetric activity of radioactive substances in the air at the plume landing point within the established dose limit for the public.

In addition to general ventilation, the following local extraction systems are envisioned in Building 153:

1. from filter unit of the retrieval machine;
2. ventilation module of the SFA transfer station;
3. from the exhaust hood of the chemical sampling module.

Two inlet and exhaust systems are envisioned for general ventilation of the transport process hall. Air diffusers are installed on inlet air ducts. Self-contained local extraction systems are envisioned for the ventilation of the retrieval machine. The air flow discharged from the machine is 500 m^3/h. The retrieval machine will have a two-stage air filtration unit and a flow booster. The exhaust plants serving the transport process hall are located in the northern face end of the building. Air is discharged via a single high stack. One-stage filtration via FVEA-3500 aerosol filters is envisioned for the general exhaust ventilation of the transport process hall. The local extraction systems of the main and auxiliary retrieval machines will have a third stage of filtration via FVEA-3500 aerosol filters.

Air supply plants serving the transport process hall are located externally along the eastern and western walls of the building in insulated containers. A self-contained local extraction system is planned for the exhaust hood of the chemical sampling module. The exhaust hood has one stage air treatment. Secondary treatment will take place over the FVEA-3500 aerosol filter. SERF-type spring exhaust reels complete with a SovPlim-made fan for the removal of vehicle exhaust gases are envisioned for the vehicle airlocks. Negative air balance is envisioned in order to maintain standardized under-pressure between 10 and 20 Pa in Zone 2, which will be compensated for by supplying air to Zone 3.

Air removed from Zone 2 is released via the high stack of Building 153 after one-stage treatment at FVEA-3500 aerosol filters. Air removed from Zone 3 is discharged at the rooftop of the building untreated. Under normal operating conditions, 153 will have no adverse impact on surface and ground water, water area, soils and geological environment, flora and fauna. 11 observation wells are planned around Building 153 to monitor possible radionuclide migration with ground water.

Building 151 is designated for the temporary storage of empty and full TUK-108/1 (TK-18) shielded transport casks at the Andreeva Bay facility. The accumulation pad can accommodate 48 TUK-108/1 (TK-18) shielded casks at the same time (full or empty). TUK-108/1 (TUK-18) packages containing SNF must be brought to Building 151 from Building 153 on a special vehicle, designated for the transport of such casks. A rail transfer car must be used for the transfer of TUK-108/1 (TUK-18) packages from Building 151 to the PMK-67 pier and the transfer of empty casks to the accumulation pad. Building 151 has a vehicle access way and a rail track running from the building to a ramp for the rail transfer car. Transfer of casks within Building 151 is performed with the help of 50/12-tonne bridge crane. The locations of Building 151 and PMK-67 pier are shown in Figure 6.

TUK-108/1 (TUK-18) packages with SNF from Building 153 will arrive with a frequency of one-two casks per week regularly during the year. Design quantity of packages arriving from Building 153 is 96 a year. People will be present in Building 151 during the intake of SNF casks from Building 153 but not more than 4 hours per shift. TUK-108/1 (TUK-18) casks with SNF from Building 1 (from TSF) will be shipped in batches of 6 or 12 packages per transport ship voyage. The transfer of casks with SNF to the transport ship is a continuous operation until the transfer is complete, but no more than 2÷3 days. A shift is 6 hours long with 4 shifts a day. Only TUK-108/1 and TK-18 shielded casks are accepted for temporary storage between the voyages. Building 151 is assigned Class 3 potential radiological hazard. The building has natural ventilation, untreated air from the cask storage hall leaves via grilles at the height of 12 m.

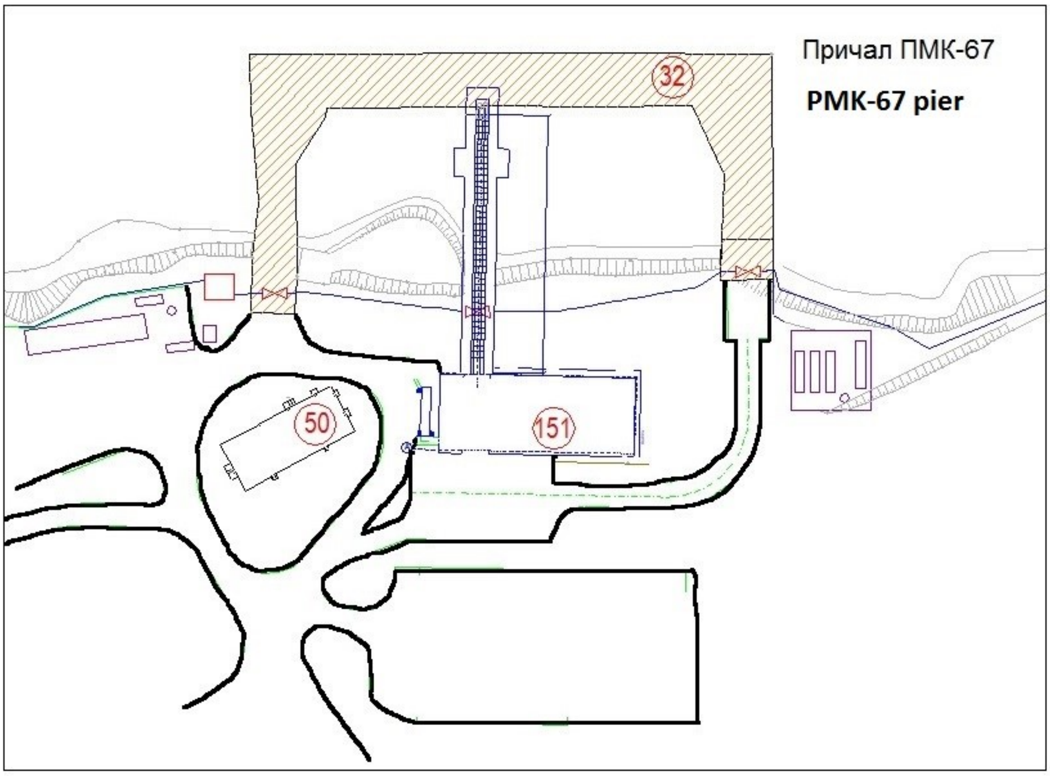

Figure 6. Locations of the accumulation pad and PMK-67 pier at the Andreeva bay facility.

3 The Radiological Environment of Andreeva Bay

The buildings designated for the storage of SNF, SRW and LRW are sources of radioactive contamination and affect the radiological environment at the Andreeva Bay facility. The radiological environment at the Andreeva Bay faciity depends on the following sources of radioactive contamination:

1. LRW storages in Building 6 and Building 7V;
2. Building 5 (former SNF storage). The building houses contaminated equipment, building structures and concrete ceilings;
3. Building 67A (SRW storage facility). Waste is stored in temporary packages and bags;

4. Areas 7V, 7G, 7E montejus pad for storage of SRW (total volume 1802 m^3). SRW is comprised of temporary packages, filters, transfer equipment, concrete beams, containers;
5. Building 67 storing containers with SRW;
6. Building 7 – SRW storage containing sources of ionizing radiation, measurement channels, polyethylene cans, bags with waste, filters, equipment;
7. Building 7A storing temporary packages with SRW.

Gamma dose rates and beta radiation flux densities in buildings at the Andreeva Bay facility are shown in Table 2.

Table 2. Gamma dose rates and beta contamination densities in buildings

Station (Structure)	**Gamma dose rate, µSv/h**		**Particle flux density (average), part/cm²*min**	
	Average	**Maximum**	**Alpha**	**Beta**
Controlled access zone of Building 5	160.0	430.0	<2	1440
Building 7D	0.584	0.88	<2	12
Building 67A	16.8	67.3	<2	120
Building 7V	3.788	7.95	<2	900
Building 7G	4.253	25.3	<2	120
Building 7B1	1.418	5.73	<2	42
Building 202	0.878	1.24	<2	120
Building 201	2.706	3.29	<2	120
Building 7A	8.234	23.84	<2	1200
Building 7	11.086	27.87	<2	1500
DSU tanks	3.28	5.41	<2	80
Building 67	1.176	4.09	<2	420
Building 6	1.48	6.17	<2	1800
Building 7E	2.562	3.35	<2	420
Montejus pad	30.56	55.82	<2	980

The radiological conditions in the DSU saw significant improvement after the installation of the additional horizontal shielding on top of the DSU. According to NWC SevRAO [1], gamma dose rates on the surface of the tanks range between 3.28 and 5.41 µSv/h, and beta radiation flux density is 80 part/ cm^2× min. Averaged monthly values (daily in potentially contaminated areas) for measurements of gamma dose rates and beta radiation flux densities outside buildings and select sites at the Andreeva Bay facility for 2014 are provided in Table 3.

Table 3. Radiation monitoring data in the radiation safety regime zone (potential contamination zone, PCZ) and the controlled access zone (CA zone).

Zone	Control point number and location	Gamma µSv/h	beta, part./min·cm²
RS zone	No.1 centre of gate of Building 152 (10 m towards Building 50)	0.13	<6
RS zone	No.2 on centre of gate of concrete pier	0.156	<6
RS zone	No.3 intersection Building 150 – Building 50 – fixed pier	0.174	<6
RS zone	No.4 on centre of northern gate, fixed pier	0.15	<6
RS zone	No.5 road between Building 151 and Building 50	0.16	<6
RS zone	No.6 on centre of southern gate, fixed pier	0.18	<6
RS zone	No.7 entrance to Building 50 (at 1 m)	0.18	<6
RS zone	No.8 road near Building 50 (2m from the stairway)	0.188	<6
RS zone	No.9 road to Pad 3 (6 m from the gate to Building 205 site)	0.232	<6
RS zone	No.10 roads to Pad 3 (6 m from switchboard)	0.204	<6
RS zone	No.11 access to Pad 3	0.37	<6
RS zone	No.12 access to controlled access area of DSU from Pad 3	0.338	<6
RS zone	No.13 6 m from the transformation substation (on the right of decon. station of Pad 3)	0.436	<6
RS zone	No.14 access to CAZ DSU from DPP	0.178	<6
RS zone	No.15 access to zone of the RB regime (near SPm-88 No.1 DSU)	0.134	<6
RS zone	No.16 access to CAZ DSU (between SPm-88 No.1 and DSU decon. station)	0.278	<6
RS zone	No.17 gate of DSU decon. station (from Building 5)	0.322	<6
RS zone	No.18 road between DSU decon. station and temporary building for storage of containers with SNF	0.524	<6
RS zone	No.19 access to CAZ DSU (from Building 5)	0.588	<6
CA zone	No.20 entrance to PRK of Building 5 (at 1 m)	0.408	<6
CA zone	No.21 entrance to temporary building for containers with SNF	1.58	<6
CA zone	No.22 End of Building 5 facing the bay (at 4 m)	0.83	24
CA zone	No.23 between entrance to SPm-88 No. 1 DSU (between DSU airlock and SPm-88 No. 1)	0.33	6
CA zone	No.24 between DSU decon. station and DSU 3A	0.73	9
CA zone	No.25 Entrance to DSU 3A (at 2 m)	2.436	18
CA zone	No.26 Entrance to DSU 2A (at 2 m)	0.386	18
CA zone	No.27 Entrance to DSU 2B (at 2 m)	0.614	9
CA zone	No.28 road between Pad 3 decon. stationand SPm-10 No.1 of Building 5 (limit of DSU CAZ and Building 1 construction site)	0.502	9

Zone	Control point number and location	Gamma µSv/h	beta, part./min·cm²
CA zone	No.29 entrance of Building №6 (at 1 m)	0.71	18
CA zone	No.30 middle of the road between Building 67A and Building 6	2.234	24
CA zone	No.31 gate of Building 67 (at 3 m)	1.334	9
CA zone	No.32 intersection of roads from Building 201, Building 67 and road to Building 7D	0.786	24
CA zone	No.33 between Building 7D and gate of PEPE site	0.874	18
CA zone	No.34 access to Building 7V (from Building 202)	2.7	180
CA zone	No.35 access to left gate of Building 202 (at 3 m)	1.696	9
CA zone	No.36 access to juice pump pad	5.584	780
CA zone	No. 37 intersection – montejus pad, Building 202, Building 67, access to PL-3	0.698	9

Observation wells were drilled at the Andreeva Bay facility to monitor potential migration of radionuclides with groundwater. The wells are used for radiochemical sampling and monitoring of groundwater level. Spectrometric analysis of water from monitoring wells shows that the mean annual activity of radionuclides in the wells is below minimum detectable activity (MDA). The radiological environment at the TSF Andreeva Bay in 2013 was concluded as satisfactory by the FMBA with insignificant radiation burdens of 0.425 mSv/y for Group A and 0.116 mSv/y for Group B workers (Table 4). However according to radiological survey data, the following areas of the facility have elevated gamma-radiation levels: Building 5, montejus pad, Building 6, Building 67, Buildings 7, 7A, 7G and 7V (See Table 2). Work in these buildings must therefore be time limited to avoid personnel overexposure. The radiological environment in other areas, in terms of external gamma radiation, is within values acceptable for the continuous presence of personnel. Soil contamination is within background levels. The average annual external dose rate outside the technical area at the limit of the sanitary protection zone (SPZ) is 0.12 µSv/h with minor fluctuations [3]. Gamma does rate at control points within the SPZ range between 0.10 and 0.20 µSv/h, while beta particle flux densities at control points within the SPZ are below 6 part/min*cm^2; no alpha contamination has been identified at control points within the SPZ. Gamma dose rates at control points within the OZ range between 0.10 and 0.14 µSv/h, while beta particle flux densities at control points within the OZ are below 6 part/min*cm^2; no alpha contamination has been identified at control points within the OZ.

Table 4. Annual personnel exposure at the TSF Andreeva Bay in 2013.

Group	Number of persons	Number of persons with individual doses in the following ranges mSv/y							Mean dose mSv/y	Collective dose, manSv/y
		0-1	1-2	2-5	5-12.5	12.5-20	20-50	>50		
Group A	68	59	8	1	-	-	-	-	0.425	0.02892
Group B	51	51	-	-	-	-	-	-	0.116	0.00594
Total	119								0.293	0.03486

Measurement results for aerosol activity in the atmospheric air of the Andreeva Bay facility are shown in Table 5. Measurement results of average annual fallout densities are provided in Table 6.

Table 5. Average annual aerosol activity in the air

Sampling point	Total volumetric alpha and beta activity, Bq/m³
SPM88-1 (DSU sanitary pass)	< 0.02
Radiation monitoring checkpoint	< 0.02
Security checkpoint KPP-1	0.0004

Table 6. Average annual fallout density

Sampling point	Total fallout density, Bq/d*m²
SPM88-1 (DSU sanitary pass)	0. 471
Radiation monitoring checkpoint	0.174
Security checkpoint KPP-1	0.105

Fallout radioactivity ranges from 0.1 to 0.47 Bq/d*m^2, which is significantly below the reference level of 8 Bq/d*m^2. The 2013 radiological and hygienic certificate of the Andreeva Bay branch [3] provides values for the average annual volumetric activity of radionuclides in the air in the sanitary protection zone (SPZ) and in the observation zone (OZ), which are shown Tables 7 and 8. The values in the table do not exceed ^{137}Cs and ^{90}Sr air volumetric activity established by the Russian standard NRB-99/2009. The contribution of radioactive noble gasses and radioactive aerosols to air contamination is negligible. This can be explained by the fact that the SNF stored on the site has been cooling for more than 30 years. Krypton (with the exception of ^{85}Kr) and xenon radionuclides have almost fully decayed. The release of ^{85}Kr from the nuclear material via microcracks in the SFAs is so small that it is undetectable by sensitive modern radiation monitoring instrumentation. Only radioactive dust blown off contaminated surfaces in the DSU and SRW storage pad comprise the main source of radioactive aerosols.

Table 7. Average annual volumetric activity of radionuclides in the air of sanitary protection zone

Radionuclide	Atmospheric air, Bq/m³				
	Number of sumples	Average		Maximum	
		Bq/m³	in VAL_{pub}	Bq/m³	in VAL_{pub}
^{137}Cs	94	2.93E-04	1.09E-05	6.04E-04	2.24E-05
^{90}Sr	94	-	-	-	-
^{226}Ra	94	8.42E-05	2.81E-03	4.66E-04	1.6E-02

Table 8. Average annual volumetric activity of radionuclides in the air of observation zone

Radionuclide	Atmospheric air, Bq/m³				
	Number of samples	Average		Maximum	
		Bq/m³	in VAL_{pub}	Bq/m³	in VAL_{pub}
^{137}Cs	11	2.8E-06	1.04E-07	3.8E-06	1.41E-07
^{90}Sr	11	9.75E-05	3.61E-05	1.07E-04	3.96E-05
^{226}Ra	11	-	-	-	-

The 2013 radiological and hygienic certificate of Andreeva Bay branch [3] provides specific activity of radionuclides in the surface water bodies in the sanitary protection zone and observation zone, which are shown Tables 9 and 10.

Table 9. Specific activity of radionuclides in the surface water bodies in the sanitary protection zone

Radionuclide	Water in surface water bodies, Bq/l		
	Number of samples	Average	Maximum
		Bq/l	Bq/l
^{137}Cs	149	<3	<3
^{90}Sr	149	<1	<1
^{226}Ra	145	<8	<8

Table 10. Specific activity of radionuclides in the surface water bodies in the observation zone

Radionuclide	Water in surface water bodies, Bq/l		
	Number of samples	Average	Maximum
		Bq/l	Bq/l
^{137}Cs	2	<3	<3
^{90}Sr	2	<1	<1
^{226}Ra	2	<8	<8

Tables 9 and 10 show that the activity levels of water are determined by the natural radionuclide ^{226}Ra. Its average annual specific activity is above the intervention level (0.5 Bq/kg) established by NRB-99/2009. For many years, emergency leaks of water from the pools of the SFA storage facility (Building 5) were the main source of radioactive contamination of aquatic and hydrogeological compartments in the Andreeva Bay. The data provided by NWC SevRAO [1] indicate that the specific activity of seawater at the mouth of a former stream of Building 5 in 2014 did not exceed that of the samples taken at other locations along the shoreline at the Andreeva Bay facility. Total specific activity of seawater for all radionuclides in the samples taken at the PMK-67 pier, the old concrete pier, the buoyancy tanks dryer and at the mouth of the former stream is below 1 Bq/kg. The results of water sampling in surface freshwater bodies in the SPZ and OZ are provided in Table 11.

Table 11. Average annual activity of fresh water surface bodies in the SPZ and OZ

Radionuclide	Sampling point, specific activity, Bq/kg			
	SPZ	OZ		
	Stream near checkpoint 12	PSM	Lake Bezymyannoe	Lake Podkova
^{137}Cs	<3	-	<3	<3
^{226}Ra	5.85	7.44	7.3	5.16
^{232}Th	5.75	4.96	5.18	3.95
^{90}Sr	<1	<1	<1	<1
ΣAα	5.40E-03	-	5.4E-03	1.60E-01
ΣAβ	5.40E-02	<7.32	<1	3.00E-02

Radionuclide content in soil and sediment in the sanitary protection zone and in the observation zone of the TSF Andreeva Bay is provided in Tables 12 and 13. Data comparison indicates that the specific activity of radionuclides at these points has decreased by factors of between 2 and 3 since 2003.

Table 12. Average annual specific activity of soil in the SPZ and OZ

Radionuclide	Sampling point, specific activity, Bq/kg				
	SPZ			OZ	
	Roadside opposite ABK	Stream valley near checkpoint 12	Area behind Building 5	Road near the stadium	Road near Lake Podkova
^{137}Cs	0.41	3.22	0.42	<0.41	0.58
^{226}Ra	1.34	1.57	1.90	1.42	1.35
^{232}Th	2.09	<0.32	4.33	3.01	2.64
^{40}K	72.43	75.89	125.81	<12.99	84.8
^{90}Sr	2.67	2.03	14.5	1.082	3.1

Table 13. Average annual specific activity of sediments in the SPZ and OZ

Radionuclide	Sampling point, specific activity, Bq/kg			
	PMK-67	Old concrete pier	BT dryer	Mouth of former stream of Building 5
^{137}Cs	1.31	6.96	16.5	18.9
^{226}Ra	1.32	0.805	1.27	1.93
^{232}Th	2.28	1.28	1.87	4.37
^{40}K	30.86	<32.14	35.16	25.6
^{90}Sr	12.48	9.75	18.53	39.0

The influence of radioactive contamination at the Andreeva Bay facility manifests itself as the accumulation of radionuclides in vegetation and aquatic organisms. Average annual specific activities in the SPZ and in the OZ are provided in Tables 14 and 15.

Table 14. Average annual specific activity of vegetation of the SPZ and OZ

Radionuclide	Sampling point, specific activity, Bq/kg				
	SPZ			OZ	
	Roadside opposite ABK	Stream valley near checkpoint 12	Area behind Building 5	Road near the stadium	Road near Lake Podkova
^{137}Cs	<0.01	<0.012	<0.267	<1.38	1.03
^{226}Ra	<0.29	0.013	<0.422	<2.35	0.327
^{232}Th	0.40	0.02	0.55	3.71	0.248
^{40}K	3.34	2.33	40.07	185.78	23.15
^{90}Sr	0.93	5.37	15.48	14.83	1.13

Table 15. Average annual specific activity of aquatic organisms of the SPZ and OZ

Radionuclide	Sampling point, specific activity, Bq/kg			
	PMK-67	Old concrete pier	Buoyancy tank drier	Mouth of former stream of Building 5
^{137}Cs	1.24	0.0002	0.039	0.0747
^{226}Ra	0.036	0.0825	0.0366	0.0477
^{232}Th	0.0444	0.0697	0.0508	0.114
^{40}K	2.76	4.67	3.68	3.98
^{90}Sr	2.18	2.8	5.24	8.85

4 SNF and RW Management at FSUE ATOMFLOT

FSUE Atomflot is a permanent base for nuclear-powered icebreakers and nuclear service ships and a range of activities in this context are conducted there. These include the maintenance and repair of general and special marine equipment, the refuelling of nuclear icebreakers, the preparation of SNF for rail transport, reception and loading of fresh nuclear fuel for nuclear icebreakers, the reception, treatment and temporary storage of liquid and solid radioactive waste and other ancillary activities related to operation of nuclear icebreakers. The railway is used for the transport of various technical cargo, including fresh and spent nuclear fuel. The facility has three cranes along dockside including a 100-ton KONE portal crane. Currently, a new 100-ton crane is being installed to replace the overage KONE crane. The general layout of SNF and RW handling facilities at FSUE Atomflot is shown in Figure 7.

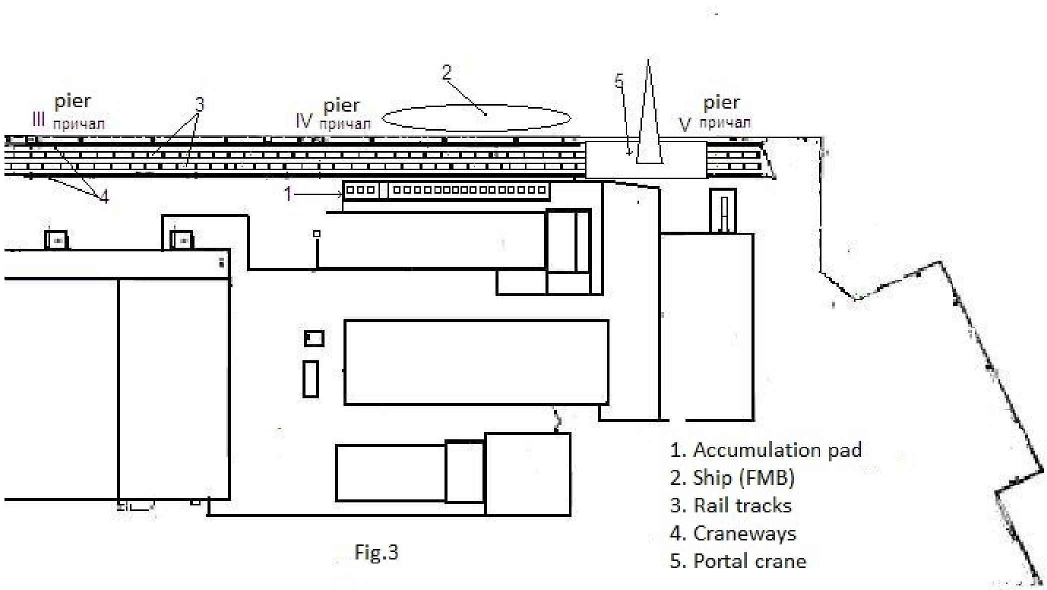

Figure 7. Layout of SNF handling facilities at FSUE Atomflot.

The ATOMFLOT enterprise comprises of the following divisions:

1. Repair-technological complex comprising units for the repair of general marine equipment, metalworking and fabrication of ship structures;
2. Special facility for the maintenance of process equipment of nuclear power plants;
3. Storage facility for SRW containers (400 m^3);
4. Storage facility for high-level SRW (containers with spent ion-exchange materials from heat transport main circuit and emergency control rods);
5. Storage area for high-level equipment (steam generators and primary coolant pumps);
6. Storage area for containers with reactor pull-out parts;
7. Pilot LRW treatment facility;

8. A central laboratory, environmental laboratory and unit for determining the presence of radionuclides in the human body – "whole-body counter";
9. A floating dock;
10. A host of auxiliary shops, a boiler house, a transport department and a fire department;
11. Gantries with portal cranes, etc.

The accumulation pad is located in Zone A near piers 4 and 5 (a plan of the site being displayed in Figure 7), its actual appearance being depicted in Figure 8. The pad is located parallel to the mooring line along Buildings 4 and 5. The accumulation pad consists of the following structures and equipment:

- A fixed marine pier;
- The accumulation pad proper for storage of transport packages with SNF;
- A 100-ton KONE portal crane;
- A physical protection system;
- A communication system;
- Routine and emergency lighting system.

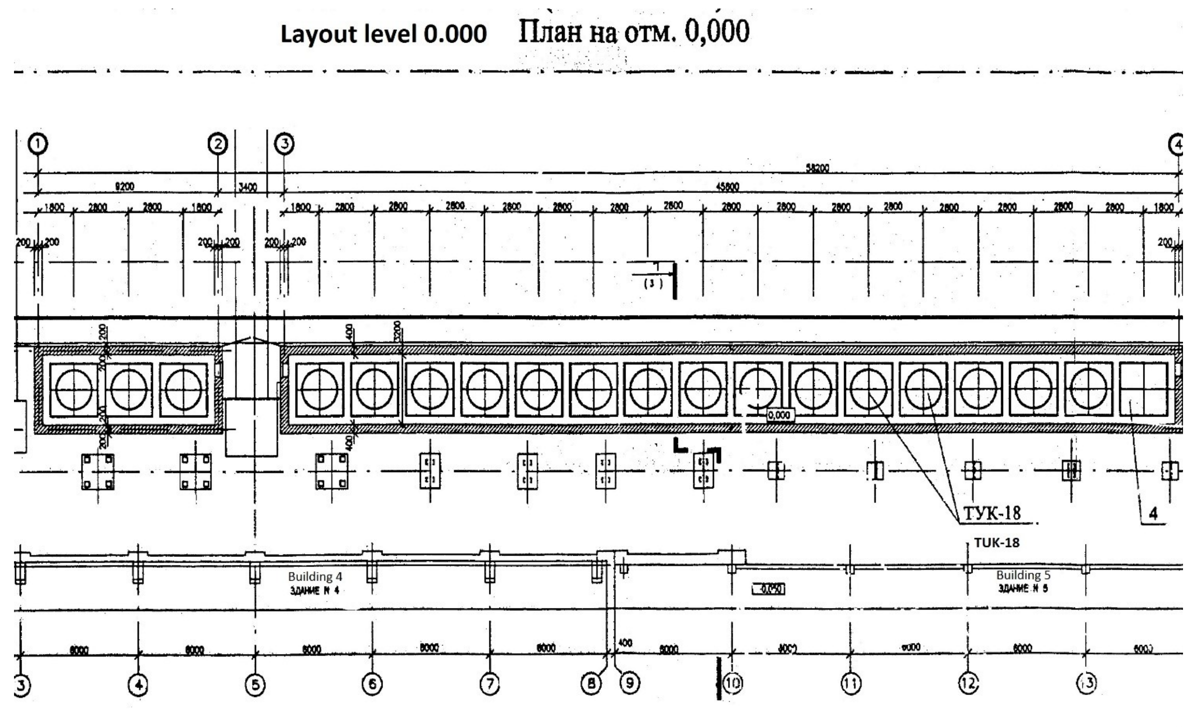

Figure 8. Site plan of the accumulation pad at FSUE Atomflot.

The accumulation pad is divided in two sections, each being 4 meters wide and 9.6 and 46 meters long. Utility conduits and a pipe rack run between the sections. The sections are covered by a common 4.6 meter-wide service platform, which serves as the ceiling for the sections. The service platform provides access to the trunnions of the stored casks. The shielded transport casks are transferred to the pad via hatchways. Which are covered with lidded boxes. The accumulation pad can store 19 TUK-18 packages. The 9.6-meter-long section fits three packages and the 46-meter-long section fits 16 packages. The spacing between the packages is 2.8 m. The box removal device is also placed on the service platform. The device is handled manually. The 45-ton cross-beam is stored on overhangs in the middle of the pad. A catwalk bridge connects the service platform to the sanitary pass in Building 5. Shielding of the accumulation pad is provided for by the structural elements. The walls and base slabs are made of cast, reinforced concrete. The base slab is 600 mm thick including the asphalt layer. A lenticular sheet-steel floor deck is welded to beams and the plates are welded to each other with composite welds. The gap between the sections has a wire mesh fence and a gate providing access to underground services. Internal reinforced concrete and metal surfaces have chemically resistant enamel coating, while the external surfaces have an organo-silicon coating.

Each cask sits on a two-layered stainless steel spacer plate (5 and 1.5 mm thick) to prevent contamination of the pad's floor. To monitor possible radionuclide migration with groundwater, there are three 10-meter deep observation wells between the rail tracks along the crane trestle axis. The wells are 25 m apart and have filters and sunken wellheads with a top hatch at the top. Water is supplied to the accumulation pad via a utility and drinking water line and a fire line running along the pipe rack. The pad is equipped with a storm water system. Handling of wastes is performed by a portal crane travelling along the accumulation pad on ground rail tracks on the pier side.

The sanitary protection zone (SPZ) of Atomflot facility is a circle of radius 1 km centered within the facility. The observation zone (OZ) is a circle (excluding the SPZ) of radius 5 km and centered on the same point. Both zones have been agreed with the municipal authorities in Murmansk and ZATO Severmorosk.

The Radiological environment in the FSUE Atomflot area

The current radiological environment in the FSUE Atomflot area is considered as being normal, the facility having operated normally during the 2008-2013 period. The radiation safety and environmental department of the facility conducts continuous radiation monitoring of the on-shore area of the site, SPZ and OZ as per the approved schedule and relevant Russian procedural guidelines. In 2013, the exposures of group A and group B personnel of FSUE Atomflot were within relevant limits. Individual and collective doses for the facility's personnel in 2013 are presented in Table 16. There was no overexposure of group A or group B personnel in 2013. The maximum individual doze incurred by a staff member in 2013 was 17.62 mSv. Average dose of this staff member in 2009-2013 is 5.06 mSv.

Average gamma dose rates measured at various locations of FSUE Atomflot are shown in Table 17. Gamma dose rates measured at four points of the FSUE Atomflot sanitary protection zone (within 1 km of the centre of the facility) are provided in Table 18. Gamma dose rates measured at points of the FSUE Atomflot observation zone are provided in Table 19. Table 20 provides gamma dose rates in settlements of Abram-mys and Drovyanoe situated 8.5 km and 14 km from the site, respectively, which were used as background levels.

Table 16. Individual and collective doses of the FSUE Atomflot personnel in 2013.

Group	Number of persons	Number of persons with individual doses in the following ranges (mSv/y)							Mean individual dose, mSv/y	Collective dose, manSv/y
		0 - 1	1 - 2	2 - 5	5-12.5	12.5-20	20-50	>50		
Group A	691	544	60	44	36	7	-	-	1.154	0.7975
Group B	1446	1446	-	-	-	-	-	-	0.244	0.3226
Total	2137	1990	60	44	36	7	-	-	0.538	1.15

Table 17. Dose rates throughout the FSUE Atomflot facility

Monitored areas	Number of control points	Average gamma dose rate (µSv/h)
Main pier	18	0.223
Main area	20	0.176
Special production department area	18	0.791
Total for the facility	56	0.397

Table 18. Dose rates in the SPZ at FSUE Atomflot

Measurement point	Position (degrees)		Dose rate, µSv/h
	N	E	
1	69,043	33,077	0.056
2	69,044	33,078	0.058
3	69,049	33,080	0.064
4	69,049	33,084	0.063

Note: Limits of intrinsic relative error are 20 %

Table 19. Dose rate in the observation zone at FSUE Atomflot

Measurement point, distance	Position (degrees)		Dose rate, µSv/h
	N	E	
Belokamenka - 5 km	69,0759	33,1737	0.042
Mishukovo – 2.4 km	69,0373	33,0296	0.059

Note: Limits of intrinsic relative error are 20 %

Table 20. Background dose rate levels

Measurement point	Position (degrees)		Dose rate, µSv/h
	N	E	
Abram-mys – 8.5 km	68,9663	68,9663	0.055
Drovyanoe - 14 km	68,9259	68,9259	0.048
Note: Limits of intrinsic relative error are 20 %			

The values show that the average dose rate at FSUE Atomflot facility are an order of magnitude higher than the background level for this region. However, according to the data of the FSUE Atomflot radiation safety and environmental monitoring department, the storage of TUK-108/1 and TUK-18 packages at the accumulation pad does not affect the radiological environment at the facility. For example, the gamma background on the accumulation pad, especially in its northern end outside the enclosure and on the ceiling is up to 20 µSv/h due to the vicinity of the SRW facility. The gamma background elsewhere on the ceiling of the accumulation pad when there are no operations with RW in its vicinity, is commensurate with the facility's average level of up to 0.4 µSv/h. The accumulation pad has no observable surface contamination.

Measurements showed that the gamma level on the surface of TUK-18 arriving for temporary storage at the accumulation pad was between 1.0 and 20 µSv/h depending on the location of the measurement point on the surface. Fixed surface contamination of TUK-18 was up to 1000 β-part/(cm^2 × min). No releases of radioactivity during TUK-18 handling have been registered in the air near the accumulation pad. Maximum personnel radiation burden during operations on the pad was up to 30 µSv, mainly due to background from RW storage facilities.

Air and water quality

According to the data provided by FSUE Atomflot [2], the average annual volumetric activities of radionuclides in air and water in the sanitary protection zone and in the observation zone are very close to background levels and do not exceed regulatory air volumetric activity limits for ^{137}Cs and ^{90}Sr (Tables 21, 22, 23).

Table 21. Volumetric activity of radionuclides in air and water in the sanitary protection zone

Sampling point	Position		Sampled medium	Volumetric activity of radionuclides, Bq/m^3	
	N	E		^{90}Sr	^{137}Cs
1	69.043	33.077	Water	29.7	<53.29
5	On-site		Air	<1.8×10^{-3}	<15.8
Note: Confidence error is 35 % (P=0.95) for ^{137}Cs and 40 % (P=0.95) for ^{90}Sr.					

Table 22. Volumetric activity of radionuclides in the observation zone

Sampling point	**Position**		**Sampled medium**	**Volumetric activity of radionuclides, Bq/m³**	
	N	**E**		**^{90}Sr**	**^{137}Cs**
Belokamenka	69.0759	33.1737	Water	71.08	<47.09
			Air	$<1.8\times10^{-3}$	<15.64

Note: Confidence error is 35 % (P=0.95) for ^{137}Cs and 40 % (P=0.95) for ^{90}Sr.

Table 23. Background volumetric activity of radionuclides in air and water

Sampling point	**Position**		**Sampled medium**	**Volumetric activity of radionuclides, Bq/m³**	
	N	**E**		**^{90}Sr**	**^{137}Cs**
Drovyanoe	68.9259	33.0155	Water	42.23	<40.08
			Air	$<1.9\times10^{-3}$	<15.71

Note: Confidence error is 35 % (P=0.95) for ^{137}Cs and 40 % (P=0.95) for ^{90}Sr.

Analysis of environmental conditions

Analysis of the impact of ^{90}Sr and ^{137}Cs radionuclides on vegetation, soil, sediment and algae in the sanitary protection zone and in the observation zone is presented in Tables 24 and 25. For comparison, background levels obtained in the settlements of Abram-mys and Drovyanoe (8.5 and 14 km from FSUE Atomflot, respectively) are provided in Table 26.

Table 24. Specific activity of radionuclides in the sanitary protection zone

Point	**Position**		**Sampled medium**	**Specific activity, Bq/kg**	
	N	**E**		**^{90}Sr**	**^{137}Cs**
1	69.043	33.077	Grass	<4.2	15.33
			Soil	<3.75	72.92
2	69.044	33.078	Grass	<4.79	18.89
			Soil	<2.84	82.61
3	69.049	33.080	Grass	<7.02	14.48
			Soil	<10.73	48.25
4	69.049	33.084	Grass	<7.34	<16.34
			Soil	<29.14	16.77
5	On-site		Fish	<2.89	<71.91
6	On-site		Algae	10.3	<4.88

Note: Confidence error is 35 % (P=0.95) for ^{137}Cs and 40 % (P=0.95) for ^{90}Sr

Table 25. Specific activity of radionuclides in the observation zone

Sampling point	Position N	Position E	Sampled medium	Specific activity of radionuclides, Bq/kg ^{90}Sr	^{137}Cs
Belokamenka	69,0759	33,1737	Grass	43.29	<4.99
			Soil	<12.63	13.19
			Sediment	36.62	<0.8
			Algae	6.7	<6.54
Mishukovo	69,0373	33,0296	Grass	<5.43	<12.43
			Soil	<21.18	<1.51
			Algae	11.37	<7.09

Note: Confidence error is 35 % (P=0.95) for ^{137}Cs and 40 % (P=0.95) for ^{90}Sr

Table 26. Background specific activity of radionuclides in environmental samples

Sampling point	Position N	Position E	Sampled medium	Specific activity of radionuclides, Bq/kg ^{90}Sr	^{137}Cs
Abram-mys	68,9663	33,0270	Grass	<6.41	<9.49
			Soil	<29.17	<1.21
			Algae	<5.32	<5.82
Drovyanoe	68,9259	33,0155	Grass	<3.1	<14.17
			Soil	<38.19	<0.95
			Algae	10.44	<15.14
			Sediment	<71.98	<0.98

Note: Confidence error is 35 % (P=0.95) for ^{137}Cs and 40 % (P=0.95) for ^{90}Sr

According to the data provided, the activities conducted FSUE Atomflot do not have any significant impact on the public resident in the observation zone. There is virtually no radioactive pollution of the environment. The following sources contribute to the radioactive pollution of the environment (air, soil, vegetation, etc.): natural background radiation due to natural radionuclides (^{226}Ra, ^{40}K, etc), global fallout (^{90}Sr, ^{137}Cs) and technogenic radionuclides (^{60}Co, $^{152,154}Eu$, ^{90}Sr, ^{137}Cs, ^{134}Cs). As seen from the data provided, the contribution of technogenic sources of radioactive contamination has little influence on the general background radiation in the surrounding area.

Discharges of radioactive substances

In 2013, nuclear powered vessels and the onshore facilities of FSUE Atomflot released 1.83×10^{12} Bq of inert radioactive gases to the atmosphere [4], whereas the regulatory limit imposed by the Murmansk regional department of technological and environmental oversight of Rostechnadzor was 11.1×10^{12} Bq. The actual release was 16.6% of the limit. In 2013, the discharge of water from sanitary passes, special laundries and treated effluents from the liquid radioactive waste treatment plant to the Kola Bay totaled 943 m^3. Specific concentration of radionuclides was within regulatory limits. Totals are provided in Table 27.

Table 27. Discharges of radionuclides to the Kola Bay

Radionuclide	Actual discharge, Bq/y	Discharge limit, Bq/y	Actual vs. limit, %
^{60}Co	5.58×10^{6}	2.94×10^{8}	1.90
^{90}Sr	5.94×10^{7}	1.2×10^{8}	49.49
^{95}Zr	1.46×10^{5}	1.35×10^{7}	1.08
^{54}Mn	5.6×10^{4}	3.29×10^{7}	0.17
^{134}Cs	6.0×10^{5}	5.35×10^{7}	1.14
^{137}Cs	3.12×10^{7}	3.95×10^{8}	7.89
^{152}Eu	2.01×10^{5}	7.36×10^{7}	0.27
^{154}Eu	1.6×10^{5}	2.82×10^{8}	0.06

5 SNF Removal From The Andreeva Bay Facility And Transport To FSUE Atomflot: Process And Technology Description

The process developed for SNF handling at the Andreeva Bay facility and at FSUE Atomflot [5] must ensure safe - both for the personnel and the public - retrieval of all SFAs from DSU cells, transfer to TUK-108/1 and TUK-18 casks, temporary storage and shipping of TUK-108/1 and TUK-18 packages to FSUE Atomflot in the shortest time possible. The following main principles have been assumed in the development of the SNF and RW handling technology:

1. Nuclear and radiological safety assurance in relation to SNF removal from Andreeva Bay in accordance with the existing regulatory and legal requirements;
2. Prevention of the dispersal of radioactive substances inside the process rooms and to the environment;
3. The use of the ALARA principle (minimizing impact of radiation on the personnel, public and environment as much as technically achievable and economically viable);
4. The use of a physical barrier system preventing dispersal of ionizing radiation and radioactive substances to the environment (defense-in-depth principle);
5. Use of various controls;
6. The optimization of transport and handling operations in respect to SNF and resultant RW;
7. The minimization of secondary RW generation;
8. Radiological security (physical protection) at all stages of SNF management and control and accounting of nuclear materials and radioactive substances at all stages of SNF and RW management;

9. Monitoring of the radiological environment in buildings, facilities, on-site areas, the sanitary protection zone and the observation zone when handling SNF and resultant RW.

Taking account of the new SNF handling infrastructure under construction at the Andreeva Bay facility, the general flow chart of SNF retrieval from the DSU cells and SNF transport for reprocessing includes the following major operations/activities:

1. Preparation of the canisters and spent nuclear fuel assemblies in the DSU cells;
2. Removal of the SFAs from canisters stored in the DSU cells;
3. Transferal of the SFAs to ChT-type canisters;
4. Transferal of the ChT-type canisters filled with SFAs to a TUK-108/1 (TUK-18) cask and preparation of the cask for transport;
5. Transportation of the TUK-108/1 (TUK-18) packages to the accumulation pad using a vehicle;
6. Buffer storage of packages on the accumulation pad;
7. Transportation of the TUK-108/1 (TUK-18) packages to the pier using a transfer railcar;
8. Transferal of the TUK-108/1 (TUK-18) packages to the hold of a transport ship (m/v Serebryanka or m/v Rossita);
9. Sea passage of the transport ship to FSUE Atomflot in Murmansk;
10. Transferal of the TUK-108/1 (TUK-18) packages from the transport ship to the FSUE Atomflot accumulation pad or to the special train;

The retrieval of SNF from the DSU cells, transfer of the SFAs to ChT type canisters or sleeves, transferal of canisters with SFAs to TUK-108/1 (TUK-18) packages for shipment to FSUE PA Mayak for reprocessing must be performed sequentially and includes the following main stages:

Stage 1: removal of all undamaged SFAs from the canisters stored in tanks 2A and 2B.

Stage 2: retrieval of 'repaired' and damaged (defective) SFAs with substantial mechanical damage (missing or damaged grab part, ruptured active part and the like) from the canisters stored in tanks 2A and 2B.

Stage 3: retrieval of damaged SFAs from tanks 2A and 2B, which could not be retrieved during stages 1 and 2 due to swelling, bending or other reasons. Once all fuel is removed from tanks 2A and 2B, the retrieval machine is transferred from the eastern aisle (over tanks 2A and 2B) of Building 153 to the western aisle (over tank 3A).

Stage 4: retrieval of all SFAs from Tank 3A.

Retrieval of undamaged and damaged SFAs from the DSU, transfer to TK-18 (TUK-108/1) transport casks in Building 153 and shipping from the Andreeva Bay

All operations involving SNF retrieval from DSU cells, transfer of SFAs to ChT canisters and transfer of canisters with SFAs to TUK-108/1 (TK-18) transport shielded casks must be carried out in the DSU Enclosure (Building 153). Before commencement of SNF retrieval from the DSU cells, the rooves and walls of tanks 2A, 2B and 3A must be removed and horizontal shielding must be in place. The bulk of water must be removed from tanks 2B and 3A and hydraulic works must be performed to prevent reinfiltration of groundwater to the DSU cells. SNF preparation for retrieval and retrieval from DSU cells must be performed with the help of special-purpose equipment mounted on the retrieval machine. A detachable SFA transfer cask (OK-300 PBU ver. 2) must be used for the retrieval of individual SFAs stored in the DSU cells. The transfer cask is handled inside of the process hall with the help of a 20-ton capacity bridge crane. The transfer of individual SFAs retrieved from the DSU cells to ChT canisters must be performed at a stationary Ch-T canister loading station, arranged in a buried caisson in the process hall of Building 153.

Damaged (defective) SFAs, which show evidence of mechanical damage (breakage, shell ruptures, bending and similar) during retrieval from the DSU cells, must be placed in sleeves for damaged SFAs in three-place ChT-11Sh or ChT-14Sh canisters. Filled ChT canisters must be transferred in a canister transfer cask (KB-651 cask) in a transfer car to the cask preparation hall, where they are to be placed in TUK-108/1 (TK-18) standard transport shielded casks. ChT canisters with SFAs must be transferred to TUK-108/1 (TK-18) transport shielded casks at the process stand arranged in process hall for cask preparation for transport (Room 113). A ready-to-go full TUK-108/1 (TUK-18) transport shielded cask is transferred to the transport corridor of the DSU Enclosure and placed on a motor carrier with the help of a 50-ton capacity bridge crane. If it is impossible to retrieve all SFAs from the canister in a DSU cell with the help of standard equipment, the canister must be removed together with the stuck SFAs. The canister with SFAs may be removed from a DSU cell only after removal of water from the interior of the canister and the cell it is stored in. Canisters with SFAs must be retrieved from the DSU cells and placed in the station for retrieval of SFAs from “old” canisters with the help of a canister transfer cask (KB-651). At the station for retrieval of SFAs from “old” canisters, damaged SFAs must be “repaired” with the help of special-purpose tools and fixtures. “Repaired” SFAs must be transferred to one-place sleeves placed inside ChT-11Sh or ChT-14Sh canisters with the help of a standard transfer cask (OK-300 PBU ver. 2). Canisters with irretrievable SFAs must be transferred in a canister transfer cask (KB-651 cask) in a transfer car to the hall for TUK cask preparation for transport, where they are placed in modernized shipping packages consisting of a special multiple sleeve for canisters and a TK-18 transport shielded cask.

Solid radioactive waste generated during SNF removal in the DSU Enclosure is to be collected on-site and placed in returnable collector containers for internal transport. Further handling takes places in Buildings 201, 202 and 205 of the RW management complex. Liquid radioactive waste removed from canisters and the DSU cells must undergo mechanical purification to remove corrosion products as well as purification from radionuclides using the filters at the water removal plant to reduce activity to low-level waste. Low-level LRW is transferred to holding tanks and then to the vessel m/v Serebryanka to be shipped for treatment. In the DSU Enclosure (Building 153) all gaseous waste as well as air removed by general ventilation systems from Zone 2 after being filtered is discharged via a high stack. The selected stack height (40 m) ensures that the plume stays out of the air shadow of the building and reduces the volumetric activity of radioactive substances in the air at the plume landing point within the established exposure limit. Air, removed from under the horizontal shielding, DSU cells and canisters by the filtration unit, inbuilt into the retrieval machine, undergoes a three-stage treatment over HEPA filters and is transferred via a system of flexible hoses to a separate exhaust ventilation system, where it undergoes additional one-stage treatment before discharge to the atmosphere via a 40 m high stack.

Ready-to-go full TUK-108/1 (TUK-18) packages must be transported from the DSU Enclosure to the accumulation pad (Building 151) on a special-purpose 50-ton capacity motor carrier. At the accumulation pad (Building 151), packages may be placed for temporary storage or transferred to a rail transfer car with the help of 50-ton capacity bridge crane in Building 151 to be transported to the stationary PMK-67 pier. TUK-108/1 (TUK-18) packages are not opened and SNF is not handled at the accumulation pad. At the PMK-67 pier TUK-108/1 (TUK-18) packages must be transferred from the transfer rail car to the cargo hold of a transport ship (m/v Rossita or m/v Serebryanka).

TUK-108/1 (TUK-18) packages with SNF removed from DSU cells are transported by sea from the PMK-67 pier in Andreeva Bay to the SNF transshipment facility at FSUE Atomflot in Murmansk.

Transshipment of TUK-108/1 (TK-18) casks with SNF at FSUE Atomflot

Transport of SNF from the Andreeva Bay facility to FSUE PA Mayak requires transshipment of the TUK-108/1 (TUK-18) packages from the transport ship to the special train at the FSUE Atomflot SNF transshipment facility (with the possibility of temporary storing the packages at the accumulation pad of FSUE Atomflot).

Handling operations and equipment used for the transshipment of TUK-108/1 and TUK-18 packages at FSUE Atomflot are identical for both SNF removal options from the Andreeva Bay facility and involve the use of existing SNF handling infrastructure at FSUE Atomflot. The transshipment will require performing the following operations:

- Mooring of the transport ship arriving from the Andreeva Bay facility, with TUK-108/1 (TUK-18) packages onboard, at the pier of FSUE Atomflot as per the approved mooring diagram;
- Preparation the transport ship for the offloading of packages;
- Preparation a special railcar or a cell of the accumulation pad for the transfer of TUK-108/1 (TUK-18) packages from the cargo section of the transport ship;
- Transferal of an empty TUK-108/1 (TK-18) shielded cask from the railcar to the FSUE Atomflot accumulation pad using the 100-ton capacity onshore portal crane and a standard 45-ton cross-beam;
- Unrigging of the fastening of TUK-108/1 (TUK-18) packages in the cargo section of the transport ship;
- Transferal of the TUK-108/1 (TUK-18) package from the cargo section of the transport ship to a cell of the accumulation pad or directly to the special railcar using the onshore portal crane and a 45-ton cross-beam;
- Repeating of the sequence to remove all packages from the cargo section of the transport ship.

Any transshipment operations with TUK-108/1 (TUK-18) packages at the SNF transshipment facility must be performed by the staff of FSUE Atomflot. TUK-108/1 (TUK-18) packages are not opened and there no interim transshipment of SFAs from the packages at the SNF transshipment facility during temporary storage on the FSUE Atomflot accumulation pad or during transit.

6 SNF Removal From The Andreeva Bay Facility And Transport To FSUE Atomflot: Environmental Impacts

Removal of undamaged and damaged SFAs, transfer them to TUK-108/1 (TK-18) casks in Building 153 and transport on a transport ship.

Under this transport scheme, all operations (SNF removal from DSU cells, transfer of SFAs to ChT canisters and the transfer of the canisters to TUK-108/1 (TUK-18) shielded transport casks) must be performed inside the DSU Enclosure (Building 153). Further SNF handling (temporary storage at the accumulation pad and loading onto a transport ship) must be in sealed shielded TUK-108/1 (TUK-18) casks.

The removal of SNF from the DSU cells and its transfer to casks inside Building 153 will result in the generation of gaseous radioactive waste (GRW) which must be treated to prevent emissions of radioactivity that exceed regulated limits. Under normal operation, the atmospheric impact of Building 153 is caused by gas-aerosol processes and ventilation releases. The following gas treatment systems are envisioned in Building 153 for the treatment of process generated GRW:

1. local gas treatment systems for 'venting' gases of the water removal plant tanks;
2. local gas treatment system of the retrieval machine;
3. local gas treatment system of SFA transfer stations.

To remove radioactive aerosols, 'venting' gases of the water removal plant tanks must undergo a two-stage treatment over FVEA-3500 filters with which the water removal plant must be fitted. Treated air is removed via flexible ducts to the stationary duct and is then released via a 40-meter high vent stack. Discharged air flow is up to 50 m^3/h. Volumetric activity of the discharged air is up to 5.3×10^{-2} Bq/m^3. The air, removed from the work area on the DSU tank through an opening in the horizontal shielding, undergoes a three-stage treatment over the filters of the filtration unit, inbuilt into the retrieval machine, and is transferred via a system of flexible hoses to a separate exhaust ventilation system, where it undergoes additional one-stage treatment before discharge to the atmosphere via the 40 m high stack. The discharge air flow is up to 500 m^3/h, the volumetric activity of the discharged air being up to 1×10^{-3} Bq/m^3.

The air removed from the ChT canister filling stations, after treatment in the ventilation unit, is transferred to the exhaust ventilation of the retrieval machine where it also undergoes additional one-stage treatment before discharge to the atmosphere. Discharged air flow is up to 750 m^3/h, the volumetric activity of the discharged air being up to 1×10^{-3} Bq/m^3. Under normal operation of Building 153, the total annual radioactive emissions from the process gas treatment systems will be 1.2×10^4 Bq/y with the discharged air flow not exceeding 4.0×10^6 m^3/year. To ensure the normal performance of Building 153, a centralized supply and exhaust ventilation, local ventilation with mechanical activation and natural ventilation are envisioned. To minimize emissions of radioactive aerosols to the environment, contaminated air from local suctions and exhaust hoods, as well as air removed by general ventilation from Zone 2 is discharged to the atmosphere via a 40 m high stack after one-stage treatment over FVEA-3500 filters. Total airflow discharged via the stack is 71200 m^3/h or 6.2×10^8 m^3/y.

If the volumetric activity of the air in Zone 2 is conservatively assumed to be 5 Bq/m^3, the design annual radionuclide emissions with discharged air via the stack will be 3.1×10^7 Bq/y given the annual airflow of 6.2×10^8 m^3/year and filter decontamination factor of 10^2. Thus, under normal operation of Building 153, the emissions are determined largely by ventilation releases and is 3.1×10^7 Bq/y.

The following radionuclide composition of the emissions is assumed as being:

^{137}Cs – 50 % - 1.55×10^7 Bq/y;

^{90}Sr – 45 % - 1.39×10^7 Bq/y;

^{60}Co – 5 % - 1.55×10^6 Bq/y.

To determine the dose burden to the public during the normal operation of Building 153, radionuclide atmospheric dispersion calculations were performed. The module “Nuclide” of the Garant-Universal software, version 4.0 (certificate of conformity ROSS RU.ME20.H00882 issued by Gosstandart of Russia) was used for the calculation, based on the provisions of regulatory document ‘Guidelines for establishing limits for emissions of radioactive substances (DV-98)’. Calculations were performed for three locations outside the SPZ of the Andreeva Bay (Fig. 5.1) facility:

1. Northern limit of Nerpichya Bay – 1.8 km;
2. Northwestern limit of Bolshaya Lopatka Bay – 2.4 km;
3. Northern limit of Zaozersk – 5.5 km.

The following parameters were calculated for these locations:

1. The mean annual ground-level concentrations of radionuclides;
2. the annual radionuclide fallout on land;
3. the annual effective dose to the public exclusive and inclusive of radionuclide intake via food chains.

The resultant calculations are shown in Table 28. Calculated values of annual ground-level concentrations of ^{137}Cs, ^{90}Sr and ^{60}Co are much lower than VAL_{pub} (permitted level for public) values for these radionuclides of 27 Bq/m^3, 2.7 Bq/m^3 and 11 Bq/m^3, respectively.

Calculated values of annual effective doses to the public are significantly lower than main dose limits regulated by NRB-99/2009.

Table 28. Annual ground-level concentrations, annual fallout on land and annual effective doses to the public.

Distance from the source	**Radionuclide**	**Mean annual ground-level concentration (Bq/m^3)**	**Annual fallout on land (Bq/m^2×year)**	**Annual effective dose (µSv/y)**	
				exclusive of food chains	**inclusive of food chains**
1.8	^{137}Cs	$6.75 \cdot 10^{-8}$	$1.09 \cdot 10^{-2}$	$1.36 \cdot 10^{-3}$	$7.12 \cdot 10^{-3}$
	^{90}Sr	$6.05 \cdot 10^{-8}$	$9.81 \cdot 10^{-3}$	$2.21 \cdot 10^{-5}$	$9.83 \cdot 10^{-3}$
	^{60}Co	$6.69 \cdot 10^{-9}$	$1.09 \cdot 10^{-3}$	$2.32 \cdot 10^{-4}$	$3.102 \cdot 10^{-4}$
	Total	-	-	$1.617 \cdot 10^{-3}$	$1.727 \cdot 10^{-2}$
2.4	^{137}Cs	$5.10 \cdot 10^{-8}$	$8.27 \cdot 10^{-3}$	$1.02 \cdot 10^{-3}$	$5.37 \cdot 10^{-3}$
	^{90}Sr	$4.58 \cdot 10^{-8}$	$7.42 \cdot 10^{-3}$	$1.67 \cdot 10^{-5}$	$7.44 \cdot 10^{-3}$
	^{60}Co	$5.04 \cdot 10^{-9}$	$8.27 \cdot 10^{-4}$	$1.75 \cdot 10^{-4}$	$2.341 \cdot 10^{-4}$
	Total	-	-	$1.214 \cdot 10^{-3}$	$1.304 \cdot 10^{-2}$
5.5	^{137}Cs	$1.77 \cdot 10^{-8}$	$2.88 \cdot 10^{-3}$	$3.57 \cdot 10^{-4}$	$1.877 \cdot 10^{-3}$
	^{90}Sr	$1.59 \cdot 10^{-8}$	$2.59 \cdot 10^{-3}$	$5.79 \cdot 10^{-6}$	$2.60 \cdot 10^{-3}$
	^{60}Co	$1.75 \cdot 10^{-9}$	$2.88 \cdot 10^{-4}$	$6.13 \cdot 10^{-5}$	$8.18 \cdot 10^{-5}$
	Total	-	-	$4.248 \cdot 10^{-4}$	$4.555 \cdot 10^{-3}$

Radioactive emissions from Building 151 depend on the presence of TUK-108/1 and TK-18 shielded casks filled with SNF from the DSU tanks. During storage of shielded casks in Building 151, radionuclides from the gas space of casks containing SNF might leak into the process hall and then escape untreated to the environment via the ventilation system. At that, the safety of workers and the public is ensured by the prevention of radionuclide dispersal mainly through the shielding properties of the package.

The design of TUK-108/1 and TUK-18 shielded casks excludes leaks of radioactive medium in higher than permitted quantities. Radionuclide releases to the atmosphere from the accumulation pad were calculated using the design values of gaseous content leak from the cask under normal operating conditions listed below:

- 4.7×10^{-6} m^3×Pa/s for TUK-18;
- 1×10^{-6} m^3×Pa/s for TUK-108/1 (given only one sealing barrier).

Approximate radionuclide composition of the gas space of a TUK-108/1 (TK-18) shielded cask for various reactor core types is shown in Table 29. Total release of radionuclide activity from storing 48 casks with SNF in Building 151 under normal operation is shown in Table 30.

Table 29. Radionuclide composition of cask's gas space

Nuclide	Normal operation (Bq)		
	First generation NPS	Second generation NPS	Nuclear icebreaker
^{60}Co	$2.3\cdot10^{7}$	1.7×10^{7}	1.0×10^{7}
^{85}Kr	9.4×10^{10}	7.0×10^{10}	1.9×10^{11}
^{90}Sr	3.8×10^{8}	2.8×10^{8}	8.3×10^{8}
^{134}Cs	3.6×10^{7}	2.7×10^{7}	1.6×10^{8}
^{137}Cs	4.2×10^{9}	3.1×10^{9}	8.8×10^{9}
^{238}Pu	5.5×10^{5}	4.1×10^{5}	1.7×10^{5}
^{239}Pu	4.3×10^{4}	3.2×10^{4}	7.8×10^{4}
^{240}Pu	4.9×10^{4}	3.6×10^{4}	4.8×10^{4}
^{241}Pu	3.6×10^{6}	2.7×10^{6}	7.8×10^{6}

Table 30. Releases from Building 151, Bq/y

Nuclide	Release	Nuclide	Release
^{60}Co	5.7×10^{5}	^{238}Pu	1.4×10^{4}
^{85}Kr	2.3×10^{9}	^{239}Pu	1.1×10^{3}
^{90}Sr	9.3×10^{6}	^{240}Pu	1.2×10^{3}
^{134}Cs	9.1×10^{5}	^{241}Pu	8.9×10^{4}
^{137}Cs	1.1×10^{8}	–	–

Volumetric activity of radionuclides in the indoor air of the SNF accumulation pad given the airflow of 15000 m^3/h is expected to be 19.1 Bq/m^3 and 0.93 Bq/m^3 (exclusive of ^{85}Kr activity), which is significantly lower of the permissible volumetric activity for personnel of 12000 Bq/m^3 and 570 Bq/m^3 (exclusive of ^{85}Kr activity) as per NRB-99/2009. To determine the dose burden to the public under normal operation of Building 151, radionuclide atmospheric dispersion calculations were performed for three nearest residential locations outside the SPZ of the Andreeva Bay facility:

1. Northern limit of Nerpichya Bay – 1.8 km;
2. Northwestern limit of Bolshaya Lopatka Bay – 2.4 km;
3. Northern limit of Zaozersk – 5.5 km.

Table 31 provides calculated values of effective dose to the public exclusive and inclusive of radionuclide intake via food chains.

Table 31. Effective doses to the public

Control points	**Distance from the source (km)**	**Annual effective dose (µSv/y)**	
		exclusive of food chains	**inclusive of food chains**
Nerpichya Bay	1.8	6.3×10^{-2}	9.5×10^{-1}
Bolshaya Lopatka Bay	2.4	2.8×10^{-2}	4.2×10^{-1}
Zaozersk (northern limit)	5.5	9.4×10^{-3}	1.4×10^{-1}
Zaozersk (southern limit)	6.5	7.9×10^{-3}	1.2×10^{-1}

Considering all irradiation pathways, the maximum expected dose to individual members of the public at the limit of existing SPZ of TSF (territorial limit) is indicated to be about 8.9 µSv/y. Considering the actual location of residential communities (Nerpichya Bay, Bolshaya Lopatka Bay and Zaozersk), annual doses to individual members of the public will be 0.95 µSv/y, 0.42 µSv/y, 0.14 µSv/y and 0.12 µSv/y, respectively, which is significantly lower that the hygiene standard for the public of 1,000 µSv/y specified by Russian Federal Law No. 3 and does not exceed the minimum significant dose of 10 µSv/y, specified by NRB-99/2009. Thus, the conclusion can be taken that in case of normal operation, air emissions from SNF removal and transport will have no adverse impact on the public and environment in the area.

Assessment of impact on soil and geological environment.

Under normal conditions, SNF removal from the DSU cells, its placement in TUK-108/1 (TK-18) casks in Building 153, temporary storage of packages in Building 151 and transport on a transport ship may have a radiological impact on the soils and geological environment of the TSF Andreeva Bay only through emissions of gas-aerosols containing radionuclides. As shown previously, the calculated values of doses to individual members of the public from radioactive gas-aerosol emissions are expected to be below 10 µSv/y. Ground-level concentrations of emitted radionuclides at control points are below respective values of VAL_{pub} and the annual fallout on land is below the relevant deposition limit. Thus, one can draw a conclusion that, SNF removal and transport from the Andreeva Bay site as described in this section will have no adverse impact on the area, land use and geological environment.

Impact on surface and ground water.

The following water bodies in the area of the Andreeva Bay facility are considered important:

1. near shore water area of the Andreeva Bay and the Zapadnaya Litsa Bay;
2. Lake Pityevoe, supplying water to the facility;
3. Lake Podkova.

The following is envisioned in Building 153:

1. Domestic wastewater is assumed to be discharged to the external domestic sewer of the TSF industrial site;
2. Wastewater from traps of industrial sewer must drain by free flow to the external

storm water sewer of the industrial site;

3. Conditionally clean effluents from the decontamination of the running gear of vehicles must be also drained via industrial sewer, if their radioactive contamination is below 10 levels of intervention;
4. Effluents from washing of Zone 2, TUK decontamination station and SRW container decontamination station are assumed to be drained into a trap and then together with the effluents from sanitary airlock to a sump from where the effluents are pumped without radiation monitoring to a special purpose tank truck and taken to m/v Serebryanka;
5. Effluents from decontamination of the running gear of vehicles in process rooms will be drained off either to the external storm water sewer of the industrial site, if its radioactive contamination is below 10 levels of intervention, or pumped to a special purpose tank truck and taken to m/v Serebryanka.

Water supply and sewer systems are not envisioned in Building 151 and water is not used in operations with TUK-108/1 and TK-18 shielded casks at the accumulation pad. Should external surfaces of shielded casks, vehicles, hoisting machinery or structural elements require decontamination, aqueous solutions will be used in quantities of no more than 10 liters at a time. Thus, no contamination of the near shore water area of the Andreeva Bay facility and the Zapadnaya Litsa Bay, Lake Pityevoe and Lake Podkova via effluent discharge is expected. No effluents will be discharged on land. Atmospheric precipitation of gas-aerosol radioactive emissions should not be a threat to surface water bodies and adverse impact on the surface water bodies is improbable. The absence of negative impact on soils, geological environment and surface water bodies makes it possible to draw a conclusion on the absence of adverse impact on underground water.

Predictive estimate of expected changes in fauna and flora.

There will be no need for new land allocations as the construction of new buildings and the operation of SNF management complex under this operational scheme will take place at the existing SNF and RW temporary storage facility at Andreeva Bay. As there are no large agricultural or fisheries operations near the Andreeva Bay facility and the surrounding land is not arable there will be no expected additional adverse impact on the flora and fauna in the area of the facility.

Assessment of the radiological situation during SNF removal and transport.

Penetrating radiation will primarily affect personnel involved in the retrieval of SNF from the storage facility and filling of TUK-108/1 and TK-18 transport shielded casks in Building 153. Special-purpose non-standard equipment for SNF retrieval, shielding of the equipment and measures to reduce personnel exposure were developed taking into account actual radiation levels obtained during the radiological survey of the DSU tanks. Use of a retrieval machine and remote-controlled equipment will reduce the duration of personnel's involvement in SFA retrieval operations inside the storage and consequently reduce the dose burden. The estimate of individual doses to personnel based on the number of workers involved and process procedures was made in [14]. Outside of Building 153, the safety of personnel, public and environment is mainly assured by the intrinsic properties of the shielded TUK-108/1 and TK-18 casks. The design of the shielded casks provides for sub-criticality, heat removal, containment of radionuclides and shielding under normal operating conditions and design-basis accidents as well as restricting the release of radionuclides in beyond-design-basis accidents. The intake of TUK-108/1 (TK-18) casks with SNF in Building 151 must be performed by a team of two riggers and one crane operator. The shipping of shielded casks with SNF to the pier and loading into the hold of the transport ship is performed in 4 shifts several times a year. Calculated maximum external irradiation dose for the personnel will be as follows:

1. 7.2 mSv/y for a rigger;
2. 3.8 mSv/y for a crane operator,

These values are below the annual dose limit for personnel of 20 mSv/y. Those involved in operations in Building 151 (driver, decontamination worker, electrician, physical protection electronics engineer, etc.) will incur a dose below 1 mSv/y. The internal irradiation exposure of the personnel operating in Building 151 depends on the volumetric activity of radionuclides in the air. Calculations show that the volumetric activity of radionuclides in the air of Building 151 will not exceed 1 % of VAL_{pers}, so given 800 hours of operational time a year (shipping of 96 packages a year) the internal irradiation dose will be below 0.2 mSv/y, which is significantly less than the external irradiation dose. The maximum expected dose from radioactive emissions to individual members of the public at the limit of existing SPZ of TSF (territorial limit) considering all irradiation pathways will be about 8.9 µSv/y. The maximum expected dose to individual members of the public considering all irradiation pathways at the limit of settlement (Nerpichya Bay, Bolshaya Lopatka Bay and Zaozersk) will not exceed 0.95 µSv/y, which is significantly lower than the hygiene standard for the public of 1.000 µSv/y specified by Federal Law No. 3 and does not exceed the minimum significant dose of 10 µSv/y, specified by NRB-99/2009, Personnel irradiation dose from gas-aerosol emissions at the Andreeva Bay facility will not exceed 0.4 µSv/y.

Management of solid radioactive waste

The following radioactive wastes will be generated by SNF retrieval from the DSU cells and SNF transfer to shielded casks in Building 153:

1. plugs of old canisters in DSU cells (ILW);
2. foreign objects in DSU cells (LLW/ILW);
3. filter elements of the local gas treatment system for the gas removed from the retrieval machine and SFA transfer stations (ILW);
4. filters of Stage 3 of the vent air filter system for the air removed from the retrieval machine and SFA filter stations (LLW);
5. filters and containers for shop vacuum waste (ILW);
6. filter elements of the local gas treatment systems for 'breathing' gases of the water removal plant tanks (LLW);
7. mechanical filters of the water removal plant not containing fissile nuclear materials (ILW);
8. mechanical filters of the water removal plant containing fissile nuclear materials (ILW/HLW);
9. container filters with ion-selective sorbent of the water removal plant (ILW);
10. filters of the vent air filter system for the air removed from Zone 2 (LLW);
11. disposable or overage equipment and tools (LLW);
12. solid waste generated by decontamination of equipment, vehicles and rooms (decontamination wipes, materials on hand, film coating and the like) (LLW);
13. PPE (LLW).

The following SRW handling concept is envisioned in Building 153: the SRW is collected in-situ and sorted by type and activity level, the SRW is placed in a primary package, the primary package is placed in a returnable container for transport within the facility and the SRW is taken to Building 203 for further handling. Building 153 has a dedicated room for SRW collection, outgoing inspection (radiation monitoring and weight checking) with the following equipment:

1. monorail hoist (5-tonne capacity);
2. decontamination tray connected to the special-purpose sewer;
3. storage area for containers;
4. decontamination equipment.

The following solid radioactive wastes will be generated by SNF retrieval from DSU cells using the retrieval machine:

1. foreign objects removed from DSU cells;
2. plugs of old canisters;
3. shop vacuum waste containers;
4. shop vacuum filters;
5. filters of the local gas treatment system for the gas removed from the retrieval machine;
6. filters of the SFA transfer stations ventilation module

Solid radioactive waste from the DSU cells (foreign objects and canister plugs) is collected in a shielded returnable container placed on the platform of the retrieval machine with the help of special equipment for the removal of foreign objects and debris from the butt end of the canister plug (grabs of different types). A fully shielded returnable container is transferred by a bridge crane to the SRW collection station where the container is checked for surface radioactivity and decontaminated if necessary. The shielded returnable container ready for transport is transferred to an airlock, placed on a special-purpose vehicle (a modified KAMAZ 6540 truck) and transported to Building 203. Shop vacuum filters, shop vacuum containers and intermediate-level filters of retrieval machine's gas treatment system and of the ventilation module of the transfer stations are removed from the equipment as per manufacturers' manuals. The SRW is transported from Building 153 in a returnable shielded container as described above.

Filter elements of the local gas treatment system of the water removal plant tanks, mechanical filters and activity reducing filters will be handled in accordance with the recommendations of the water removal plant designer. The following SRW will be generated at all stages of Building 153:

1. filters of the vent air filter system for the air removed from Zone 2 (LLW);
2. filters of Stage 3 of the vent air filter system for the air removed from the retrieval machine and SFA transfer stations (LLW);
3. filter of the local ventilation system;
4. disposable or overage equipment and tools (LLW);
5. filters and containers for shop vacuum waste (ILW);
6. solid waste generated by decontamination of equipment, vehicles and rooms (decontamination wipes, materials on hand, film coating and the like) (LLW);
7. PPE (LLW).

Low-level ventilation filters are removed manually and placed in primary packages (plastic bags). Then packages are moved with labour saving tools to the SRW collection area and placed inside

KRAD-3,0 containers. Full KRAD-3,0 containers are checked for surface radioactivity and decontaminated, if necessary, and transferred to the vehicle airlock, placed on a special-purpose vehicle (a modified KAMAZ 6540 truck) and transported to Building 203. Operational low-level SRW (PPE, wipes, tools/equipment) is collected in-situ in 100-liter polyethylene bags (primary package) and placed in KRAD-1,36 container of BN-0,2 drums. A container/drum is checked for surface radioactivity and decontaminated, if necessary. Then a full container/drum is transferred to the vehicle airlock, placed on a special-purpose vehicle (a modified KAMAZ 6540 truck) and transported to Building 203. An indicative nomenclature, characteristics and volume of SRW generated in Building 153 during SNF removal are shown in Table 32.

In Building 151, solid radioactive waste may be generated only in abnormal operation: loss of integrity of a full TUK-108/1 (TK-18) shielded cask or arrival of a contaminated container from Building 153. Container surfaces are decontaminated with wipes soaked in a SF-ZK solution. The quantities and types of solid radioactive waste are shown in Table 33. Temporary storage of SRW produced by the decontamination of contaminated shielded containers is not envisioned in Building 151. The SRW produced by surface decontamination of shielded containers and storage areas must be packed in 10-liter plastic bag No. 10 (version 5) inserted in a 10-liter STO-1-10-OS solid radioactive waste collector-container manufactured by Moscow-based OAO V/O ISOTOP. STO-1-10-OS SRW collector-containers are placed in the shielded containers service area. Upon completing a decontamination job, a full collector-container is removed from Building 151. Afterwards containerized SRW must be handled in accordance with the established on-site procedure. Used personal protective equipment and broken tools must also be packed in separate plastic bags No. 10 (version 5) inserted in a 10-liter STO-1-10-OS solid radioactive waste collector-container. Full collector-containers are removed from Building 151. Dose rates and surface contamination of SRW collector-containers are monitored with the designated radiation monitoring instrumentation. If necessary, the surface of the STO-1-10-OS collector-container is decontaminated with wipes soaked in a SF-Z3K solution.

Table 32. Nomenclature, characteristics and volume of SRW generated by SNF removal from DSU cells

SRW	Type	Quantity per year	Total quantity	Notes
Debris and foreign objects	LLW -ILW	M = 0.007 t/y V = 0.13 m^3/y	V = 0.78 м^3	
Old canister plugs	ILW	500 pcs.	3000 pcs.	
Retrieval machine gas treatment filters	ILW	Stage 1 - 4 pcs. Stage 2 - 2 pcs. Stage 3 - 2 pcs.	Stage 1 – 24 pcs. Stage 2 – 6 pcs. Stage 2 – 6 pcs.	
Shop vacuum filters	ILW	1 pcs.	6 pcs.	
Shop vacuum container	ILW	1 pcs.	6 pcs.	
Filters of local gas treatment systems of the WRP	LLW up to 10^6 Bq/kg	Stage 1 – 4 pcs. Stage 2 – 2 pcs.	Stage 1 – 24 pcs. Stage 2 – 12 pcs.	
Mechanical filters of the WRP	ILW up to 10^9 Bq/kg	12 - 16	100 pcs. (20 % with NFM)	To be specified by the WRP designer
Container filters with selective sorbent	ILW 2.2×10^9 Bq/kg	11 pcs. (average per year)	120 pcs.	
Filters of Zone 2 air treatment ventilation systems	LLW up to 10^6 Bq/kg	16 pcs.	96 pcs.	
Filters of Stage 3 of the vent air filter system for the air removed from the retrieval machine and SFA transfer stations	LLW up to 10^6 Bq/kg	2 pcs.	12 pcs.	
Filters of the local ventilation system (CVD hood)	LLW up to 10^6 Bq/kg	1 pcs.	6 pcs.	
Equipment. Tools	LLW 10^4 - 10^5 Bq/kg	2 t/year (1 m^3/y)	6 m^3	5 BN-0.2 drums
Wipes	LLW 10^3 - 10^5 Bq/kg	0.25 t/y (2.5 m^3/y)	15 m^3	15 BN-0.2 drums
PPE	LLW 10^3 - 10^5 Bq/kg	1.5 t/year (15 m^3/y)	90 m^3	70 BN-0.2 drums
Total for Building 153	HLW ILW LLW	0.01 m^3/y 15 m^3/y 25 m^3/y	0.06 m^3 90 m^3 150 m^3	

Table 33. Quantities and types of solid radioactive waste

No.	Waste	Quantity (kg)	Specific activity (beta-emitting radionuclides), $Bq \times 10^3$ /kg
1	Wipes	100	$<10^3$ (LLW)
2	Personal protective equipment	50	(LLW)
3	Tools	20	(LLW)

Management of liquid radioactive waste.

The following LRW is accumulated and will be generated in Building 153:

1. intermediate-level low-salt LRW (accumulated in the DSU cells and canisters with SFAs in the cells);
2. intermediate-level low-salt LRW, removed from ChT canisters and sleeves;
3. low-level and conditionally clean LRW, removed from TUK-108/1 and TK-18 transport shielded casks;
4. low-level saline LRW from decontamination of Zone 2, vehicles, TUK-108/1 (TK-18) transport casks, collector-containers with SRW and other equipment;
5. low-level low-salt LRW generated in sanitary airlocks.

The following will be performed immediately before SNF removal from a DSU cell:

1. water removal (lowering water level in a cell) down to the canister head when preparing for the channel-by-channel removal of SFAs;
2. removal of all water from a cell and interior of the canister when removing canisters with stuck SFAs.

The inspection of tanks 2A, 2B and 3A of the dry storage unit performed in 2000-2007 by AO NIKIET and FSUE NITI established that there is virtually no water in the cells of Tank 2A, while the cells of Tanks 2B and 3A are filled with water. The total volume of LRW in DSU cells is about 300 m^3. Water samples taken from the DSU cells show that this water is mainly intermediate-level LRW, with activities in individual cells in the 10^7 - 10^9 Bq/l range. Specific activity of the water on the surface is almost entirely determined by ^{137}Cs. Increase of specific activity of ^{137}Cs and especially ^{90}Sr with depth is observed for all cells. Alpha-emitters were found in samples from cells of tanks 2B and 3A. This provides strong evidence of the contact between fuel and water and that actinides also migrate to the water in addition to fission products. The estimated volume of water above the canister head in an individual cell of tanks 2A and 3B may be from 44 to 123 liters depending on the cell size and type of canister in that cell. The volume of water from the bottom to the canister head in a cell may range from 20 to 100 l. For the LRW material balance calculation, it is assumed that the volume of water to be removed from cells of tanks 2B and 3A to the top of the canister heads is ~ 150 m^3 and the total volume of water in DSU cells is ~300 m^3. LRW accumulated in the DSU tanks is characterized in Table 34.

Table 34. LRW in DSU cells characterization

	Parameter	Range	Value assumed in the design
1	Volume, m^3	300	300
	– Uranium, mg/l	0.01 - 1.86	1.86
4	Total activity of LRW, Bq/l	10^5 - 10^9	3.7×10^7
5	LRW beta and gamma activity, Bq/l	10^5 - 10^9	3.7×10^7
6	LRW alpha activity, Bq/l	10 - 5.4×10^4	1×10^2
7	Radionuclide composition:		
	– ^{137}Cs	10^5 - 10^9	$3\cdot10^7$
	– ^{90}Sr	10^3 - 10^8	$7\cdot10^6$
	– ^{60}Co	1×10^2 - 2×10^3	1×10^2
	– ^{3}H	1×10^5 - 3×10^6	1×10^5

Note: Some cells may contain fuel spills in nuclear hazardous quantities.

The DSU cells house about 3000 canisters with SFAs of different types (types 21, 22, 22M, 24, 24M, 25, 25M, 26, 26M, 34M, 35M and 36M). Canisters of all types have membranes made of soft alloy which is punctured to drain water from the canister. It is known that some canisters had punctured membranes before being placed in the DSU, however which canisters these are is unknown. Therefore, three possible variants may be assumed for each canister in DSU cells:

1. A canister with a punctured membrane is full of water because the cell housing this canister is full of water (LRW in the canister and the cell is like in communicating vessels);
2. There is no water in the canister with punctured membrane because it is a dry cell;
3. A canister with non-punctured membrane has water inside regardless of the presence or absence of water in the cell (LRW in the canister and the cell may have different radiological and chemical characteristics).

There is no reliable data on the characterization of LRW inside the canisters as no canisters were opened and had their water sampled. Based on available data it may be assumed that the radionuclide composition of the LRW in the canisters will be quite similar to that of waters in DSU cells, though the specific activity may be significantly higher due to stress corrosion cracking of the fuel elements' cladding. Thus, the expected specific activity of water in the canisters in immediate contact with the fuel composition via leaks in fuel elements cladding may be as high as 7.4×10^{10} Bq/l. Chemical composition of the water in a canister with a non-punctured membrane may also be substantially different from that of the water in a DSU cell. During the transfer of SFAs to ChT canisters, water may drip from the SFA surface and accumulate in the ChT canisters. The volume of water in one ChT canister may be as high as 0.3 l having the same radionuclide composition and characteristics as those of the water in the canister being removed. As the quantity of water in ChT canisters must not exceed 0.1 l for nuclear safety considerations, any extra water is removed before placing the canisters in TUK-108/1 (TK-18) shielded casks. The quantity of residual water in the TUK-108/1 or TK-18 cask is checked at the ChT canisters loading station. According to nuclear safety requirements, it must not exceed 2.5 l. The presence of water in the shielded cask may have various causes. The major ones are either condensation or the casks were not dried at FSUE PA Mayak after decontamination, filling with empty canisters and preparation for transport.

Decontamination of Zone 2, vehicles, TUK-108/1 (TK-18) transport casks, SRW collector-containers and other process equipment may produce low-level saline LRW and conditionally clean liquid waste. The characterization and approximate quantity of LRW and conditionally clean wastes produced by the decontamination of equipment and rooms are provided in Table 35. No liquid radioactive waste is produced in Building 151.

Table 35. Characterization of LRW and conditionally clean liquid waste

Decontaminated item	**LRW, m^3/y**	**Specific activity, kBq/kg**	**Chemical composition of LRW**
LRW drained to the special-purpose sewer			
TK-18, TUK-108/1 transport casks	1	< 10	$C_2O_4^{2-}$; NH_4^+
SRW containers	2	< 10	$C_2O_4^{2-}$; NH_4^+
Zone 2 premises	32	< 10	$NaHCO_3$
Sanitary airlock	700 l/shift, 350 m^3/y		
TOTAL LRW:	~35		
Conditionally clean liquid waste drained to control tanks			
Cask carrier	10	< 1	$C_2O_4^{2-}$; NH_4^+
Special-purpose truck for SRW, tank truck	11	< 1	$C_2O_4^{2-}$; NH_4
Special-purpose truck, tank truck	10	< 1	$C_2O_4^{2-}$; NH_4
Access way room (005)	10	< 1	
Access way room (119)	12	< 1	
Access way room (110)	10	< 1	
Zone 3 premises	27	< 1	SF-ZK
TOTAL conditionally clean waste	~90	< 1	

Intermediate-level low-salt LRW must be removed from DSU cells and canisters with the help of special modular water removal plant (WRP). The WRP must purify LRW from suspended solids, corrosion products, fuel spills on mechanical filters and reduce LRW activity to low-level waste at selective filters. Then, after checking LRW for specific activity and salt content, the LRW is taken to accumulation tanks as low-level LRW and then to m/v Serebryanka to be transported for treatment. Water from the interior of TUK-108/1 (TK-18) transport casks must be removed to holding tanks with the help of a vacuum plant developed by NIPTB Onega. Water from transport containers as well as water from decontamination of special-purpose vehicles, access ways and Zone 3 is considered conditionally clean LRW and is removed to control tanks of the special-purpose sewage system. From there, depending on the specific activity, it must be removed to the domestic sewage system or to holding tanks and then to m/v Serebryanka to be transported for treatment. Water produced by decontamination of containers, process equipment, Zone 2 and sanitary airlock are removed to holding tanks and then to m/v Serebryanka to be transported for treatment.

6. Environmental Impact Assessment Of Handling TUK-108/1 (TK-18) Packages At FSUE Atomflot Under Normal Operating Conditions

The fail-safe operation of FSUE Atomflot when unloading TUK-108/1 (TUK-18) packages with SNF removed from the Andreeva Bay facility from the transport ship and transferring them to the cells of the accumulation pad or to the train is assured through well-proven technology, structural safety and equipment reliability, uninterruptable power supply, modern monitoring equipment, etc. The transfer of TUK-108/1 (TUK-18) packages from a transport ship to the train or accumulation pad and temporary storage of packages on the accumulation pad are routine processes at FSUE Atomflot. Since becoming operational, the accumulation pad has housed from 1 to 19 empty and full TUK-108/1 and TUK-18 transport shielded packages at a time. SNF removal from the Andreeva Bay facility implies that the SNF transshipment facility of FSUE Atomflot will handle and store temporarily 96 TUK-108/1 (TUK-18) packages a year. Under normal operating conditions, there will be no opening of SNF packages delivered from Andreeva Bay and transferring SNF from them at FSUE Atomflot. Under normal operating conditions, the presence of a certain number of TUK-108/1 (TUK-18) packages at FSUE Atomflot will have an additional impact on the environment. It is assumed that 12 packages will be continuously stored on the pad throughout the year. During temporary storage of TUK-108/1 (TUK-18) packages on the accumulation pad, radionuclides may escape the gas space of the SNF cask to the shelter, from where the untreated air is emitted to the environment via air holes. At that, the safety of workers and the public is assured by the prevention of radionuclide dispersal mainly through the shielding properties of the package. The approximate radionuclide composition of the gas space of a TUK-108/1 (TK-18) shielded cask for various reactor core types is shown in Table 36.

Table 36. Radionuclide composition of cask's gas space

Nuclide	Normal operation (Bq)		
	First generation NPS	**Second generation NPS**	**Nuclear icebreakers**
^{60}Co	2.3×10^{7}	1.7×10^{7}	1.0×10^{7}
^{85}Kr	9.4×10^{10}	7.0×10^{10}	1.9×10^{11}
^{90}Sr	3.8×10^{8}	2.8×10^{8}	8.3×10^{8}
^{134}Cs	3.6×10^{7}	2.7×10^{7}	1.6×10^{8}
^{137}Cs	4.2×10^{9}	3.1×10^{9}	8.8×10^{9}
^{238}Pu	5.5×10^{5}	4.1×10^{5}	1.7×10^{5}
^{239}Pu	4.3×10^{4}	3.2×10^{4}	7.8×10^{4}
^{240}Pu	4.9×10^{4}	3.6×10^{4}	4.8×10^{4}
^{241}Pu	3.6×10^{6}	2.7×10^{6}	7.8×10^{6}

Under normal operating conditions, the loss of radioactive contents from TUK-108/1 and TUK-18 packages should not exceed $A_2 \cdot 10^{-6}$ per hour [12]. Emissions of radioactive aerosols to the atmosphere during SNF storage on the accumulation pad were calculated taking into account specific activity of radionuclides in the cask's gas space, size of the loss of radioactive contents from the casks and number of packages inside the shelter. Radionuclide releases to the atmosphere from the cask accumulation pad were calculated using the design values of gaseous content leak from the cask under normal operating conditions listed below:

- 4.7×10^{-6} $m^3\times Pa/s$ for TUK-18;
- 1×10^{-6} $m^3\times Pa/s$ for TUK-108/1 (given only one sealing barrier).

The modernized TK-18 transport shielded cask, used for the transport of damaged SNF has an additional sealing barrier – the body of a sleeve. The design of the cask prevents losses of the radioactive medium in higher than permitted quantities. Therefore, the leaks of gaseous medium from the gas space of the modernized cask with damaged SNF under normal operation are expected to be lower by an order of magnitude. Total release of radionuclide activity from 12 casks with SNF on the accumulation pad under normal operation is shown in Table 37.

Table 37. Releases from the accumulation pad, Bq/y

Nuclide	**Release**	**Nuclide**	**Release**
^{60}Co	1.4×10^5	^{238}Pu	3.5×10^3
^{90}Sr	2.3×10^6	^{239}Pu	2.7×10^2
^{134}Cs	2.3×10^5	^{240}Pu	3.0×10^2
^{137}Cs	2.7×10^7	^{241}Pu	2.2×10^4

The public doses from normal operation of the accumulation pad were calculated in accordance with the recommendations of DV-98 [11]. The meteorological dilution factor near the emission source was assessed for 8 directions taking into account wind frequencies as presented earlier. Mean annual effective doses to individual members of the public from radioactive gas-aerosol releases from the SNF storage in TUK-108/1 and TUK-18 on the accumulation pad of FSUE Atomflot were assessed for a selected area with quadrangle sides X = 10 km, Y = 10 km in normal grid points with a predetermined grid size. The area in question covers the city of Murmansk and settlements nearest to the facility:

Mishukovo – 2.4 km;

Belokamenka – 5.5 km;

Roslyakovo – 6.5 km.

Murmansk is situated ~2 km south of FSUE Atomflot. FSUE Atomflot has a sanitary protection zone – 1 km from Building 2 which serves as the center of the SPZ. Release height is 4 m. Calculated values of additional dose to members of the public (exclusive of consumption of local produce) from 12 TUK-108/1 and TUK-18 packages at FSUE Atomflot range from 0.2 to 1.5 µSv/y at the above locations. Calculation of dose values taking into account all irradiation pathways shows that the maximum annual dose to individual members of the public will be 22 µSv/y for those residing at the northern limit of Murmansk and 16 µSv/y, 11 µSv/y and 4 µSv/y for those residing in Mishukovo, Belokamenka and Roslyakovo, respectively. Calculated maximum public doses at the southern limit of FSUE Atomflot's SPZ (1.0 km) (assuming consumption of local produce) will not exceed 34 µSv/y. This is significantly lower than the hygiene standard for the public of 1,000 µSv/y specified by Federal Law No. 3. Calculated values of mean annual ground-level concentrations of ^{137}Cs, ^{90}Sr and ^{60}Co are much lower than VAL_{pub} values for these radionuclides of 27 Bq/m^3, 2.7 Bq/m^3 and 11 Bq/m^3, respectively. Thus, one can arrive at the conclusion that under normal operation, the air emissions resulting from handling and storage of TUK-108/1 (TUK-18) packages at FSUE Atomflot will have no adverse impact on the public and environment in the area.

Under normal operating conditions, handling and storage of TUK-108/1 (TUK-18) packages may have an impact on the soils and geological environment of FSUE Atomflot only through emissions of radioactive gas-aerosols. Calculated doses from radioactive gas-aerosol releases to individual members of the public are below public hygiene standards. Ground-level concentrations of emitted radionuclides at control points are below respective values of VAL_{pub} and the annual fallout on land is below the relevant deposition limit. Thus, under normal operation conditions any negative impact on the territory, land use conditions and geological environment is excluded when this solution for SNF removal and transport option is applied in Andreeva Bay.

Water is not used in handling TUK-108/1 and TK-18 packages at FSUE Atomflot. Should external surfaces of shielded casks, vehicles or hoisting machinery require decontamination, aqueous solutions will be used in quantities no more than 10 l. Thus, no contamination of the near shore water area through discharge will occur. No effluents will be discharged on land. Atmospheric precipitation of gas-aerosol radioactive emissions will not be a threat to surface water bodies. Adverse impact on the surface water bodies is improbable. The absence of negative impacts on soils, the geological environment and surface water bodies makes it possible to conclude an absence of adverse impacts on underground water. Handling of TUK-108/1 (TK-18) packages at FSUE Atomflot may produce solid radioactive waste only in abnormal operation: loss of integrity of a full TUK-108/1 (TK-18) shielded cask or arrival of contaminated container from another facility. Container surfaces are decontaminated with wipes soaked in a SF-ZK solution. SRW resulting from decontamination is packed in plastic bags and transferred to the SRW handling complex. Handling of TUK-108/1 (TK-18) packages at FSUE Atomflot does not generate any liquid radioactive waste.

7 Environmental Impacts Of Potential Accidents Related To SBF Removal From The Andreeva Bay Facility

Environmental impact assessment regarding an accident during SNF removal from the DSU cells, transfer of SNF to TUK-108/1 (TK-18) casks in Building 153 and shipping onboard the transport ship.

A safety assessment regarding SNF handling systems at the Andreeva Bay facility was performed to verify the safety of operation of the SNF handling complex at the temporary storage facility in the Andreeva Bay [13, 16]. SNF handling is considered safe if the radiological impact on the personnel, the public and the environment under normal or abnormal operation, including design-basis accidents, does not exceed established dose limits for the personnel and the public, limits for radioactive emissions/discharges and permissible environmental burden, as well as restricts this impact in case of beyond-design-basis accidents.

As per regulatory requirements [15], the following initiating events were postulated for the analysis of design-basis accidents:

1. Natural conditions typical for the Andreeva Bay site (seismic events of magnitude 7 on the MSK-64 scale, floods, hurricanes, lightning strike, etc.).
2. Air pressure wave resulting from an on-site explosion.
3. Complete loss of electrical power.
4. Fire at the site or in an on-site vehicle carrying SNF casks.
5. Drop of SFAs, canister with SFAs, transfer casks, TUK-108/1 (TUK-18) packages during handling.
6. SNF storage and handling systems' failure.

7. Human error.

The following initiating events were postulated for the analysis of beyond-design-basis accidents:

1. Self-sustaining chain reaction from various causes.
2. Drop of equipment (cranes) and structural elements onto the ceilings of SNF storage compartments.
3. Crash of a light aircraft.
4. Air pressure wave resulting from an off-site explosion (neighbouring site, passing traffic and the like)

A detailed analysis of the above-mentioned initiating events, near-accidents, accident scenarios, accident consequences, technogenic impacts, design solutions and preventive, mitigation and contingency measures for the SNF removal from DSU cells, transfer of SFAs to ChT canisters, filling of TUK-108/1 (TUK-18) transport packages, transport of packages to the accumulation pad and transfer to the transport ship has identified the accidents with most adverse radiological consequences for the public. A drop of a mating device onto a TUK-108/1 (TK-18) cask while filling it with ChT canisters with SFAs in Building 153 Enclosure (Room 113) was postulated as a design-basis accident for SNF removal from DSU cells, transfer of SFAs to ChT canisters and filling of TUK-108/1 (TK-18) transport packages in Building 153. A crash of an aircraft onto a TUK-108/1 (TUK-18) cask while it is being filled with ChT canisters with SFAs in the same room was postulated as a beyond-design-basis accident. A drop of a TUK-108/1 (TUK-18) package from less than 9 m and a fire of a vehicle carrying the package was postulated as a design-basis accident for the transport of packages within the TSF, temporary storage at the accumulation pad and transfer to the transport ship. Drops of equipment (cranes and their elements) and structural elements onto the packages in Building 151 arising from natural or technogenic causes were postulated as a beyond-design-basis accident.

The main radiological factor for the public residing in the area of the Andreeva Bay facility are radioactive gases and aerosols. The following exposure pathways are possible:

1. External gamma irradiation of the human body by radioactive substances present in the ground-level air;
2. External gamma irradiation of the human body by radionuclides accumulated in the topsoil;
3. Internal irradiation of organs and tissues through inhalation of air containing radionuclides;
4. Internal gamma irradiation of the human organs and tissues through digestion of contaminated local produce.

As the consumption of local produce in the area is insignificant, this pathway was not considered in the assessment of emergency doses to the public.

The Gaussian diffusion model, having the largest experimental base and thus being more reliable, was chosen to estimate the dispersion of accidental releases from the Andreeva Bay facility. The model is recommended for practical application by international organizations, including the World Meteorological Organization (WMO), the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee of the Effects of Atomic Radiation (UNSCEAR), the World Health Organization (WHO) and others. The modification of the model used is fully detailed in 'Guidelines for Calculation of Air Radiation Situation and Expected Public Exposure during Short-Time Radioactive Releases in the Atmosphere' (MPA-98).

As the accidental releases are of a random nature, the worst-case dispersion conditions and pathways were considered for the assessment of their radiological impact. Effective doses to individual members of the public were estimated at the close limit of SPZ and at three locations outside the SPZ of the TSF Andreeva Bay:

1. Close limit of SPZ of the TSF - 0.2 km;
2. Northern limit of Nerpichya Bay – 1.8 km;
3. Northwestern limit of Bolshaya Lopatka Bay – 2.4 km;
4. Northern limit of Zaozersk – 5.5 km.

Consequence analysis for design-based accidents

When filling TUK-108/1 (TK-18) transport shielded casks with ChT canisters containing SFAs in Room 113, human error, for example, may lead to a drop of a mating device into an open cask. In the worst case this may damage three canisters and all the SFAs within (21 NPS SFAs or 15 icebreaker SFAs). The force impact on the SFAs may result in the spilling of SNF inside the canister and the release of volatile radioactive substances from the cask to indoor air. Radionuclides will enter the canister first, then the interior of the cask and then the cask filling station. The dispersal of radioactive substances beyond the room is prevented by the ventilation system. General ventilation is envisioned in Room 113. Before discharge to the atmosphere, the air undergoes one-stage treatment (decontamination factor – 100) and then released via a 40-meter high stack. The expected release of radionuclides from a drop of a mating device onto casks TUK-108/1 or TK-18 is shown in Table 38. Table 39 shows the expected public doses in case of a design-basis accident involving a drop of a mating device onto a cask and loss of integrity of three canisters containing 21 NPS SFAs.

Table 38. Release of radionuclides (Bq)

Nuclide	Release from the building after treatment (Bq)
^{60}Co	4.9×10^{4}
^{85}Kr	4.0×10^{12}
^{90}Sr	8.1×10^{5}
^{134}Cs	7.8×10^{4}
^{137}Cs	9.0×10^{6}
^{238}Pu	1.2×10^{3}
^{239}Pu	9.3×10^{1}
^{240}Pu	1.0×10^{2}
^{241}Pu	7.7×10^{3}
Total	4.0×10^{12}
Total without ^{85}Kr	1.0×10^{7}

In case of a drop of the mating device onto a TUK-108/1 (TK-18) cask containing SNF, the maximum expected emergency dose to the public outside the sanitary protection zone in worst-case weather conditions will be below 20 nSv during the first year after the accident. This value is much less that a minimum significant doze of 10 µSv/y stipulated by NRB-99/2009. Expected individual effective dose for the first year after the accident in worst case weather conditions at distances of 1.8 km, 2.4 km and 5.5 km in Nerpichya Bay, Bolshaya Lopatka Bay and Zaozersk will be 8.8 nSv, 6.7 nSv and 3.5 nSv, respectively. The maximum expected effective doses to the members of the public at the SPZ limit will be 0.37 nSv in the first year after the accident, which is much less than the minimum significant public dose of 10 µSv (NRB-99/2009, OSPORB-99/2010). Expected individual effective dose in the first year after the accident at the distances of 1.8 km, 2.4 km and 5.5 km in Nerpichya Bay, Bolshaya Lopatka and Zaozersk will be 0.069 mSv, 0.057 mSv and 0.025 nSv, respectively.

The maximum expected emergency dose to the public in worst-case weather conditions outside the SPZ in case of a design-basis accident involving a drop of a package in Building 151 will be below 0.15 µSv in the first year after the accident, which is much less that a minimum significant public doze of 10 µSv/y stipulated by NRB-99/2009. The estimates consider a scenario with venting of TUK-18 and release of untreated air from Building 151 via grilles at the height of 12 m. Table 40 shows expected public doses from a design-basis accident involving a drop of TUK-18 in Building 151.

Table 39. Effective doses to individual members of the public (drop of a mating device onto a cask, nSv)

Distance (km)	**Atmospheric stability class**	**Exposure pathways**			
		1*	**2****	**3*****	**1+2+3**
0.05	A	22.2	6.6E-04	3.9E-03	22.2
0.1	A	22.2	1.6	9.9	33.7
0.2 - SPZ limit	A	22.2	4.2	24.9	51.3
0.5	E	8.7	1.6	9.6	19.9
0.7	E	7.8	1.4	8.7	17.9
1	F	6.0	1.1	6.6	13.7
1.8 - Nerpichya Bay	G	3.9	0.69	4.2	8.8
2	G	3.6	0.63	3.9	8.1
2.4 - Bolshaya Lopatka Bay	G	2.9	0.51	3.3	6.7
3	G	2.3	0.39	2.4	5.1
4	G	1.9	0.33	2.0	4.2
5	G	1.6	0.28	1.7	3.6
5.5 - Zaozersk	G	1.6	0.26	1.6	3.5
6	G	1.6	0.24	1.5	3.3
10	G	1.6	0.25	1.5	3.3

1 - External irradiation of the human body by radionuclides present in the ground-level air;*
*2** - Internal irradiation of organs and tissues through inhalation of air containing radionuclides;*
*3***- External irradiation of the human body by radionuclides accumulated in the soil in the first year after the accident*

An SNF handling operation at the TSF Andreeva Bay with the highest risk of fire is the transport of a TUK-18 (TUK-108/1) package on a special-purpose vehicle from Building 153 to Building 151. A component failure of the special-purpose vehicle may lead to a fire. A fire of a vehicle with a TUK-108/1 (TUK-18) package on-board in Building 151 is postulated as a design-basis accident. The estimate is based on a scenario that a TUK-108/1 (TUK-18) package remains in the body of fire for 30 minutes. The staff extinguish the fire. Then the package cools down for 3 hours. During the fire, aerodynamic force causes the hot air to leave the building via grilles and lifts it to about 50 m. Table 41 shows expected public doses from a design-basis accident involving a fire with a TUK-108/1 (TK-18) package containing SNF inside Building 151.

Table 40. Effective doses to individual members of the public (drop of a cask inside Building 151, μSv)

Distance (km)	**Atmospheric stability class**	**Exposure pathways**			
		1*	**2****	**3*****	**1+2+3**
0.05	A	3.1E-04	0.056	0.31	0.37
0.1	A	1.8E-04	0.032	0.18	0.21
0.2 - SPZ limit	D	1.2E-04	0.022	0.12	0.15
0.5	F	8.0E-05	0.014	0.079	0.093
0.7	F	6.8E-05	0.012	0.067	0.079
1	G	7.9E-05	0.014	0.078	0.092
1.8 - Nerpichya Bay	G	6.8E-05	0.011	0.061	0.072
2	G	6.2E-05	9.8E-03	0.054	0.064
2.4 - Bolshaya Lopatka Bay	G	5.1E-05	7.6E-03	0.042	0.050
3	G	3.9E-05	5.3E-03	0.029	0.034
4	G	2.6E-05	3.0E-03	0.017	0.020
5	G	1.9E-05	1.8E-03	0.010	0.012
5.5 - Zaozersk	G	1.7E-05	1.4E-03	8.0E-03	9.4E-03
6	G	1.5E-05	1.2E-03	6.4E-03	7.6E-03
10	G	7.0E-06	2.7E-04	1.5E-03	1.8E-03

1 - External irradiation of the human body by radionuclides present in the ground-level air;*
*2** - Internal irradiation of organs and tissues through inhalation of air containing radionuclides;*
*3***- External irradiation of the human body by radionuclides accumulated in the soil in the first year after the accident*

Table 41. Maximum expected effective doses to individual members of the public in case of design-basis accident involving a fire of a TUK-108/1 (TUK-18) package containing SNF (nSv).

Distance (km)	**Atmospheric stability class**	**Exposure pathways**			
		1*	**2****	**3*****	**1+2+3**
0.05	A	7.9E-11	1.4E-08	7.9E-08	9.4E-08
0.1	A	3.4E-05	6.2E-03	3.4E-02	4.0E-02
0.2 - SPZ limit	A	3.2E-04	5.7E-02	0.32	0.37
0.5	A	1.4E-04	0.026	0.14	0.17
0.7	C	1.1E-04	0.021	0.11	0.13
1	D	1.0E-04	0.018	0.10	0.12
1.8 - Nerpichya Bay	E	5.9E-05	0.011	0.059	0.069
2	E	5.6E-05	0.010	0.055	0.065
2.4 - Bolshaya Lopatka Bay	E	4.9E-05	8.8E-03	0.049	0.057
3	E	4.0E-05	7.2E-03	0.040	0.047
4	E	3.0E-05	5.3E-03	0.029	0.034
5	F	2.3E-05	4.1E-03	0.022	0.026
5.5 - Zaozersk	F	2.2E-05	3.9E-03	0.021	0.025
6	F	2.1E-05	3.7E-03	0.020	0.024
10	G	1.5E-05	2.5E-03	0.014	0.016

1 - External irradiation of the human body by radionuclides present in the ground-level air;*
*2** - Internal irradiation of organs and tissues through inhalation of air containing radionuclides;*
*3***- External irradiation of the human body by radionuclides accumulated in the soil in the first year after the accident.*

Consequence analysis of beyond-design-based accidents.

A crash of an aircraft onto a TUK-108/1 (TK-18) cask while being filled with canisters containing SFAs at the process hall (room 113) of Building 153 and a drop of heavy machinery (cranes and their components) and structural elements onto TUK-108/1 (TUK-18) packages in Building 151 from natural and technogenic causes were postulated as worst-case beyond-design-basis radiological accidents for the public.

The following assumptions were made for an aircraft crash accident:

1. The building is partially destroyed (roof);
2. The fuel spills into the full cask and ignites;
3. Heat damages cladding of all 49 SFAs;
4. 100 per cent of inert radioactive gas (^{85}Kr), up to 50 per cent of volatile fission products (^{137}Cs), 5 per cent of ^{90}Sr and up to 0.5 per cent of actinides are released to the environment.

Expected release of radionuclides to the environment is shown in Table 42.

Table 42. Release of radionuclides to the environment from a crash of aircraft onto Building 153

Radionuclide	Activity (Bq)
^{60}Co	5.7×10^{10}
^{85}Kr	1.6×10^{13}
^{90}Sr	9.4×10^{12}
^{134}Cs	9.1×10^{11}
^{137}Cs	1.1×10^{14}
^{238}Pu	1.4×10^{10}
^{239}Pu	1.1×10^{9}
^{240}Pu	1.2×10^{9}
^{241}Pu	9.0×10^{10}
Total	1.3×10^{14}
Total without ^{85}Kr	1.1×10^{14}

To assess the radiological impact, it was assumed that smoke fumes will be released via a resultant opening in the building and the fume cloud will reach the height of 50 m. Table 43 shows estimates of expected doses to the public as a result of an aircraft crash onto Building 153. The calculations of effective public doses show that external irradiation will be the main irradiation factor for the public. According to calculations, the expected individual effective dose in the first year after the accident (aircraft crash onto Building 153) in worst-case weather conditions at the distances of 1.8 km, 2.4 km and 5.5 km in Nerpichya Bay, Bolshaya Lopatka Bay and Zaozersk will be 41 mSv, 34 mSv and 15 mSv, respectively. Overturning of several TUK-108/1 (TUK-18) packages sitting next to each other and loss of cask containment due to destruction of a cask lid and partial damage to SFAs were postulated as consequences of beyond-design-basis accidents involving the damage to Building 151 caused by natural or technogenic impact, by fall of a bridge crane of 50/12.5 tonne capacity (or its elements) or by an aircraft crash.

To assess the radiological impact, the overturning of two adjacent rows of casks in Building 151 (24 casks in total) was postulated. The drop (overturning) of an SNF package may result in the release of volatile radioactive substances from its interior via cask's seals. Values of expected activity releases from Building 151 are shown in Table 44. Table 45 provides calculated expected public doses resulting from the overturning of 24 TUK-18 packages in Building 151. The calculations show that the expected maximum public dose at the SPZ limit from the overturning of 24 packages will be 2.2 µSv, which is much lower than the minimum significant public dose of 10 µSv (NRB-99/2009, OSPORB-99/2010). Additionally, an initiating event involving the damage to the lid of the cask and partial damage to the SFAs was considered. Table 44 shows expected emissions of radioactive substances as a result of loss of containment of a shielded cask with SNF. Volumetric activity of nuclides in the indoor air of Building 151 hall in case of a loss of cask containment may exceed VAL_{pers} by several times. In this radiological environment, personnel may incur a dose of 12 mSv in 15 minutes. For safety reasons the personnel must immediately leave Building 151. Use of respiratory protective equipment of the Lepestok-200 type with an aerosol protection factor of 200 will substantially reduce personnel exposure.

Table 43. Public doses from aircraft crash onto Building 153 in the first year after the accident (mSv)

Distance (km)	Exposure pathways					
	1*	2**	3***	1+2+3	4****	1+2+4
0.05	2.2×10^{-3}	7.6×10^{-6}	1.3×10^{-6}	$2,2\times10^{-3}$	$4,7\times10^{-5}$	$2,2\times10^{-3}$
0.1	0.10	3.3	0.58	3.9	20	24
0.2 - SPZ limit	0.10	30	5.3	36	189	220
0.5	0.046	14	2.4	16	85	99
0.7	0.036	11	1.9	13	68	78
1	0.032	9.6	1.7	11	60	69
1.8 - Nerpichya Bay	0.019	5.7	0.99	6.7	35	41
2	0.018	5.3	0.94	6.3	33	38
2.4 - Bolshaya Lopatka Bay	0.016	4.7	0.82	5.5	29	34
3	0.013	3.8	0.67	4.5	24	28
4	9.3×10^{-3}	2.8	0.49	3.3	17	20
5.5 - Zaozersk	6.9×10^{-3}	2.1	0.36	2.4	13	15
10	4.5×10^{-3}	1.3	0.23	1.6	8.3	9.6
20	4.6×10^{-3}	1.4	0.24	1.6	8.5	9.9
55	1.2×10^{-3}	0.36	0.062	0.42	2.2	2.6

1 - External irradiation of the human body by radionuclides present in the ground-level air;*
*2** - Internal irradiation of organs and tissues through inhalation of air containing radionuclides;*
*3*** - External irradiation of the human body by radionuclides accumulated in topsoil in the 10 days after the accident*
*4****- External irradiation of the human body by radionuclides accumulated in topsoil in the first year after the accident*

Table 44. Accidental radionuclide activity releases from Building 151 (Bq)

Nuclide	Venting of TUK-18	Venting of TUK-108/1	Venting of 24 casks	Loss of cask containment
^{60}Co	4.8×10^{4}	9.6×10^{3}	1.2×10^{6}	1.1×10^{8}
^{85}Kr	2.0×10^{9}	3.9×10^{8}	4.7×10^{10}	4.7×10^{12}
^{90}Sr	7.9×10^{5}	1.6×10^{5}	1.9×10^{7}	1.9×10^{9}
^{134}Cs	7.6×10^{4}	1.5×10^{4}	1.8×10^{6}	1.8×10^{8}
^{137}Cs	8.9×10^{6}	1.8×10^{6}	2.1×10^{8}	2.1×10^{10}
^{238}Pu	1.2×10^{3}	2.3×10^{2}	2.8×10^{4}	2.8×10^{6}
^{239}Pu	91	18	2.2×10^{3}	2.2×10^{5}
^{240}Pu	1.0×10^{2}	21	2.5×10^{3}	2.4×10^{5}
^{241}Pu	7.5×10^{3}	1.5×10^{3}	1.8×10^{5}	1.8×10^{7}
^{241}Am	2.8×10^{2}	56	6.7×10^{3}	6.6×10^{5}
Total	2.0×10^{9}	4.0×10^{8}	4.8×10^{10}	4.7×10^{12}

Table 45. Expected public doses resulting from the overturning of 24 TUK-18 packages in Building 151 (µSv)

Distance (km)	Class	Exposure pathways			
		1**	2**	3***	1+2+3
0.05	A	3.8E-03	0.70	3.9	4.6
0.1	A	3.5E-03	0.64	3.5	4.1
0.2 - SPZ limit	D	1.9E-03	0.34	1.9	2.2
0.5	E	1.2E-03	0.22	1.2	1.5
0.7	F	9.9E-04	0.18	1.0	1.2
1	F	8.1E-04	0.14	0.80	0.94
1.8 - Nerpichya Bay	G	9.3E-04	0.16	0.90	1.06
2	G	9.1E-04	0.16	0.86	1.01
2.4 - Bolshaya Lopatka Bay	G	8.2E-04	0.14	0.75	0.89
3	G	6.8E-04	0.11	0.59	0.70
4	G	5.0E-04	0.07	0.39	0.46
5	G	3.8E-04	0.05	0.26	0.31
5.5 - Zaozersk	G	3.3E-04	0.04	0.22	0.26
6	G	3.0E-04	0.033	0.18	0.22
10	G	1.4E-04	9.8E-03	0.054	0.064

* Atmospheric stability class resulting in maximum public dose

1 - External irradiation of the human body by radionuclides present in the ground-level air; 2** - Internal irradiation of organs and tissues through inhalation of air containing radionuclides; 3***- External irradiation of the human body by radionuclides accumulated in topsoil in the first year after the accident*

Table 46 shows calculated expected public doses resulting from loss of containment of a TUK-18 cask with SNF. In case of an accident involving a damage to the lid of the cask and partial damage to SFAs, the maximum expected emergency dose to the public in worst-case weather conditions outside the SPZ will be 0.22 mSv in the first year after the accident, that is less than 1 mSv. The calculated effective public doses show that in all accident situations the external irradiation by radionuclides accumulated in topsoil will be the main radiation factor for the public.

Table 46. Expected public doses resulting from the loss of containment of shielded cask with SNF (mSv)

Distance (km)	Class*	Exposure pathways			
		1*	2**	3***	1+2+3
0.05	A	3.8E-04	0.070	0.39	0.46
0.1	A	3.5E-04	0.063	0.35	0.41
0.2 - SPZ limit	D	1.9E-04	0.034	0.19	0.22
0.5	E	1.2E-04	0.022	0.12	0.15
0.7	F	9.9E-05	0.018	0.10	0.12
1	F	8.1E-05	0.014	0.079	0.094
1.8 - Nerpichya Bay	G	9.3E-05	0.016	0.090	0.11
2	G	9.0E-05	0.016	0.086	0.10
2.4 - Bolshaya Lopatka Bay	G	8.2E-05	0.014	0.075	0.089
3	G	6.8E-05	0.011	0.059	0.070
4	G	5.0E-05	7.1E-03	0.039	0.046
5	G	3.8E-05	4.8E-03	0.026	0.031
5.5 - Zaozersk	G	3.3E-05	4.0E-03	0.022	0.026
6	G	3.0E-05	3.3E-03	0.018	0.022
10	G	1.4E-05	9.8E-04	5.4E-03	6.4E-03

** Atmospheric stability class resulting in maximum public dose;*
1 - External irradiation of the human body by radionuclides present in the ground-level air;*
*2** - Internal irradiation of organs and tissues through inhalation of air containing radionuclides;*
*3***- External irradiation of the human body by radionuclides accumulated in topsoil in the first year after the accident*

Of the accidents considered, the aircraft crash onto a full TUK-108/1 (TK-18) cask without the lid in Building 153 will have the most adverse radiological effect on the public. According to calculations, in case of an aircraft crash onto Building 153 expected individual effective dose in the first year after the accident in worst-case weather conditions at the distances of 1.8 km, 2.4 km and 5.5 km in Nerpichya Bay, Bolshaya Lopatka Bay and Zaozersk will be 41 mSv, 34 mSv and 15 mSv, respectively. As per NRB-99/2009, in case emergency public dose exceeds 5 mSv/y public protective measures will be required in accordance with principles of justification and optimizations taking into account specific situation and local conditions.

8 Environmental Impacts Of Potential Accidents Arising From TUK-108/1 (TUK-18) Handling At FSUE Atomflot

To assess the environmental impact of potential accidents during the temporary storage and handling of TUK-108/1 and TUK-18 packages at FSUE Atomflot an analysis of initiating events (as per recommended list in the regulatory guidelines [15]) has been performed. As a result of the detailed preliminary analysis of considered initiating events, near-accidents, accident scenarios, accident consequences, technogenic impacts, design solutions and preventive, mitigation and contingency measures, accidents with most adverse radiological consequences for the public have been identified. A drop of a TUK-108/1 (TUK-18) package during its offloading from a transport ship and its transfer to a cell in the accumulation pad or to a railcar was postulated as a design-basis accident. A drop of a portal crane (crane balance) onto a TUK-108/1 (TUK-18) package was postulated as a beyond-design-basis accident.

Drop of a package during handling.

A drop of a TUK-108/1 (TUK-18) package is possible during its unloading from the transport ship, transfer within the FSUE Atomflot site and placing in an accumulation pad. FSUE Atomflot employs a KONE K 6295 portal crane to handle TUK108/1 and TK-18 casks. Currently the facility is installing a new 100-tonne capacity portal crane to replace the K 6295. The possible drop height when handling a TUK-108/1 (TUK-18) cask is limited by a preset load-lifting height. The height limit switch of the K 6295 stops the main hoist when the hook is 12.4 +/- 0.1 m above the pier. At that, the lifting height of a TUK-108/1 (TK-18) cask above the pier (the distance between the bottom of the cask and surface of the pier) is about 6.8 m.

Given the parameters of the K6295 height limit switch, the maximum potential drop height of a TUK-108/1 (TUK-18) cask will be:

- about 5.5 m (onto the floor of the accumulation pad);
- about 3.2 m (onto the ceiling of the accumulation pad);
- about 6.8 m (onto the pier);
- about 8.0 m (into the cargo hold of the container ship, provided administrative and technical measures are observed).

Thus, the potential drop height of a TUK-108/1 (TUK-18) cask during any handling operation does not exceed 8.0 m. As per regulations [28] TUK-108/1 and TK-18 transport shielded casks must retain their integrity and leak-tightness after a drop from 9.0 m onto a hard surface. At that, regulations [28] set forth limits on the loss of radioactive contents from their interior for each particular radionuclide. When analysing radiological consequences of an accidental TUK-108/1 or TUK-18 drop it is assumed that the drop will result in a cladding failure of all fuel pins and a portion of radionuclides in the form of gases and aerosols will enter the interior of the cask. Instantaneous loss of activity from the cask is assumed to equal a standard weekly release. The nuclide activity leaving the cask creates a volumetric activity of 9.78 × 104 Bq/m^3 within a 20-meter range, which does not exceed the standardized volumetric activity limit for personnel VAL_{pers}. The radionuclide composition and released radioactivity values for a TUK-18 package after its drop are shown in Table 8.1. The table also contains volumetric activity limits for personnel VAL_{pers} specified in NRB-99/2009. The radionuclide composition and released radioactivity values for a TUK-18 package after its drop are shown in Table 47. The table also contains volumetric activity limits for personnel VAL_{pers} specified in NRB-99/2009.

Table 47. Radionuclide release from a TK-18 cask with SNF after drop

Radionuclide	Radionuclide activity in TUK gas space, Bq	Radionuclide release from TUK, Bq	Volumetric activity on accident site, Bq/m³	VAL_{pers}, Bq/m³
^{60}Co	2.3×10^{8}	4.8×10^{4}	2.37	280
^{85}Kr	9.4×10^{12}	2.0×10^{9}	9.73×10^{4}	2.20×10^{7}
^{90}Sr	3.8×10^{9}	7.9×10^{5}	38.9	330
^{134}Cs	3.6×10^{8}	7.6×10^{4}	3.77	1200
^{137}Cs	4.2×10^{10}	8.9×10^{6}	4.37×10^{2}	1700
^{238}Pu	5.5×10^{6}	1.2×10^{3}	5.73×10^{-2}	0.19
^{239}Pu	4.3×10^{5}	9.1×10^{1}	4.51×10^{-3}	0.17
^{240}Pu	4.9×10^{5}	1.0×10^{2}	5.06×10^{-3}	0.17
^{241}Pu	3.6×10^{7}	7.5×10^{3}	3.71×10^{-1}	9.4
^{241}Am	5.9×10^{5}	2.8×10^{2}	1.41×10^{-2}	0.21
Total	9.4×10^{12}	2.0×10^{9}	9.78×10^{4}	1.20×10^{5}
Total without ^{85}Kr	4.7×10^{10}	9.6×10^{6}	4.8×10^{2}	593

From data in Table 47 it follows that in case of a TUK-108/1 or TUK-18 drop from 9 meters onto a hard surface the volumetric activities will not exceed VAL_{pers}. The calculation of effective doses to individual members of the public resulting from a drop of a TUK-108/1 or TUK-18 package at the FSUE Atomflot site was performed for the city of Murmansk (2 km from the accident site) and for the following settlements closest to the site:

1. Mishukovo – 2.4 km;
2. Belokamenka – 5.5 km;
3. Roslyakovo – 6.5 km.

The calculation was made for the following public exposure factors:

1. external irradiation of the human body by radionuclides present in the ground-level air;
2. internal irradiation of organs and tissues through inhalation of air containing radionuclides;
3. external irradiation of the human body by radionuclides accumulated in topsoil in the first year after the accident

According to calculations, the maximum expected emergency dose to the public outside the sanitary protection zone in case of a TUK-108/1 (TUK-18) package drop in worst weather conditions will be 6.4×10^{-3} µSv/y, which is below the minimum significant dose of 10 µSv/y stipulated by OSPORB-99/2010. Public exposure dose at the northern limit of Murmansk will be 2×10^{-3} µSv/y and 1.7×10^{-3} µSv/y, 0.84×10^{-3} µSv/y and 0.72×10^{-3} µSv/y in Mishukovo, Belokamenka and Roslyakovo, respectively.

Drop of a portal crane (balance) onto a TUK-108/1 (TUK-18) package.

A very-low probability accident - a drop of a К6295 KONE crane (crane balance) onto a package – is assumed as a beyond-design-basis accident. Such an accident will result in the loss of package containment and the disintegration of all 49 SFAs in standard canisters inside the cask. The following was assumed in the calculation of radiological consequences of the accident:

- The accident occurs outdoors;
- All activity from 49 SFAs is released;
- Elimination of radioactive aerosols from the atmosphere through sorption on the canisters and cask surfaces is ignored.

Expected activity release from the damaged cask is shown in Table 48.

Table 48. Radionuclide release from a damaged package

Radionuclide	Activity (Bq)
^{85}Kr	1.8×10^{13}
^{90}Sr	1.03×10^{8}
^{137}Cs	1.12×10^{9}
^{239}Pu	6.5×10^{5}

The calculation of effective doses to individual members of the public resulting from the drop of a TUK-108/1 or TUK-18 cask at FSUE Atomflot was made for Murmansk (2 km from the accident site) and other settlements in the immediate vicinity:

1. Mishukovo – 2.4 km;
2. Belokamenka – 5.5 km;
3. Roslyakovo – 6.5 km.

The calculation was made for the following public irradiation factors:

1. External irradiation of a human body by radioactive substances present in the ground-level air;
2. Internal irradiation of organs and tissues through inhalation of air containing radionuclides;
3. External irradiation of the human body by radionuclides accumulated in topsoil in the first year after the accident

According to calculations, the maximum expected emergency dose to the public will be 1.38 mSv/y at the northern limit of Murmansk and 0.97 mSv/y, 0.114 mSv/y and 0.092 mSv/y in Mishukovo, Belokamenka and Roslyakovo, respectively. Maximum expected emergency dose at the limit of the sanitary protection zone under worst weather conditions will be 9.3 mSv/y. The values of maximum emergency doses at the nearest residential area (northern limit of Murmansk) will not exceed an average basic dose limit for the public of 1 mSv per year for any five consecutive years, but not more than 5 mSv in one year, established by NRB-99/2009. No relocation of the public will be required. There are no residential areas within the sanitary protection zone.

9 Environmental Protection Measures

Environmental protection measures at the Andreeva Bay site.

The following measures will make it possible to reduce the possible impact on atmospheric air of the SNF removal from DSU cells, transferring SFAs to canisters and sleeves and filling transport packages (casks) when the future SNF and RW handling system in Andreeva Bay is fully utilized:

1. Dividing the DSU Enclosure (Building 153) into three zones as an element of radiation safety in handling sources of radiation;
2. Analysis of the atmospheric dispersion of radioactive emissions from SNF handling sites and facilities;
3. Installing filters in immediate proximity to pollution sources in separate rooms to reduce contamination of main air ducts;
4. Polluted air after being treated at the filters of the stationary ventilation plant is emitted via a high stack to minimize release of radioactive aerosols to the environment. The selected stack height (40 m) ensures that the plume stays out of the air shadow of the building and reduces the volumetric activity of radioactive substances in the air at the plume landing point within the established dose limit for the public;
5. Redundancy of all main ventilation units with automatic switching to a redundant unit in case the primary main unit fails.

The following measures are envisioned in the DSU enclosure to prevent pollution of the geological environment and underground waters:

1. Non-contaminated domestic and industrial sewage will be released via the TSF industrial sewage system;
2. Conventionally clean sewage after the decontamination of the running gear of the vehicles shall be drained to the industrial sewer;
3. Effluents from washing of Zone 2, TUK decontamination station and SRW container decontamination station will be collected to a sump. From there the effluents will be pumped to a special purpose tank truck and taken to m/v Serebryanka for treatment;
4. The effluents from decontamination of the running gear of vehicles in process rooms will be drained off either to the external storm water sewer of the industrial site, or in case of contamination pumped to a special purpose tank truck and taken to m/v Serebryanka for treatment;
5. No land disposal of effluents will be permitted;
6. Observation wells will be made around Building 153 to monitor pollutants and radioactive substances in groundwater and groundwater level;
7. Organization of temporary storage of industrial waste in a way that prevents contact between the stored waste and underground and surface water.

Environmental protection measures at FSUE Atomflot

Shipment of TUK-108/1 (TUK-18) packages containing SNF from NPS and nuclear icebreakers from Andreeva Bay from a transport ship to a special train or to a temporary storage will take place at the existing site of FSUE Atomflot, employing existing technology, equipment and facilities. FSUE

Atomflot site has been subject to anthropogenic disturbance for several decades as the main maintenance facility of the nuclear icebreaker fleet. Therefore, handling of sealed TUK-108/1 and TUK-18 casks meeting nuclear and radiation safety requirements is not expected to have an additional impact on the ecosystems in the FSUE Atomflot area. Section 8 addresses accidents, which may occur during handling of TUK-108/1 and TUK-18 packages at FSUE Atomflot.

As the calculations show, the public exposure outside SPZ in a worst-case design-basis accident (drop of a TUK-18 package onto the pier or into the cargo hold of the transport ship) will not exceed the minimum significant dose of 10 µSv/y. According to Section 6.18 of OSPORB-99/2010, no protective measures for the public are required in this case.

In a worst-case beyond-design-basis accident (drop of a portal crane onto a TUK-108/1 or TUK-18 package) public exposure outside the SPZ during the first year may exceed 1 mSv, but will not exceed the main emergency dose limit for the public of 5 mSv/y established by NRB-99/2009. According to Section 6.7 of NRB-99/2009, this situation will not require implementing protective measures pertaining to the disruption of normal life or economic and social functioning of the area.

10 Conclusions

This report presents data on the environment and climate of the Andreeva Bay and FSUE Atomflot sites and on the current state of radioactive pollution in these areas. The report describes the main buildings and facilities of the SNF handling system. The report presents an analysis of the impact of emissions of radioactive substances on the public, fauna and flora within the observation zone of the Andreeva Bay facility. The analysis of the environmental impact of the SNF removal from the DSU cells, transferring the SNF to canisters and sleeves and filling TUK-108/1 TUK-18 shipping packages at the SNF and RW temporary storage facility in Andreeva Bay produced the following results:

1. Under normal operating conditions, doses to the public outside the SPZ during the operations at the Andreeva Bay facility with the use of the infrastructure of SNF handling system will be between 0.009 µSv/y and 0.063 µSv/y.
2. Under normal operating conditions, Building 153 will have no adverse impact on the surface and ground waters, water area, soils, geological environment, vegetation and fauna.
3. Consequence analysis of design-basis accidents, which could occur during the operations at the Andreeva Bay facility with the use of the SNF handling system, shows that an accident involving a drop of a TUK-18 cask at the accumulation pad will produce a maximum expected effective dose to an individual member of the public of 72 nSv/y, 50 nSv/y and 9,4 nSv/y in Nerpichya Bay, Bolshaya Lopatka Bay and Zaozersk, respectively, which is significantly lower than the minimum significant dose to the public of 10 µSv per year.
4. In a worst-case beyond-design-basis accident (crash of an aircraft onto an open TUK-108/1 (TK-18) in Building 153 or at the loading station onboard m/v Serebryanka) the maximum expected effective dose to the public under worst weather conditions in the nearest settlement outside the SPZ limit may be as high as 41 mSv in the first year after the accident, thus exceeding the annual dose limit of 1 mSv. This would require protective measures for the public in accordance with the optimization principle (restoring control of the source and minimizing exposure, number of exposed persons, contamination of the environment and economic and social losses caused by contamination).

The environmental impact assessment of handling TUK-108/1 and TUK-18 packages containing SNF from Andreeva Bay at FSUE Atomflot produced the following results:

1. Under normal TUK-108/1 and TUK-18 storage and handling conditions at FSUE Atomflot, maximum effective public dose will be 22 µSv/y at the northern limit of Murmansk, and 16 µSv/y, 11 µSv/y and 4 µSv/y in the settlements of Mishukovo, Belokamenka and Roslyakovo, respectively. The radiological environment at FSUE Atomflot will be determined by the existing operations.
2. In a worst-case design-basis accident (drop of a TUK-108/1 (TUK-18) containing SNF during handling) the expected emergency dose to the public will be 2 nSv/y at the northern limit of Murmansk and 1.7 nSv/y, 0.84 nSv/y and 0.72 nSv/y in the settlements of Mishukovo, Belokamenka and Roslyakovo, respectively.
3. In a worst-case beyond-design-basis accident (drop of a portal crane onto a TUK-18 package filled with NPS SNF) the expected annual emergency dose to the public at the nearest (northern) limit of Murmansk will be 1.38 mSv/y. This will not exceed an average basic dose limit for the public of 1 mSv per year for any five consecutive years, but not more than 5 mSv in a year established by NRB-99/2009. No relocation of the public will be required. Maximum doses to the public in the settlements of Mishukovo, Belokamenka and Roslyakovo will be 0.97 mSv/y, 0.114 mSv/y and 0.092 mSv/y, respectively.

Overall, the process of removing SNF from the DSU tanks at the Andreeva Bay facility and shipping of SNF for reprocessing in TUK-108/1 and TUK-18 transport packages with the use of the SNF transhipment facility at FSUE Atomflot will have no adverse impact on the public and the environment, provided regulatory requirements are met.

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Abbreviations

CAZ	Controlled access zone
CCTS	Complete containerised transformer substation
DSU	Dry storage unit
EIA	Environmental impact assessment
FMBA	Federal medical biological agency
FSUE	Federal state unitary enterprise
GRW	gaseous radioactive waste
HLW	High-level waste
HS	Horizontal shielding
HSC	Harmful chemical substances
ILW	Intermediate-level waste
LLW	Low-level waste
LRW	Liquid radioactive waste
MAC	Maximum allowable concentration
NFM	Nuclear fissile material
NPS	Nuclear powered submarine
OZ	Observation zone
PPE	Personal protective equipment
RNG	Radioactive noble gases
RW	Radioactive waste
SFA	Spent fuel assembly
SNF	Spent nuclear fuel
SPZ	Sanitary protection zone
SRW	Solid radioactive waste
TSF	Temporary storage facility
SRLI	Safe reference levels of impact
VAL	Volumetric activity limit

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