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RADIOLOGICAL CONDITION OF ANDREEVA BAY TERRITORY AND WATER AREA

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Buildings and structures of the SNF and RW interim storage facilities at Andreeva Bay (former coastal technical base of the Northern Fleet) were constructed at the end of 1950s – in the beginning of 1960s. Since delivery of SNF significantly exceeded its removal, a large amount of fuel (~ 100 NPS reactor cores) and RW has accumulated at the storage facilities. During more than 40 years of operation the buildings and structures have not undergone any repair, hence many of the storages are in emergency condition [1]. Decreasing leakproof of the storages has been leading to radioactive substances being taken to the site by underground water. Snow slush and rain flows have been gradually extending the contamination area and taken radionuclides into Andreeva Bay sea waters.

Radioecological measurements within the site and the water area. Surveys of Andreeva Bay buildings, structures, site and water area were carried out on a repeated basis by the Navy Radiation Safety Service, as well as by NIKIET experts (land survey) and KI experts (water area survey). In 2002-2004 owing to gratuitous financial aid of the Norwegian Radiation Protection Authority radiation contamination maps (Fig.1) were drawn, as well as hydrogeological and radiation and geological surveys of the most part of Andreeva Bay area were carried out. These measurements differed from the previous ones in term of quality and quantity: the number of ground samples measurements exceeded the previous years' number by dozens of times; large-scaled field study was the basis for drawing a γ-radiation field map of the site and the water area, for identifying the radioactive contamination sources and for estimating radionuclide composition. Based on the given results a three-dimensional data base was made up, which contained the data on the sources of radiation contamination of the site, buildings and facilities. By means of the data base it is possible to assess real and potential radioecological hazard sources and to plan elimination work of the same.

Building 5 – former spent nuclear fuel storage. The first stage of the building with two smaller pools was commissioned in 1962. In 1973 an accessory building with two large pools was constructed. A water leakage from one of the large pools was recorded in 1982, attempts to stop the leakage did not succeed. [2]. Later the second pool also started to leak. By this time the fuel had been partly damaged, some canisters with fuel had fallen onto the pool bottom due to the chains breakages. It resulted in ^{137}Cs and ^{90}Sr penetrating into the ground together with water. The building walls and foundation were saturated with radioactive substances. The dose equivalent rate amounted to 10-20 mSv/h at the outer walls surface. Radionuclides penetrated into the stream under the building, which went out to the surface 20 meters lower than the building's level, at a hill slope, and fell into the bay. In 1999 the stream was lead off from the building, but its most part remained contaminated to an immense extent up to the depth of 1 meter. Even in 2005 the dose equivalent rate amounted to 100-200 μSv/h with the value of 400 μSv/h in some areas, while ^{137}Cs ground concentration reached $6x10^6$ Bq/kg and ^{90}Sr ground concentration reached $4x10^6$ Bq/kg.

The concrete and bricks samples of the building walls and foundation were characterized by ^{137}Cs specific activity of $3x10^8$ Bq/kg and ^{90}Sr specific activity up to 10^9 Bq/kg. The ground around the building was also heavily contaminated (up to 10^9 Bq/kg). These radionuclides have been constantly washed away by snow slush and rain flows, thus enlarging the contamination area and penetrating into the bay coast and water areas.

Specific activity of the bottom sediments within the area of the stream inflow into the bay at the distance of 20-30 meters from the coast amounts to 200-300 Bq/kg. Radionuclides content in the sea water does not exceed 100 Bq/m^3 [3], which is significantly less than the natural sea water activity specified as ^{40}K (~10 000 Bq/m^3).

After the fuel had been discharged from the pools, there remained some silt layer containing radioactive substances. The near-bottom radiation level on average amounts to 100 mSv/h, in some places radiation reaches 200-600 mSv/h, which indicates presence of fuel fragments in the silt. In 2005 NIKIET experts first managed to take some silt samples. The silt represented intermediate level RW basing on the following characteristics: density ~ 1,5 g/cm^3 , layer thickness – up to 10 cm, specific activity of ^{137}Cs – $2,9x10^8$ Bq/kg, specific activity of ^{90}Sr – $7,5x10^8$ Bq/kg, specific activity of ^{60}Co – $2x10^5$ Bq/kg, α – emitting radionuclides – up to $7,2x10^4$ Bq/kg. There is a thick dust layer on the floor of the process flow hall left from the concrete slabs, which had been used to protect against irradiation during spent nuclear fuel discharge. Specific activity of the dust amounts to $2,3x10^9$ Bq/kg while of α – emitting radionuclides – to $8,6x10^5$ Bq/kg. The dust and the silt are potential sources of the territory contamination when Building No.5 is to be demolished or when various potential emergencies may occur. This should be considered while deciding on the building decommissioning technology.

Solid and Liquid Radioactive Waste Storage. The solid waste is stored in seven storages and at three open pads; part of it is stored in two liquid waste storage tanks in Building 6. Four tanks of Building 6 are used for storing liquid waste. The tanks are made of concrete, coated with steel plates and are deepened to the top. Their operation life has long expired; three containers are not leak-tight letting the liquid waste penetrate into ground waters. Two containers with solid waste are not leak-tight as well, they are filled up with ground water, which has turned to liquid radioactive waste. Attempts to pump them out were a failure, since the storage had been filled up with water again. No progress has been observed in surveying the other deepened storages, but they are considered to be not leak-tight according to the implicit data. The precise quantity, content and condition of the solid waste in the storages are unknown.

As per the inventory results, there appeared to be much more open solid waste storage pads than it was registered during assigning the facility to Minatom (Ministry of Nuclear Energy). The radiation situation is motley. Part of the solid waste including those in containers is situated on the top of the deepened storages. In some cases it is impossible to determine what the source of the increased equivalent dose rate is: whether it is the contaminated ground irradiation or the sources in the containers. It is difficult to reach many containers to take measurements due to dense packing of a large number of various containers. Thus dose rate near facilities 7 and 7A reaches 3000 μSv/h, ground contamination with β-emitting radionuclides is $(4\text{-}6)10^3$ cm^{-2}▪min^{-1}. Such radiation situation is assessed to be due to irradiation from one, or possibly two, containers on the roof of facility 7A. They should be removed or shielded to improve the working conditions on site.

The dose rate near facility 7A is just 150 μSv/h, but the ground surface contamination reaches 2▪10^4cm^2▪min^{-1}. According to work experience, dose rate can increase by several times after removal of some containers and concrete slabs. ^{137}Cs and ^{90}Sr are most common radionuclides, but ^{60}Co (up to 10%) is found in some places as well; α – emitting radionuclides have not been identified.

SNF Storage Facilities in Dry Storage Units. When SNF from Building 5 was transferred to the DSU cells, the canisters were supposed to be stored in steel tubes spaces between which were to be plugged with concrete. During the survey of tank 2B it was found that all the cells were filled with water of specific activity from 10^3 to 10^8 Bq/l. In 2004 NIKIET employees made for the first time water samples from several cells from different depths and discovered that ^{137}Cs concentration was increasing with depth several times, and ^{90}Sr concentration – ten and hundred times. The α-radionuclide presence was also positively registered in the water. Thus the ^{137}Cs specific activity at the bottom of cell 1147 is $8.9x10^7$ Bq/l, ^{90}Sr - $7,2x10^8$ Bq/l, α-radionuclide activity is - $5.4x10^4$ Bq/l. The fact proves the contact between fuel and water, as a consequence not only fission products but also actinides were transferred into the water. High concentration of salinity (up to 1500 mg/l), as well as chlorides (up to 400 mg/l), advances fuel degradation [2]. These measurements were implemented in the space between the cell tube and the canister where fuel assemblies with SNF were stored. Until present moment specialists have failed to detect the source of water inflow into the cells - either it is contact with ground waters or atmospheric precipitation.

Under the radiological survey of tank 2B it was found out that the dose rate measured at the surface of cells several times exceeds the estimated one. It was discovered that γ-radiation penetration between the cell tube and covering it plug or through concrete made small affect (~1 µSv/h), the most considerable input to the dose rate was made by radioactive water in the cell (100-500 µSv/h) and by the radionuclide contaminated concrete between the cells (100-200 µSv/h). The main input (up to 2000-3000 µSv/h) is done by ^{137}Cs at the inner surface of the cell tube and at the surface of structures at the canister upper part. Due to seasonal fluctuations of water level, corrosion layer containing ^{137}Cs can be found also over the water surface in the cell. These estimations were confirmed by a series of special tests.

Structure of tank 3A differs significantly from that of tanks 2A and 2B. There was no roof above the tank, so the cover made of concrete slabs covered by roof felt was constructed over the concrete surface at the height of approx. 1 m. The high level of radiation over the surface of these plates is registered: 1.5-2 times more than over the tubes in tank 2B. Nobody knew also whether there was water in the cells. In December 2005 NIKIET employees implemented radiological survey of the space under the cover slabs. The spaces between several slabs were opened (the layer of roof felt with bitumen was broken), video filming was implemented using endoscope and the dose rate was measured in different places. Water was found in the unplugged cells, notably its level was fluctuating from 20 to 100 cm below the tube top. Nobody knows whether there are canisters with SNF in the cells. The measured dose rate is fluctuating over a wide range reaching ~40 µSv/h over concrete between two plugged cells. The reason for such high background is to be found out.

The territory around the DSUs is considerably less contaminated than that at the solid waste storage pad or around Building 5. The continuing degradation inevitably leads fuel to disintegrate into small (20-200 µm) granules. According to the estimates, formation of homogeneous mixture of these particles with water can lead to spontaneous chain reaction. The most dangerous is the concentration of 5-10% in fuel volume which possibly can happen, e.g. under fall of its particles into the water in the cell when unloading the canister.

In case of spontaneous chain reaction all content of the canister will be thrown out from the cell that will lead to the intense radio contamination not only of the DSUs but of the surrounding territory as well. That is why when selecting a method for SNF handling under its removal from the cells it is important to provide conclusive exception of the possibility of spontaneous chain reaction. It is a difficult task as water should be pumped out not just from a narrow (1-3 mm) space between the canister and the cell tube but from the canister itself.

Water Area. Since there was no reliable information on the nature of the adjacent water area contamination as per 1997, main attention was paid to getting an overall image of contamination. For that purpose additional surveys were conducted. The radiation situation was assessed using the data of dosimeter measurements and radioactivity analysis of the coastal ground, water and bottom silt.

Measurements taken by a submersible γ-spectrometer and absorbing filters showed that the water did not contain γ-emitting radionuclides in the quantity exceeding the background of ^{137}Cs which is 5-7 Bq/m^3. Dosimeter survey was carried out at 56 points along the coastal line at the height of 1 meter from the soil surface. Dose rate measurements demonstrated that the most contaminated area was along the stream bed, which flew from Building No.5 (excess over the background by thousands of times), as well as the low space between the solid waste storage pad and the place where floating tanks for liquid waste were situated in 1997, and the area of the pier (excess over the background by dozens of times).

Data received as a result of the dosimeter measurement were supported by radioactivity analysis of ground samples taken within this area. 36 soil samples were taken along the site perimeter and the shoreline at every 50-60 meters, as well as 28 bottom silt samples were taken along the coastal line 20-30 meters away from the water edge. It is necessary to underline that only divers were able to take samples due to the stony ground, while sampling was possible to implement only within 10 meters from the coast due to very deep waters. Sampling was not performed at the deep waters of the water area of Zapadnaya Litsa Bay. A map of the bottom silt contamination with ^{137}Cs at the shoreline (Fig.2) was made based on the performed survey. According to Figure 2 abnormal contamination by anthropogenic radionuclides has been found at the following five areas:

- in area 1 of the shoreline water area near the stream inflow into the bay, which is flowing from Building No.5. This contamination area has formed due to constant washing out of radionuclides from the soil, which had been contaminated as a result of the emergency in Building No.5. According to the radiation survey of 1997, maximum concentration of ^{137}Cs in the bottom silt near the stream inflow into the bay reached 500 Bq/kg;
- in the low area (area 2) between the SNF and solid RW storage pad, ^{137}Cs content amounted to $2*10^4$ Bq/kg in the coastal line soil and at the water area adjacent to the low area, where in 1997 there were 14 floating tanks with liquid RW (^{137}Cs up to 500 Bq/kg, and ^{60}Co up to 30 Bq/kg contained in the bottom silt). This contamination might have been caused by radionuclides migration from the SNF and solid RW storage pad, as well as by leakage of radionuclides from the floating tanks. It should be noted that the work on cutting floating tanks on site that has been implemented up to present date could have lead to extra contamination of the coastal line and the adjacent water area;
- under the rock (area 3), eastern side of the SNF and solid RW storage pad, the concentration of ^{137}Cs is up to 850 Bq/kg and of ^{60}Co is 70 Bq/kg, which must have been conditioned by radionuclides migration from the pad;
- in the piers area (areas 4 and 5) at the eastern coast of the Andreeva Bay site, which has been caused by transfer and transportation of SNF and RW during work processes. Based on the results of the 1997 radiation survey, the maximum content of ^{137}Cs in the shoreline soil amounted to 4 kBq/kg, in the bottom silt – to1 kBq/kg and of ^{60}Co – to 0,1 kBq/kg.

Subsequent to the results of 1997 offshore strip survey it can be concluded that the main sources of its contamination were the areas covering the stream area and the open SNF and solid RW storage pad. Apart from that, considerable water area contamination has been caused by longstanding operations on transfer and transportation of SNF and RW.

In 1999 the major attention was paid to the study of radionuclides inflow to the bay with the stream flowing from Building 5. According to the data of the Navy radiobiology laboratory, the stream had the following contamination level from the moment of identifying the leakage in the building (1982) to the final drainage of the storage pools (1989): at the outlet to the surface at Building No.5 - 10^3-10^4 Bq/l, at the inflow to into the bay - 1-2 Bq/l of ^{90}Sr and ^{137}Cs. According to the Navy data, the total amount of anthropogenic radionuclides which has penetrated into the environment due to the leakage in Building No.5 storage rose to 37 TBq.

The survey in 1999 was conducted during spring and summer. The content of ^{137}Cs in the stream water samples in the early spring was the smallest and changed from 25 Bq/l to 300 Bq/l, in May it increased up to 0,5 kBq/l, while in September it reached the maximum level, which is 1,3 kBq/l.

Moreover, the potential radionuclides migration along the water area of the Zapadnaya Litsa Bay and further to the Motovsky Bay of the Barents Sea has not been yet studied. In addition to that, the measurements conducted in 1996 by the Murmansk Marine Biological Institute helped to identify the following substances in the bottom silt samples taken from exterior part of the Zapadnaya Litsa Bay: ^{60}Co (0,5-4 Bq/kg), ^{137}Cs (0,7-50 Bq/kg) and $^{239, 240}$Pu (up to 2 Bq/kg) [5]. Such values, specifically of $^{239, 240}$Pu, do correspond to the background values, nonetheless, ^{137}Cs value reaching 50 Bq/kg indicates its excessive content, not speaking about ^{60}Co presence, which confirms the anthropogenic nature of the contamination source and the migration of ^{137}Cs and ^{60}Co radionuclides to the Motovsky Bay.

Conclusion. Radiological condition of the SNF and RW interim storage facilities at Andreeva Bay is currently determined by two actual contamination sources – Building No.5 and liquid and solid RW storage pad. The area around and under the building was contaminated due to water leakage from the SNF storage pools. The stream flowing under the building carried out ^{137}Cs and ^{90}Sr to the surface which resulted in contamination of a vast area between the building and the bay coast. The exact quantity of the stream carried radionuclides and the volume of the contaminated ground are not known, since radiation and geological survey implying holes boring and core activity measurement has been performed only within a part of the contaminated area. There is no data on the radionuclides activity level in the ground under the building. Thus, it is advisable to speed up Building No.5 decommissioning process. It is required to clean the pools bottoms of silt, which apart from fission products contains fuel fragments of total activity of 70-150 TBq. When the building is demolished, it will become possible to reach the ground under it for taking measurements as well as for the ground to be removed. This will exclude the possibility for the area to be further contaminated and for the radionuclides to penetrate into the sea.

Radionuclides have continued to penetrate into the soil from the open solid waste storage and from the leaky solid and liquid waste storages, which has been gradually expanding the contamination area. There is no possibility for estimating the quantity of the contaminated ground, since no survey of the deepened storages has been performed; there is no data on the ground contamination level under the containers and the concrete slabs taken away from Building No. 5 after elimination of the emergency.

The radiation survey of the area gave the possibility to zone the area. Measures have been taken to decrease the radiation impact on the personnel. The solid waste from open pads has been partly fragmented and put into containers in Building No. 67. Several local contamination sources have been eliminated within the area.

Extra hazardous environmental impact would be possible to avoid due to surveying the main radioecological hazard source, which is the SNF storage units, as well as due to analyzing potential emergency situations and developing optimal options for SNF handling. Consequently Andreeva Bay area will be brought into an environment-friendly condition.

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