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# PROGRESSIVE UPDATING OF RADIOACTIVE WASTE MANAGEMENT STRATEGY FOR THE NORTHWESTERN REGION OF RUSSIA ALONG WITH THE IMPLEMENTATION OF STRATEGIC MASTER PLAN ON COMPREHENSIVE DECOMMISSIONING OF SHUTDOWN NUCLEAR FLEET FACILITIES

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*The paper overviews the development and implementation of RW management strategy covering both accumulated and newly generated waste in the Northwestern Region during the implementation of 'The Strategic Master Plan on Comprehensive Dismantlement and Decommissioning of Shutdown Nuclear Fleet Facilities and Environmental Remediation of Supporting Infrastructure'. The paper presents the needs and the mechanisms for the strategy adjustment with no changes affecting its main goal. The paper presents the industrial infrastructure, its capabilities and management flowsheets for various types of radioactive waste facilities of the Northwestern Region along with the areas and the ways enabling their improvement in accordance with the strategy developed.*

**Keywords:** *Northwestern Region of Russia; nuclear legacy; radioactive waste; management strategy; infrastructure of facilities; decommissioning; comprehensive decommissioning of nuclear submarines; remediation; radiation safety; environment.*

## Purpose of the radioactive waste management strategy in the Northwestern region of Russia

Strategy for the management of radioactive waste (RW) accumulated and generated during construction, operation, maintenance and disposition of nuclear fleet facilities in the Northwestern region (Murmansk and Arkhangelsk regions) was developed as part of a Strategic Master Plan for the Comprehensive Disposition of Nuclear Submarines (SMP) [1]. "Elimination of threats to the population, personnel and the environment by completing the disposition of nuclear submarines (NS), surface ships with nuclear power units (SS with NPU) and nuclear maintenance ships (ATM vessels) and environmental remediation of all radiation hazardous facilities associated with these operations in the Northwestern region of Russia" is viewed as the main (strategic) goal of the SMP.

To achieve this general strategic goal, SMP considers various focus areas, that should jointly ensure the implementation of the entire plan. Accordingly, for each focus area its own action strategies have been developed. One of them is a strategy for radioactive waste management in the Northwestern Region of Russia. Under this strategy the goal is viewed in addressing the following challenge: "radioactive waste generated as the result of past (nuclear legacy), current and future activities implemented under the SMP shall be properly conditioned, packaged and safely stored in monitored

storage facilities for a period of at least 50 years followed by subsequent final isolation (disposal). It's supposed that the final isolation of radioactive waste (disposal) should be completed before the end of a specified interim storage period" [1].

In other words, ultimate goal of the SMP as regards radioactive waste management is seen in its emplacement in a conditioned form of solid (SRW) and immobilized liquid (LRW) radioactive waste in the regional center for conditioning and long-term storage (RCCLS RW) for the purpose of its safe storage with relevant provisions in place to ensure its further transfer to a disposal site with no additional repackaging [2, 3].

## Initial data for of RW management strategy development in the Northwestern region of Russia

To develop a strategy, all types of activities and facilities containing or generating radioactive waste were analyzed, their quantitative and qualitative characteristics were determined [4].

### *Types of activities resulting in RW generation*

Radioactive waste is generated as a result of various activities, in particular:

- operation and maintenance of nuclear fleet, dismantlement of nuclear submarines withdrawn from naval service, including formation of NS reactor compartment units intended to be placed on a dry base for long-term storage purposes;
- disposition of surface ships fitted with nuclear power units which involves formation of reactor rooms (RR) providing for their emplacement on a dry base for long-term storage purposes;
- disposition of nuclear maintenance ships with storage-unit packages (US) being formed providing for their emplacement on a dry base for long-term storage purposes;
- disposition of nuclear icebreakers and a lighter carrier;
- processing and conditioning of accumulated and generated RW enabling its long-term storage;
- environmental remediation of spent nuclear fuel and radioactive waste temporary storage facilities (in Andreev Bay and at Gremikha site in the Murmansk Region), at ship repair and shipbuilding yards, at nuclear icebreaker fleet sites;
- environmental remediation of decommissioned RW temporary storage facilities in the Murmansk branch of the Northwestern Territorial division of FSUE RosRAO;
- decommissioning of Kola NPP units (not accounted for in the SMP).

### *RW generation sites of the Northwestern region*

- Northwestern Center for Radioactive Waste Management "SevRAO" (NWC "Sev-RAO") — FSUE "RosRAO" subsidiary and its branches: Andreev Bay, Gremikha and Sayda Bay;
- JSC Ship Repair Center Zvezdochka (JSC Zvyozdochka);
- Nerpa Shipyard, subsidiary of JSC Zvyozdochka (Nerpa Shipyard);
- JSC Ship Repair Facility № 10 (JSC SRF № 10);
- FSUE Atomflot;
- Murmansk branch of FSUE Ros-RAO's Northwestern Territorial Division (Murmansk branch of the RosRAO);
- Kola NPP (not taken into account in the SMP);
- JSC Production Association Northern Machine-Building Enterprise (JSC PA Sevmash);
- floating facilities (nuclear submarines, surface ships with nuclear power units, nuclear icebreakers, ATM vessels).

Figure 1 shows the geography of the above sites.


*Figure 1. Geography of RW storage and management facilities in the Northwestern Region of Russia*

### *Estimated amounts of RW resulting from the disposition of nuclear fleet ships and vessels and remediation of RW and SNF temporary storage sites*

To establish a RW management strategy under SMP development process, data were collected and systematized on the main quantitative characteristics of radioactive waste accumulated and generated during the disposition of nuclear ships, vessels and remediation of storage facilities (volume,

***Table 1. RW amounts in the Northwestern region of Russia resulted from the disposition of nuclear ships and vessels, remediation of RW and SNF temporary storage facilities: accumulated and expected to be generated until the end of 2020***

| Site | SRW accumulated/expected, $m^3$ | | | LRW accumulated/expected, $m^3$ | | |
|---|---|---|---|---|---|---|
| | LLW | ILW | HLW* | LLW | ILW | HLW |
| Disposition of nuclear ships and vessels, remediation of RW and SNF temporary storage facilities | | | | | | |
| Andreev Bay | 15,120 / up to 7,000 | 2,063 / up to 3400 | 428 / up to 50 | 2,710 / up to 41,700 | 620 / up to 4,300 | 50 / n/a |
| Gremikha | 1,300 / up to 2,000 | 200 / up to 500 | 8 / n/a | 891 / 13,200 | 128 / 520 | 0,2 / n/ат |
| JSC Zvyozdochka** | 1,630 / up to 5,000 | 881 / up to 10 | 25 / up to 1 | 1,047 / up to 600 | 189 / up to 60 | 21 / до 10 |
| JSC PA Sevmash*** | 120 / up to 5,000 | 15 / up to 5 | 2 / up to 1 | 11 / up to 450 | 42 / up to 50 | 5 / до 5 |
| Nerpa Shipyard | 2,911 / up to 100 | n/a / up to 10 | 5 / up to 1 | 173 / up to 300 | n/a / up to 30 | n/a / up to 3 |
| JSC SRF № 10 | 796 / up to 30 | 126 / up to 30 | 8 / up to 1 | 180 / up to 150 | 18 / up to 15 | 2 / up to 2 |
| FSUE Atomflot | 1,028 / n/a | 473 / n/a | 55 / n/a | n/a / n/a | n/a / n/a | n/a / n/a |
| SS with NPU (1 pcs.) | n/a / up to 1,000 | n/a / up to 215 | n/a / n/a | n/a / up to 120 | n/a / up to 100 | n/a / n/a |
| Lepse (Floating Maintenance Base) | 224 / up to 370 | 373 / up to 700 | 73 / up to 90 | n/a / up to 200 | 51 / n/a | 3,3 / n/a |
| FMB, TNT, PDKS (15 pcs.) | 56 / up to 4,170 | 410 / up to 300 | n/a / n/a | 370 / up to 700 | 174 / n/a | n/a / n/a |
| TOTAL | 23,250 / up to 25,000 | 4,540 / up to 5000 | 600 / up to 140 | 5,400 / up to 57,600 | 1,200 / up to 5,000 | 80 / up to 20 |

Notes:
* Coastal and floating storage facilities holding reactor control and safety system assemblies (RCCSAs) categorized as HLW including 1,520 RCCSAs at Andreeva Bay site, 60 RCCSAs at Gremikha site and 206 RCCSAs at FMB.
** up to 5,000 $m^3$ of SRW are expected to be generated from the decommissioning of storage facility No. 162.
*** up to 5,000 $m^3$ of SRW are expected to be generated from the decommissioning of Mironova Gora storage facility.

aggregate state, activity, composition, etc.) These data are presented in Table 1.

## Technique, conditions and principles for the development of RW management strategy for the Northwestern Region of Russia

The strategy for radioactive waste management in the Northwestern Region of Russia developed under the SMP was based on the following fundamental decisions [5]:

- Center for conditioning and long-term storage of radioactive waste should be constructed at Sayda Bay site (RCCLS RW);
- all regional sites with LLW and ILW SRW inventory being already accumulated or expected to be generated in the future should hand over such waste to RCCLS RW ensuring that the state of such waste is suitable for its long-term storage providing for subsequent waste transfer to the national operator for disposal without any additional predisposal treatment;
- SRW resulting from the dismantlement of nuclear submarines, surface ships with nuclear power units and ATM vessels are emplaced into RCs, RRs or USs and handed over for long-term storage to Sayda Bay site;
- within the SNF and RW temporary storage facility located at Andreev Bay site construction of a waste management complex for high-level SRW is underway;
- all accumulated and generated high-level SRW is handed over to NWC SevRAO's Andreeva Bay site for conditioning purposes and further transferred, first, for long-term storage at RCCLS RW and then to the national operator for disposal;
- a modular mobile unit designed for in-situ liquid HLW and ILW processing is being developed for RCCLS RW. The unit should be shipped from RCCLS RW to enterprises and facilities using a container ship.

The above was assumed provided that the following conditions are met:

- safe management of radioactive waste irrespective of its type at all waste generation sites over the next decade with a phased transition from temporary storage option to the long-term one;
- development of new and modernization of existing production units and facilities for radioactive waste management, upgrading their processing and conditioning capacities accounting for all types of waste to ensure its safe long-term storage in RCCLS RW with subsequent transfer to the national operator for disposal;

- imposing regulatory restrictions on RW temporary storage time at decommissioned facilities and remediated sites of the region to speed up the transfer of waste to RCCLS RW.

### Strategy development

Based on the evaluation of the initial data given above, a strategy enabling to achieve the stipulated strategic goal for the RW management in the Northwestern region of Russia could be developed provided its compliance with the basic principles and the goal itself. Relevant development method was based on an integration approach involving elaboration, evaluation and comparison of possible options against various parameters followed by the selection of an optimal one with its detailed fine tuning to a level allowing for the program and design development and accounting for the necessary resources [6]. At the same time, the advantages and disadvantages of the existing RW management systems at each site, their potential and likely changes associated with the upcoming reorganization (threats, risks) were examined, the existing strategies followed by enterprises were analyzed and compared against the reference ones (recommended by the IAEA). This enabled to choose acceptable ways for the development of the RW management system in the region.

Several potential strategic approaches to the development of a regional RW management system were considered: from "leaving everything as it is" to "immediate processing and final disposal of all radioactive waste" (public consent-based strategy). As a result, a phased integrated approach was chosen accounting for the positive aspects of the above strategies and existing realities. This enabled the development of an "optimization strategy" reflecting a number of general and particular strategic approaches. Actually, this is the strategy being considered and implemented under the SMP.

### The need for updating the source information and recurrent strategy adjustment in light of new circumstances

More than a decade has passed since SMP development with some significant legal, regulatory, technological and other changes that have occurred affecting the general strategy of RW management in the Russian Federation, including the one implemented in the Northwestern region. In this regard, it became necessary to adapt the proposed strategic decisions to these changes and to bring them in line with relevant provisions of the Federal Law of the Russian Federation of July 11, 2011 No. 190-FZ "On Radioactive Waste Management and Amendments to Certain Legislative Acts of the Russian Federation" [7].

This manifested an advantage of the integrated approach used in the development of the SMP, namely, it provided an opportunity for the RW management program "buildup" under the framework of an already adopted strategy. Thus, relevant adjustments in the RW management programs could be introduced safety allowing to consider a number of new circumstances:

- some new facilities planned for decommissioning had to be added to the strategy: nuclear icebreakers and Kola NPP;
- effects produced by radiation remediation of adjacent territories and marine areas should be considered;
- the possibility of engaging ATM vessel "Serebryanka" not only in SNF transportation, but also in SRW shipment allowing to speed up the remediation of Gremikha temporary storage facility;
- the possibility of engaging ATM vessel "Serebryanka" in the transportation of LRW from the entire region to FSUE Atomflot or JSC Zvyozdochka;
- a decision required to be made on a single method for high-level LRW processing at waste generation sites due to the decision on abandoning the construction of HLW management complex at the Andreeva Bay site (NWC "SevRAO");
- the need for evaluating and justifying the quantitative indicators and requirements for the long-term storage and disposal of the newly introduced waste category of VLLW.

The adjustment of already adopted RW management strategy performed with an account taken of the newly emerged circumstances and occurred changes did not affect its basics, but allowed for its transition to a higher level of detail.

SMP development involved some major efforts enabling collection and systematization of data on the main characteristics of radioactive waste, accumulated and expected to be generated as the result of further nuclear vessel and ship disposition and remediation of SNF and RW storage sites (volume, state of aggregation, activity, composition) [8]. However, due to the adoption of the Federal law on RW management, changes introduced to criteria for RW assignment to various waste categories, establishment of a unified state system for radioactive waste management, these data had to be refined. Based on the information collected from various sources, authors of the studies [4] were able to get a reliable and up-to-date knowledge on the accumulated and expected RW volumes. Table 2 provides such RW volumes split across various sites in the Northwestern region, including the Murmansk

***Table 2. Total amount of accumulated and expected RW in the Northwestern region until the end of disposition and remediation (2025)***

| Type of activity | SRW | | LRW | |
|---|---|---|---|---|
| | Volume, $m^3$ | Activity, Bq | Volume, $m^3$ | Activity, Bq |
| | Accumulated/ expected | Accumulated/ expected | Accumulated/ expected | Accumulated/ expected |
| Disposition of NS, SS with NPU and remediation of SNF and RW TSF | 30,000 / 30,000 | $7 \cdot 10^{16}$ / $4 \cdot 10^{15}$ | 7,000 / 62,000 | $5 \cdot 10^{15}$ / $3 \cdot 10^{14}$ |
| Icebreaker disposition | n/a / 20,000 | n/a / $1 \cdot 10^{15}$ | n/a / 2000 | n/a / $1 \cdot 10^{14}$ |
| Remediation of the Murmansk branch of FSUE Ros-RAO's North-Western Territorial division | 300 / 5,000 | 2·10· / $1 \cdot 10^{14}$ | 100 / 100 | $1 \cdot 10^{12}$ / $1 \cdot 10^{12}$ |
| Kola NPP power unit decommissioning of | 9,000 / 80,000 | $4 \cdot 10^{15}$ / $5 \cdot 10^{16}$ | 7,000 / 1,000 | $1 \cdot 10^{14}$ / 1·1014 |
| Total | 40,000 / 135,000 | $7 \cdot 10^{16}$ / $5 \cdot 10^{16}$ | 14,000/ 65,000 | $5 \cdot 10^{15}$ / $5 \cdot 10^{14}$ |
| **SUM** | **over 175,000** | **Approx.$1{,}3 \cdot 10^{17}$** | **over 79,000** | **Approx. $6{,}0 \cdot 10^{15}$** |

branch of FSUE Ros-RAO's North-Western Territorial Division and units 1—4 of the Kola NPP, according to the forecasts made until 2025.

## Implementation of strategic decisions on RW management in the region

In the development of the RW management strategy, as applied to nuclear submarine, surface ships with nuclear power units, ATO vessels and remediation of spent nuclear fuel and radioactive waste temporary storage facilities, both international experience and generally accepted principles were accounted for, namely such as [9]:

- implementation of IAEA recommendations on RW management;
- application of a common technical approach at all facilities;
- application of proven and tested technologies;
- maximum use of available production capacities;
- minimal construction of duplicate facilities at enterprises;
- construction of new RW processing complexes at sites accounting for the greatest geographic concentration of RW generating facilities;
- processing, conditioning and long-term storage of SRW in a single center;
- optimization of long-term storage facility/disposal facility development for solid VLLW.

The adjusted strategy aims to further replace the activities of RW management enterprises implemented using the available capacities with the use of a stationary RW management complex in the SevRAO's Sayda Bay branch and mobile units for LRW processing that should be developed, which requires the adjustment of local waste management strategies at particular enterprises.

The need for such adjustments is also prompted by changes in the ownership status and departmental affiliation of enterprises, significant shifts in the completion timeline for infrastructure development and upgrading, more precise inventory of RW being transferred for processing, actual capacity of available capacities. Bearing this in mind and also considering new-built and available facilities and technologies being currently upgraded, that are described below, the development of infrastructure and RW management flowcharts at enterprises in accordance with the updated strategy are believed to be as discussed below.

Sayda Bay branch of SevRAO [10]. Commissioning of a Coastal Station for Long-Term Storage of Reactor Compartments" (LTS RC) designed for the safe storage of reactor compartments, reactor rooms and storage of SNF and RW compartments generated due to the disposition ships and vessels with nuclear power units and a Regional Center for RW Conditioning and Long-Term Storage designed to accept SRW from regional enterprises generating such waste during nuclear fleet facility disposition.

LTS RC will enable to arrange for a surface storage of 150 nuclear submarine reactor compartments, 15 fragments of ATM vessels, 10 steam generating units of atomic icebreakers and to dispose of RC, RR and ATM vessel packaged units following the expiration of an appropriate long-term storage period.

Development of LTS RC providing for the reactor compartment land-based storage ensures their safety as the RC accepted for storage are subject to appropriate treatment by industrial enterprises with the SNF being unloaded from them. A scientific rationale was established for such storage arranged in accordance with regulatory requirements and providing a high degree of protection, control, accounting. Engineering and technical solutions for all support systems are based on the latest achievements and developments in the relevant fields of science and technology.

Under such an approach, safe storage of reactor compartments is believed to be ensured for some 70—100 years. Over this time, radiation exposure should decrease to a safe level enabling complete and final disposal of compartments providing for a possibility of reactor emplacement into high-level SRW disposal facilities.

The main LTS RC section (slipway plate) was constructed simultaneously with engineering communication and infrastructure setup. A transport-technological system designed for compartment installation on the slipway was developed. It involved a purposely equipped floating dock, ship-carrying equipment and a hydrotechnical complex with an equipped pier for a floating dock, an underwater support for its trimming and a moorage for diving. The overhaul shop is considered of a great importance in terms of the long-term storage safety: in this shop scheduled maintenance of reactor compartments will be performed decennially. Figure 3 presents the general layout of the LTS RC.

In addition, necessary infrastructure was set up to cut floating nuclear submarine reactor units (RU) and to form reactor compartment units (RC), as well as to perform all necessary operations before their transfer to long-term land-based storage. By the end of 2018, 114 RCs were arranged and emplaced into the long-term storage facility. To carry out dock operations in the RC long-term storage facility, Itarus dock pantone was built at the Italian shipyard Finkantieri and handed over to SevRAO.

The Itarus pantone dock should perform the following functions:

- transportation of floating RUs removed from dismantled submarines from temporary storage sites and their transfer to the SevRAO's Sayda Bay branch slipway for the purposes of their further cutting;
- transportation of formed RCs from to the Nerpa shipyard to RC long-term storage facility including their unloading from the ship platform on the pier;
- docking of floating RUs from dismantled nuclear submarines with the Sayda Bay RC TSF to ensure their unsinkability;
- transportation of disposed ATM vessel package-units.

In 2015, Regional Center for Radioactive Waste Conditioning and Long-Term Storage was commissioned. Construction of this center is viewed as the third stage implemented under the Saida LTS RC project being a standalone closed-type structure meeting the highest European standards in terms of its technical specifications. Its prototype was the Zwischenlager Nord (ZLN) RW storage facility operated by EWN GmbH in the German city of Lubmin. The regional center accepts RW from shipyards and former coastal technical and maintenance bases of Murmansk and Arkhangelsk regions. Kola NPP is the only exception with this issue currently being under a legal review.

The center performs series of operations enabling SRW conditioning, waste segregation into RW subject to storage and pure metal, as well as long-term storage of conditioned low- and intermediate-level waste. The center consists of four elements: SRW conditioning zone; disassembly workshops; administrative and technical units.

LRW processing unit provides for waste processing via evaporation method only for secondary LRW generated during the operation of RCCLS RW itself.

The main capacity indicators of the RCCLS RW are as follows:

- total capacity of 92,000 $m^3$ (57,500 $m^3$ — at the first stage);

*Figure 3. General layout of the LTS RC*

- annual capacity — 1,380 $m^3$ of RW per year; 5 RC units;
- design period of operation — 100 years; RW conditioning — 30 years.

**NWC SevRAO's Andreev Bay Branch.** Since this site was the one accounting for the largest RW inventory both in terms of actual RW accumulated amount and the one expected to be generated in the future, it was supposed to site there a multi-functional complex designed to manage the entire RW inventory.

The complex should have featured the following units:

- SRW management facility with a capacity of up to 2,000 $m^3$/year;
- LRW management facility with a capacity of up to 3,000 $m^3$/year;
- an accumulative site for temporary storage of RW packages with SRW held there until their hand over for long-term storage to RCCLS RW Sayda;
- shelters above the subsurface SRW storage facilities providing waste isolation from the environment before waste shipment to its further treatment site (buildings 201 and 202). Construction of such shelters was recognized as a priority task and these were built and put into operation in 2012;
- VLLW disposal facility.

Design documentation for the rest of the facilities was developed and reviewed. When preconstruction activities were started at the construction site of building 203 (SRW complex), a significant part of the soil subjected to excavation was found to be radioactively contaminated. The amount of SRW that could have been generated during the construction operations was estimated showing that it was not possible to ensure safe in-situ disposal of the waste. Therefore, by the decision of the State Corporation Rosatom, the construction site was abandoned.

A similar risk was deemed for the building 1 (LRW complex). A detailed analysis of the design documentation showed that with minor refinement of the designs, LRW handling equipment can be installed into already available building 154 (maintenance workshop and equipment decontamination unit) and in a small extension to it. Corresponding design revision was performed with relevant design approvals being obtained from Russian authorities. However, due to the fact that Italy provides funding for these activities under a technical assistance program, tender announcement and actual construction activities were restrained by the lack of approval from the Italian Ministry of Economic Development: the tender was announced only in September 2019. In accordance with the design decisions, the developed LRW management complex will be able to process low-level LRW including LRW of complex physical and chemical composition.

Building 205 for short-term storage of SRW packages before their transfer to RCCLS Sayda was built and put into operation in 2018.

Primary packages with radioactive waste and spent filter containers from liquid HLW treatment plants are shipped to Sayda Bay for long-term storage using purpose-designed vessels and/or vehicles.

**NWC SevRAO's Gremikha Branch** [11], **Nerpa Shipyard.** No RW processing capacities are available at the sites with no construction of such facilities planned in the future.

Accumulated liquid LLW and ILW are continuously shipped by the Serebryanka tanker for processing to NWC SevRAO's Andreeva Bay site (another option suggests waste transfer to FSUE Atomflot).

Liquid HLW is processed in-situ using a mobile unit with radionuclide sorption in filter containers.

Generated solid LLW and ILW are continuously shipped by purpose-fitted vessels and/or vehicles to NWC SevRAO's Sayda Bay site for temporary storage, processing and long-term storage.

**FSUE Atomflot.** Liquid LLW and ILW are processed by FSUE's own means. Packages with immobilized RW is shipped using purpose-fitted vessels to the Sayda Bay site for long-term storage.

**JSC SRF № 10.** Solid LLW is subject to in-situ treatment at a mobile unit. Packed waste is shipped using purpose-fitted vessels and/or vehicles to NWC SevRAO's Sayda Bay site for long-term storage.

**JSC Zvyozdochka.** Liquid LLW is processed by JSC's own means. Packages with immobilized RW are shipped by purpose-fitted vessels for long-term storage to NWC SevRAO's Sayda Bay site.

Solid LLW are subject to in-situ processing by JSC's own means (including by combustible LLW incineration). Packaged waste is shipped using purpose-fitted vessels to NWC SevRAO's Sayda Bay site for long-term storage.

**JSC PA Sevmash.** Accumulated liquid LLW is continuously sent for processing to JSC Zvyozdochka.

Accumulated solid LLW is sent for processing to JSC Zvyozdochka.

**Murmansk branch of RosRAO's North-Western Territorial division.** No RW processing capacities are neither available nor planned for construction at the site.

**Kola NPP.** Liquid LLW and ILW are processed by the NPP's own means. Packages with immobilized RW are shipped by vehicles to the Sayda Bay site for long-term storage.

Liquid HLW is subject to in-situ processing using a mobile unit with radionuclide sorption by filter containers.

Solid LLW is subject to in-situ processing using NNP's own means. Packaged waste is transported

by road to NWC SevRAO's Sayda Bay site for long-term storage.

To implement the proposed strategy for RW management in the Northwestern Region and its implementation options at particular enterprises, it's believed necessary to maintain active operation of facilities available at FSUE Atomflot, JSC SRF № 10, JSC Zvyozdochka and Kola NPP sites, as well as the operation of purpose fitted vessels.

## Analysis of RW management challenges in the Northwestern Region

**VLLW management.** After the RW management law was adopted and criteria for SRW assignment to the category of VLLW were established, construction of VLLW storage facilities at NWC SevRAO's Andreev Bay and Gremikha Bay sites was deemed to be unreasonable: large amount of waste assigned to the new VLLW category ruled out the possibility of building near-surface disposal facilities at these sites accounting for the distance from the coastline considered as acceptable in relevant regulations. Therefore, accumulated and newly generated solid VLLW are continued to be transferred to temporary storage facilities.

Similar setup has emerged at other enterprises of the region. Before making a general decision on VLLW near-surface disposal facility construction, enterprises are forced to store such waste at their own sites. As a result, VLLW is accumulated at nearly each enterprise engaged in RW management. Therefore, accumulated VLLW inventory and its generation rate should be reevaluated for the region in general to optimize relevant siting decisions on such VLLW disposal facilities construction [12].

**Management of high-level LRW.** At present time, liquid HLW can be subject to in-situ processing using mobile units providing radionuclide sorption with filter containers. Until now, the issues associated with the management of HLW and HLW having complex physical and chemical composition remain unresolved. It's believed necessary to create mobile modular units for such waste processing.

**Management of high-level SRW.** After the project on the construction of a SRW treatment complex at NWC SevRAO's Andreev Bay site was abandoned, SRW management challenge has arisen again.

It seems necessary to re-evaluate the possible HLW management options ultimately providing for the optimization of HLW package transfer methods for long-term interim storage to NWC SevRAO's Sayda Bay site with the transferred waste form being considered acceptable for RCCLS RW.

Currently, various one-time decisions are being made on the management of high-level SRW enabling the implementation of ongoing measures on the disposition of ships, vessels and coastal facilities removed from naval and civilian fleet services.

Thus, in 2017, NWC SevRAO's Gremikha site launched operations on pre-retrieval, retrieval, packaging into purpose-designed containers and emplacement into Sayda Bay RCCLS RW of HLW from building 19 and its temporary open-air SRW storage facility.

Long-term storage of HLW containers with spent pull-out NS reactor parts with liquid metal coolant, containers with spent rods from reactor control and safety systems and other containers with HLW is arranged in keeping with an ad hoc decision of the State Corporation Rosatom agreed upon with Rostekhnadzor authorities. A comprehensive solution addressing the accumulated HLW management challenge was postponed for 2021 and the coming years.

**Management of beryllium-containing RW.** Challenges associated with the management of RW resulting from the reprocessing of nuclear fuel discharged from nuclear submarine reactors and surface ships fitted with nuclear power units were not considered under the SMP development. All fuel has been reprocessed at FSUE PA Mayak with a smooth-running system enabling to manage SRW and LRW of all activity categories.

However, by the time of SMP development finalization, no proven industrial processing technologies were available for some types of nuclear fuel being discharged from transport reactors. These include, in particular, uranium-beryllium fuel removed form reactors with liquid metal coolant used at Alpha class nuclear submarines.

Further on U-Be fuel reprocessing infrastructure deployment was concentrated at PA Mayak RT-1 plant. Based on a pilot fuel batch reprocessing, the safety of beryllium-containing RW management technology developed by RT-1 specialists was demonstrated. Currently, U-Be SNF is reprocessed at PA Mayak with the resulting RW being conditioned and stored in PA Mayak's storage facility.

## Conclusion

To summarize the above, one can state that the strategy for the management of radioactive waste accumulated and newly generated during construction, operation, maintenance and disposition of nuclear fleet facilities in the Northwestern region developed under the Strategic Master Plan for the Comprehensive Nuclear Submarine Disposition enabled successful implementation of the Program for Comprehensive Dismantlement of Nuclear Submarines, provided timely and flexibly response to

changes and the emergence of new factors affecting the expected results, allowed identifying optimal solutions addressing the emerging issues and ensuring the safety and efficiency of relevant operations. If such factors emerge, the strategy is adjusted and updated with no changes in its basic strategic goal being considered as its aim.

Unfortunately, for objective reasons it is still not possible to solve two fundamental problems that were mentioned above. Firstly, the one associated with the final very-low level and low-level SRW management stage. VLLW challenge is mainly caused by the legislative and regulatory uncertainties, which led to VLLW accumulation at almost all enterprises engaged in the management of radioactive materials. Now accumulated VLLW inventory and the rate of new VLLW generation shall be reevaluated to optimize future siting decisions on relevant disposal facilities designed to accept such waste. As for the high-level SRW, one-time decisions on its management still do not allow for the current measures on nuclear fleet facility disposition and remediation of coastal sites. A complex solution, addressing the management of the entire accumulated HLW inventory as well, has been postponed until 2021 or even further which will be reflected in relevant provisions of the RW management strategy for the Northwestern Region of Russia.

Integrated approach used in the development and adjustment of strategic decisions can be also applied as a tool enabling the optimization of the regulatory framework for RW management by predicting the possible consequences of the proposed legislative amendments.

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