Comprehensive project on management of SNF from Alfa-class nuclear submarines and decommissioning of the fuel storage facility

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Introduction

This paper is devoted to the issues of management of spent nuclear fuel (SNF) from reactors of Alfa-class nuclear submarines (NS) and their ground-based prototype test rigs temporarily stored at Branch No.2 of SevRAO at Gremikha site and in reactors of the nuclear submarines to be dismantled.

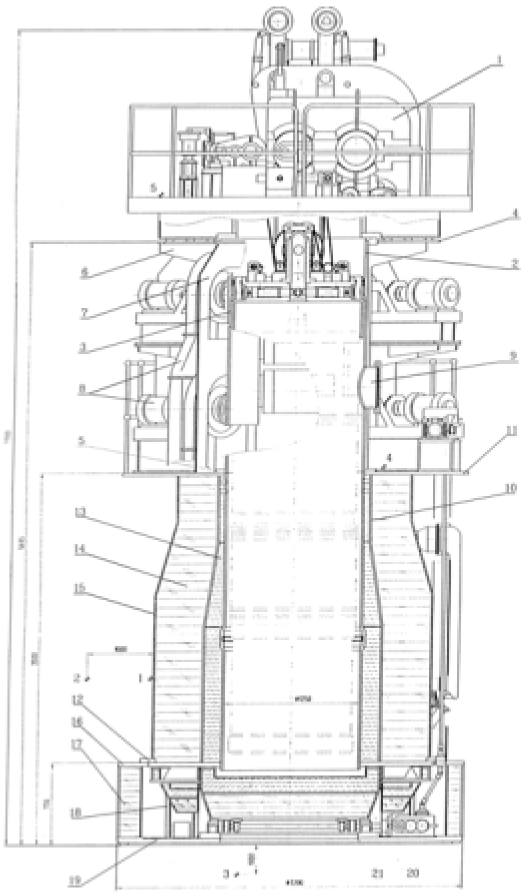
The paper presents information on the SNF storage conditions, Russian strategy for management of SNF from dismantled nuclear submarines, list of major tasks to be solved to implement a safe system for management of SNF from liquid-metal cooled (LMC) reactors, options for handling spent reactor cores (SRC) and top-priority projects.

The report has been prepared based on results of research activities undertaken at the Research and Development Institute of Power Engineering and with regard for and using working materials developed by the Gidropress Experimental Design Bureau (V.S. Stepanov, M.P. Vakhrushin, G.G. Alekseev, A.M. Strelnikov), State Research Center - Institute of Physics and Power Engineering (M.I. Bugreev, A.N. Zabudko, V.I. Chitaykin); All-Russian Research Institute for Inorganic Materials (V.I. Volk, A.Yu. Vakhrushin, E.A. Nenarokov) and All-Russian Research and Design Institute for Power Technology (N.S. Tikhonov, A.I. Tokarenko).

1. General information on the SRC storage conditions

Several nuclear submarines with reactor installations with a liquid-metal cooled (a lead-bismuth eutectic alloy) in the primary circuit were in service with the Russian Navy during the period of the 1960-1990s. The peculiarity of the NS defuelling and subsequent storage of SNF from LMC reactors is that it is unloaded through the withdrawal from the reactor a whole spent reactor core (SRC) as a single removable part module with a shielding plug and the CPS absorber rods fixed in the lowermost position (Fig. 1). This operation is conducted with the use of the SCR unloading cask.

The SRC is subsequently stored in leak-tight tanks with an lead-bismuth eutectic alloy in a «frozen» state and with the CPS rods fully inserted in the core. Under these conditions, the core subcriticality is assured at the level of not less than 5%. The total radioactivity contained in one SRC is about 0.5 MCi.



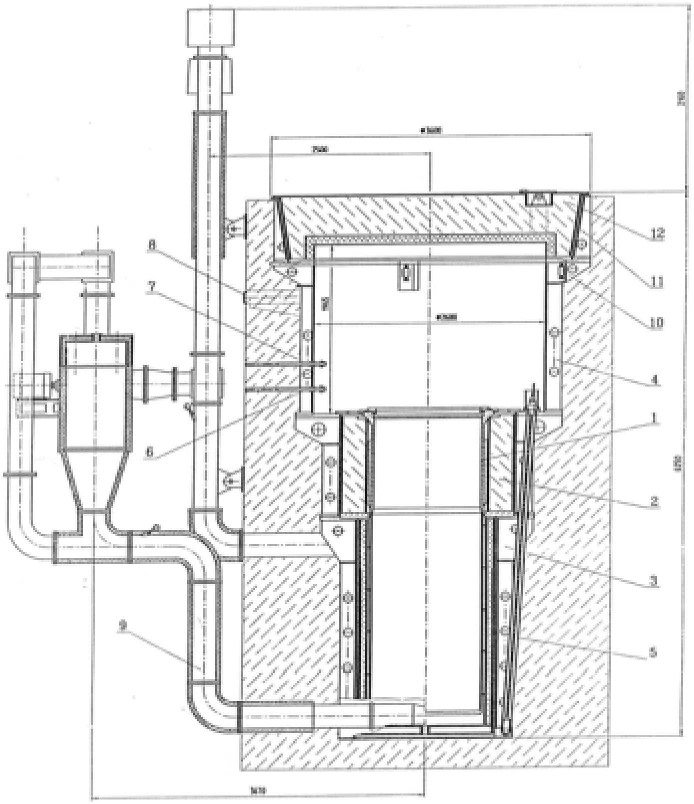
1. Hoist
2. Frame
3. Shell
4.Flange
5. Flange
6. Rib
7. Rib
8. Ventilation system
9. Hatch
10. Shell
11. Flange
12. Flange
13. Lead
14. Polyethylene
15. Liner
16. Damper box
17. Polyethylene
18. Shielding block
19. Damper
20. Lead
21. Polyethylene

Fig. 1. Unloading cask

As the SRC storage tank does not perform the radiation shielding function, the γ-radiation dose rate at its external surface may reach the values of up to 1 Sv/h (100 R/h), which requires an effective radiation protection (to ensure the acceptable attending personnel work conditions). Tanks with SRC with the decay heat release of over 20 kW are placed in type I storage facilities (Building 1A) of the SevRAO Branch (Fig. 2). Decay heat is removed through forced air pumping via special channels in the storage facility. Building 1A has two cells for the SRC accommodation. After the decay heat release in the SRCs is reduced to the level of ≤20 kW, they can be transferred to storage facility II (Building 1B). SRCs are cooled by natural air convection via special air ducts.

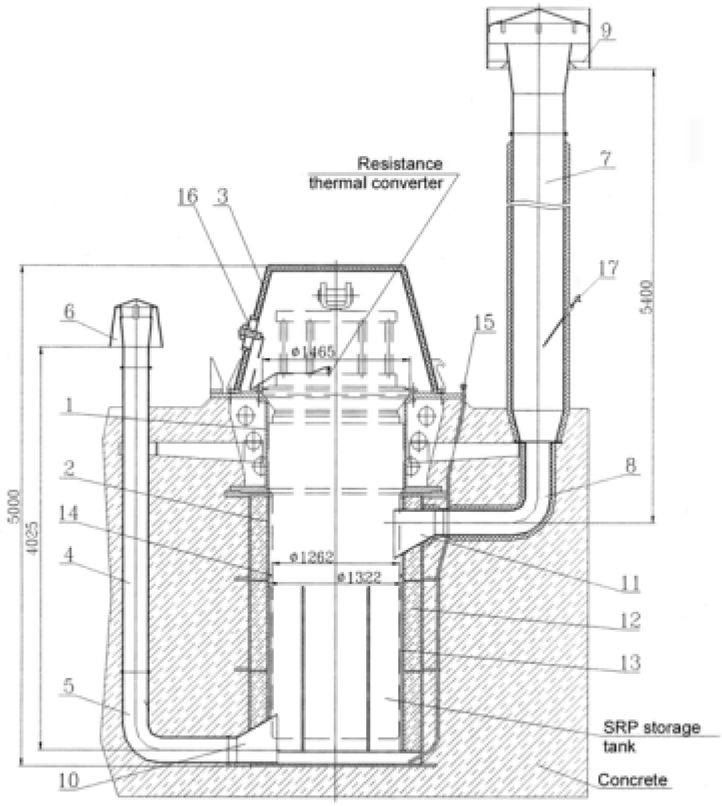
Storage facility II (Fig. 3) is a metal cylindrically shaped well with air ducts. The metal structures are surrounded with a concrete layer serving as a radiation shield for protection of attending personnel against the ionizing SRC radiation.

The total ionizing radiation dose rate at the storage facility top level (maintenance area) does not exceed $3 \cdot 10^{-5}$ Sv/h (3 mR/h). These values are much lower on the side surfaces of the storage facility.



1. Storage tank
2. Body
3. Embedded body
4. Support frame
5. Tube
6. Gas suction nozzle
7. Gas supply nozzle
8. Window
9. Air duct
10. Terminal breaker
11. Skirt
12. Storage cover

Fig. 2. Storage facility I



1. Upper body
2. Lower body
3. Cap
4. Inlet air duct
5. Elbow
6. Deflector
7. Outlet air duct
8. Elbow
9. Deflector
10. Nozzle
11. Nozzle
12. Shielding
13. Rib
14. Ring
15. Drain pipe
16. Penetration box
17. Resistance thermal transducer

Fig. 3. Storage facility II

The storage facility consists of the following basic parts:

- the upper body (item 1);
- the lower body (item 2);
- a cover (item 3);
- an inlet air duct (item 4) with an elbow (item 5) and a deflector (item 6);
- an outlet air duct (item 7) with an elbow (item 8) and a deflector (item 9).

The storage facility is equipped with an instrumentation system (thermoelectric temperature transducers and resistance thermometers) and an instrumentation panel in an annex to the storage facility. The alloy temperature in the SRC region and the air temperature in the outlet air duct are measured.

The required SRC storage conditions are ensured with the storage facility ambient air temperature changing in the range of minus 40 °C to plus 40 °C and at the relative air humidity of up to 98%.

Nuclear and radiation safety is ensured under normal storage conditions by the storage facility design and a multi-barrier protection that excludes contacts with water and high radioactive releases to the environment. In particular, water cannot enter the core because it is contained in a leak-tight storage tank filled with a «frozen» lead-bismuth alloy. The SRC tank is closed with a metal cover at the top. The gap between the cover and the metal structure of the storage facility is filled with an asphalt mixture for sealing. There are several barriers against radionuclide release to the environment and the most important of them are the fuel matrix and the fuel cladding, the «frozen» alloy surrounding the fuel elements and the storage tank metal structures.

Nuclear safety of SNF unloaded from LMC reactor facilities is ensured by the fact that the reactor cores are in a deep subcritical state in the storage facilities ($K_{eff} \leq 0.95$) thanks to the complete insertion of the CPS system absorber rods in the cores. The core CPS drives are also dismantled, the absorber rods cut at a level slightly above the reactor heads, and leak-tight steel caps that exclude any movement of the absorber rods are installed and welded to the CPS rods cans. All unloaded SRCs are in the storage tanks in the «frozen» lead-bismuth alloy. Unauthorized introduction of a positive reactivity during the SNF storage process is also excluded by the lead-bismuth alloy in the CPS rods cans being «frozen» and the absorber rods being immobilized.

Currently, storage facility II (Fig. 4) houses six SRCs: two SRCs from reactors of the nuclear submarine, serial No.601, and four SRCs from Alfa-class nuclear submarine reactors. Their storage time is from 35 to 11 years.

It is planned that three more SRCs from reactors of the retired Alfa-class nuclear submarines will be unloaded and placed in the storage facilities. In this case two SRCs can be placed in the vacant cells of storage facility II and one SRC can be placed in a cell of storage facility I.

It should be noted that due to the fact that the SRC storage facility was built a long time ago, its design and equipment do not meet the requirements of current standards and regulations with respect to installations of such type. Thus, for example, Safety Rules for Storage and Transportation of Nuclear Fuel at Nuclear Power Installations (PNAEG-14-029-1) require that the SNF storage facilities should be equipped with redundant cooling systems, systems for process (temperature, presence of water or water-containing substances) and radiation monitoring, ventilation, gas environment monitoring and filtration, fire extinguishing, fire and security alarm. Out of all above-listed systems, the SRC storage facility of SevRAO Branch No.2 has only (and not in the full extend required) a temperature monitoring system that requires reconstruction. Other systems are simply absent.

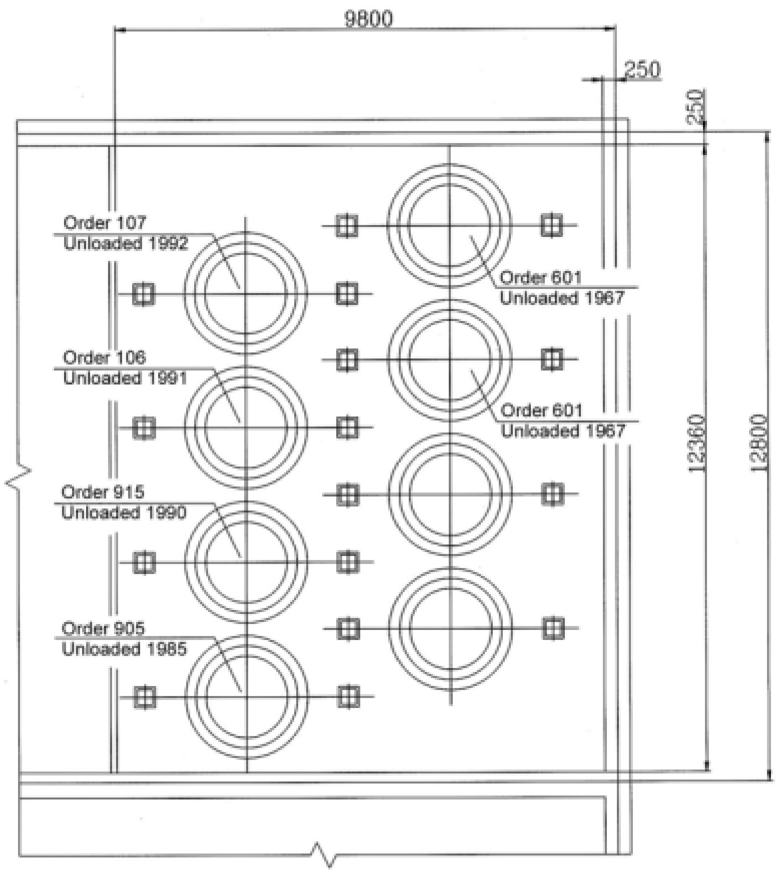


Fig. 4. Storage facility II plan

2. Russian strategy for management of SNF from dismantled nuclear submarines

In accordance with the approved Concept of the Comprehensive Dismantling of Nuclear Submarines, Surface Ships with Nuclear Power Installations and Environmental Rehabilitation of Radiation Hazardous Facilities, the principle of a «closed» fuel cycle is implemented in the Russian Federation, i.e. all SNF unloaded from reactors of dismantled nuclear submarines or stored at interim storage facilities, should be removed and subsequently processed at the Mayak reprocessing plant.

These provisions also fully apply to the SNF of LMC reactors taken into account characteristics of LMC reactor fuel, its storage time and conditions, strategic plans for environmental remediation of radiation hazardous facilities.

Therefore, a final objective of the activities for environmental remediation of the SevRAO Branch No.2 site (Gremikha) is the complete SNF removal from its territory, including the SNF of the Alfa-class NS.

3. Major tasks to be solved to implement a system of safe management of LMC reactor SNF

As noted above, the major peculiarity of the LMC reactor SNF management system is that fuel is unloaded from the core and is subsequently stored as a reactor core assembly with reactivity margin compensation elements and radiation protection components as the socalled spent removable part. And after it is unloaded from the reactor, the SRC is plunged into a tank made of stainless steel and filled with a «pure» lead-bismuth eutectic alloy that is later «frozen» and stored as such.

Therefore, to be prepared for reprocessing, the said removable part should be in any case heated up to the temperature that enables its withdrawal from the storage tank and disassembled into separate fuel elements as required by specifics of the Alfa-class NS reactor core design.

The flowchart of the LMC reactor SNF handling system includes the following basic operations:

- SRC unloading from the reactors of dismantled nuclear submarines;
- SRC preparation and subsequent interim storage at the storage facility;
- SRC unloading from the storage facility and delivery to the disassembling facility;
- SRC disassembling with withdrawal of fuel assemblies and fuel elements, disposal of solid radioactive wastes resulting from the disassembling;
- placing of fuel elements in canisters and loading of canisters into transportation casks of TUK-19 or TK-18 types. SNF casks transportation to the reprocessing plant;
- SNF reprocessing at reprocessing plants.

Based on the above, the list of the tasks to be solved to implement the accepted LMC reactor SNF management strategy can be determined. The major of these tasks are:

- implement a set of measures to fulfill the requirements of regulatory and technical documents for radiation protection of attending personnel and environmental safety assurance, included setting up a radiation monitoring system;
- bring the conditions of SRC interim storage of in storage facilities in compliance with requirements of the current standards and regulation;
- set up (restore the operability of) a set of equipment for installation of SRCs in interim storage and their removal from storage, included monitoring systems;
- set up a set of equipment and facilities for safe SRC transportation by sea or by railway transport;
- set up (upgrade) a set of equipment and facilities for disassembling SRCs, compaction and disposal of the SRW resulting from the disassembling;
- prepare equipment and facilities for the SNF transportation to the reprocessing plant;
- additional equipment of the process chain for the fuel reprocessing at the reprocessing plant with regard for the specifics features of the SNF from liquid-metal cooled reactors.

4. Major requirements to the infrastructure and auxiliary systems of the site to ensure safe SRC handling

A planned and currently implemented set of measures for restoration and reconstruction of the general engineering and the special infrastructure of the SevRAO Branch No.2 ensures safe handling of SRCs from LMC reactors practically in full. Without discussing in details the complete list of these measures, we can identify the most important measures and the ones dealing immediately with the matter considered herein, namely:

- restoring the operability and duly certifying (purchasing, if required) hoisting equipment used in the SRC handling system, including:

a. repair of the electric bridge crane with the lifting capacity of 75/20 tonne; presentation of the repaired crane to the respective supervisory authorities and its commissioning;
b. similar work for the electric bridge crane with the lifting capacity of 20/5 tonne and on the gantry crane with the lifting capacity of 10 tonne (KPM-10);
c. strengthening of the mobile gantry runways and commissioning of the electric bridge crane with the lifting capacity of 75/20 tonne;

– ensuring reliable power supply to equipment in implementing the nuclear hazardous operations, including power supply from two independent sources (main and standby) to equipment and systems that do not permit power supply interruption during potential hazardous operations;
– establishing a physical protection system of the site meeting all current requirements and also ensuring and including:
  a. guard of the object by a security watch;
  b. local fencing of the main process site using technical guard means;
  c. on-site detection means for protection of the process structures against unauthorized intrusion;
  d. a television surveillance system for process operations;
  e. construction of a check point with the access control system;
  f. organization of the guard communication system;
– developing and implementing a set of measures to ensure the receipt and docking at SD-10 dock a sea carrier (cask transportation ship) or a handling system for the SRC cask transshipment to this carrier.

5. Options for management of SRC of Alfa-class submarines

Based on the approved Concept of the Comprehensive Dismantling of Nuclear Submarines, Surface Ships with Nuclear Power Installations and Environmental Remediation of Radiation Hazardous Facilities, the following SRC management options are proposed for further consideration.

Option 1 – disassembly of SRCs into separate fuel elements in a special hot cell at the SRC storage site (Gremikha). This requires a hot cell to be designed and built at Gremikha, and a cask and special vehicles for delivery of SRC from the KM-I test rig in Sosnovy Bor to the SRC disassembling facility. Separate fuel elements may be subsequently transported to the Mayak plant in TUK-19 or TK-18 transportation casks by sea and then by railway in TK-5 or TK-VG-18 railcars. The SRW resulting from the SRC disassembling are disposed at the former SRC storage site.

Option 2 – disassembly of SRCs into separate fuel elements at IPPE in Obninsk. This option will also require development of a SRC transportation cask, a special container ship capable of being docked in SD-10 and a reconstruction of the SRC disassembling facility in IPPE. The fuel elements are further transported in TUK-19 or TK-18 transportation casks and in TK-5 and TK-VG-18 railcars by railway using the handling system currently in use at Mayak plant.

Option 3 is similar to Option 2 excluding the fact that the SRCs are disassembled into separate fuel elements directly at Mayak plant after the removable unit is delivered thereto. In this case, the above-mentioned hot cell and the SRC disassembly installation should be built on the Mayak site.

Therefore, any of the considered options for safe management of the Alfa-class NS reactor SRC meeting the basic provisions of the NS Dismantling Concept will require:

- development and construction of a transportation cask for the SRC transportation by sea and railway transport;
- development and construction (upgrade, if possible) of a container ship with the basic dimensions enabling its docking in SD-10 dock or development and implementation of an option when the cask loading/unloading onto the ship is performed on the pier;
- upgrade (additional equipment) of the TK-VG-18 (TK-VG-18-A) railcar for the SRC cask transportation;
- design and construction of a new hot cell for the SRC disassembling into separate fuel elements;
- solution of the problems related to handling and subsequent disposal of the SRW resultant from the SRC disassembling (some 10,000 kg per one SRC);
- additional equipment of the process chain for the SRC reprocessing at Mayak plant with regard for the specific features of the Alfa-class NS reactor fuel.

Besides, the measures listed in the previous sections hereof should be implemented at the SevRAO Branch No.2 also.

Exemplified below are preliminary data on the list and descriptions of the handling operations, their performance points and sequence for Option 2, i.e. the option with the SRC removal and subsequent disassembling at IPPE. There have been considered operations performed at the SevRAO Branch No.2 site, on the territory of the terminal for transhipment of the SRC cask from the sea carrier to a railcar (e.g., Atomflot enterprise in Murmansk) and on the IPPE site. The basic of these operations are as follows:

On the SevRAO Branch No.2 site in Gremikha:

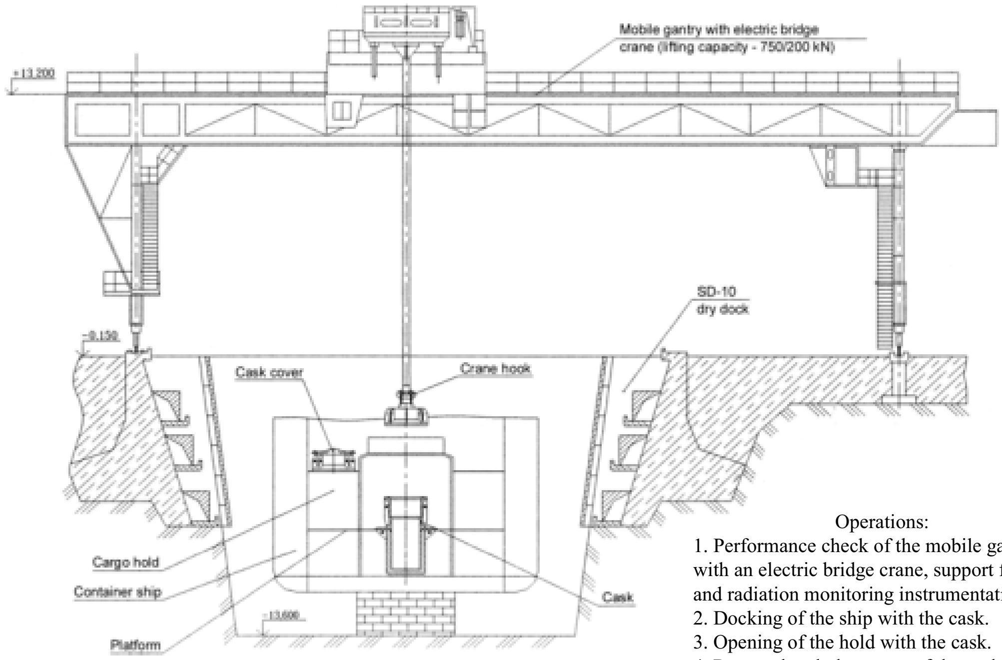
<u>Stage I</u> (Fig. 5). Preparation of the container ship for the receipt of the storage tank with the spent reactor core. The following operations are to be implemented at this stage:

- operation check of the mobile gantry with an electric bridge crane and all support equipment;
- docking of the container ship at SD-10 dock;
- opening of the hold and providing access to the SRC transportation cask;
- removal of the transportation cask cover and its placement on the container ship deck.

<u>Stage II</u> (Fig. 6). Preparation of storage facility II for unloading of the SRC storage tank. The following operations are to be implemented at this stage:

- removal of the hatch cover over the storage facility cell and withdrawal of the shielding plug from the tank;
- delivery of the reloading device (out of universal reloading equipment set) to the storage facility. Installation of the device on the storage facility cell;
- strapping of the SRC storage tank, its lifting to the reloading device and fastening on three hinged supports;
- strapping of the reloading device with the storage tank, lifting and transfer of the device from the storage facility to the container ship.

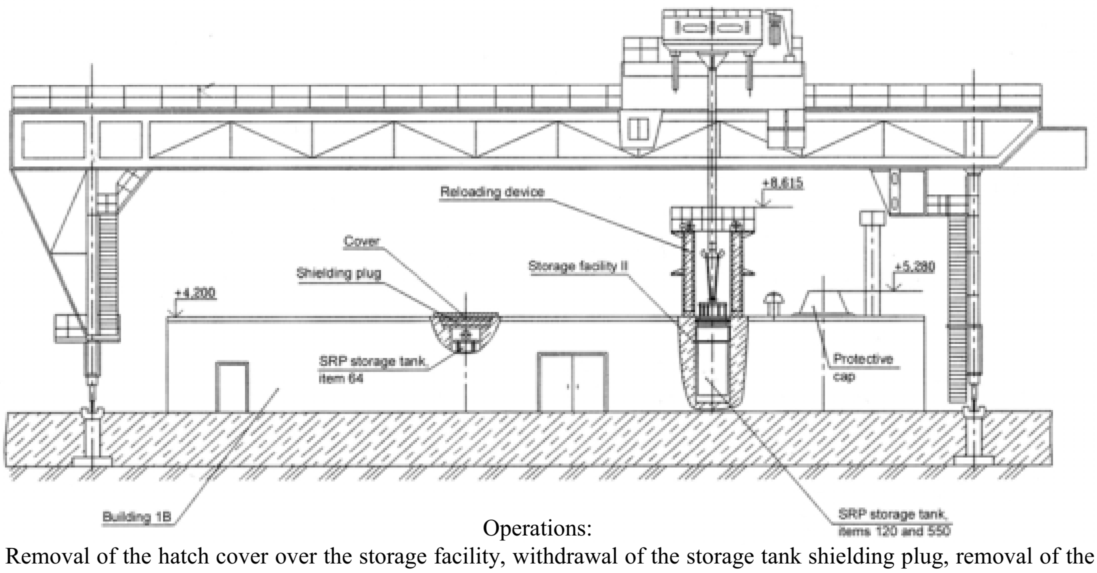
Operations performed at Gremikha site



Operations:
1. Performance check of the mobile gantry with an electric bridge crane, support facilities and radiation monitoring instrumentation.
2. Docking of the ship with the cask.
3. Opening of the hold with the cask.
4. Removal and placement of the cask cover on the ship deck.

Fig. 5. STAGE I. Preparation of the container ship for receipt of the SRC storage tank

Operations performed at Gremikha site



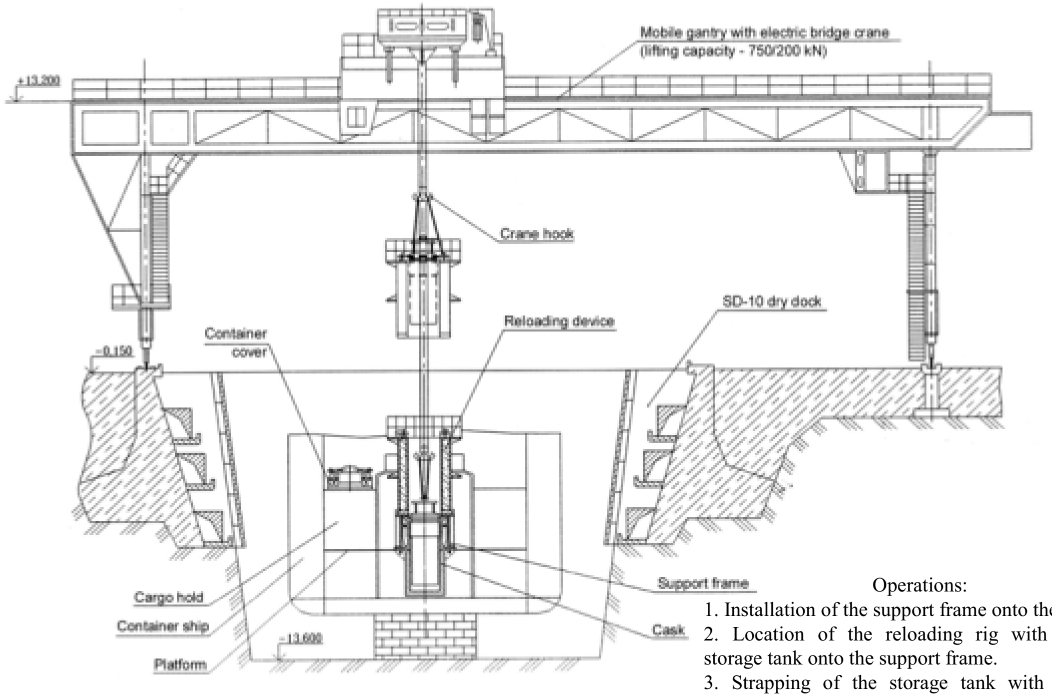
Operations:
1. Removal of the hatch cover over the storage facility, withdrawal of the storage tank shielding plug, removal of the protective cap of the SRC storage tank.
2. Strapping of the reloading device with the crane hook, its transportation and placement in the storage facility.
3. Strapping of the SRC storage tank with the crane hook and drawing of the SRC storage tank into the reloading device and its fastening on three hinged supports.
4. Strapping of the device with the storage tank with the crane hook and delivery of the storage tank from the storage facility to the ship.

Fig. 6. STAGE II. Storage facility II preparation for unloading of the SRC storage tank

Stage III (Fig. 7). Reloading of the SRC storage tank from the reloading device to the SRC transportation cask. The following operations are to be implemented at this stage:

- placement of the support frame (out of the universal reloading equipment set) on the transportation cask;
- guiding and installation of the reloading device with the SRC storage tank on the support frame;
- strapping of the SRC storage tank and its lowering inside the transportation cask.

Operations performed at Gremikha site



Operations:
1. Installation of the support frame onto the cask.
2. Location of the reloading rig with the SRC storage tank onto the support frame.
3. Strapping of the storage tank with SRC and lowering of the storage tank with SRC into the cask body.

Fig. 7. STAGE III. Reloading of the storage tank with the spent removable part from the storage facility to the container ship

Stage IV. Preparation of the container ship for departure to the transhipment terminal. The following operations are to be implemented at this stage:

- removal of the reloading device from the support frame;
- removal of the support frame from the transportation cask;
- removal of the transportation device from the SRC;
- installation and fastening of the transportation cask cover;
- leak-tightness check of the transportation cask with the SRC storage tank inside;
- closure of the container ship hold.

After these operations are completed, the container ship heads for the terminal for the SRC cask transhipment to railway transport.

At the terminal for the SRC cask transhipment to railway transport:

Stage I. Preparation of the container ship for the cask unloading. The following operations are to be implemented at this stage:

- opening of the container ship hold;
- unfastening of the storage tank from the deck;
- strapping of the cask using a special crossbeam;

– lifting of the cask and its transfer to the railway operation area.

Stage II. Preparation of a TK-VG-18 railcar for the receipt and loading of the cask. The following operations are to be implemented at this stage:

– delivery of an empty railcar to the crane operation area;
– opening of the railcar doors and check of the railcar's inside cleanliness;
– transfer of the cask with the storage tank to the railcar, guiding and lowering of the cask onto its location;
– disengagement of the crane hook from the cask crossbeam.

Stage III. Preparation of the TK-VG-18 railcar for departure. This includes:

– unfastening of the transportation cask with the SRC storage tank inside the railcar;
– closure of the railcar doors;
– transportation of the railcar to the SRC disassembly point.

At the SRC disassembling facility in IPPE:

Stage I. Preparation of the TK-VG-18 railcar for the cask unloading. The following operations are to be implemented at this stage:

– transportation of the railcar with the cask to the neutronic test rig;
– opening of the railcar doors;
– unfastening of the cask and removal of the cask lower joint fasteners.

Stage II. Unloading of the cask with the SRC storage tank from the railcar. The following operations are to be implemented at this stage:

– removal of the railcar side section;
– strapping and withdrawal of the upper section of the cask with the storage tank from the railcar;
– transfer of the upper section of the cask with the storage tank to the intermediate cell of the disassembling facility.

Stage III (Fig. 8). Placement of the upper section of the cask with the storage tank into the intermediate cell of the disassembling facility. The following operations are to be implemented at this stage:

– placement of the upper section of the cask with the storage tank in operational position;
– removal of the cask cover.

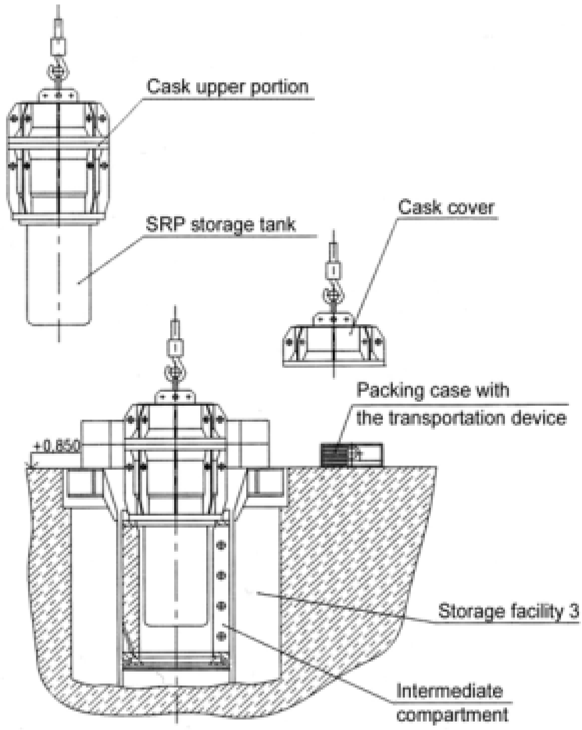
Stage IV. Unloading of the SRC storage tank from the cask. The following operations are to be implemented at this stage:

– installation of the transportation device on the SRC;
– installation of the crossbeam on the transportation device and its strapping with the crane hook;
– lifting of the SRC storage tank from the intermediate cell;
– transfer of the SRC storage tank to the heating cell.

Stage V (Fig. 9). Loading of the SRC storage tank into the heating cell. Coolant heating. The following operations are to be implemented at this stage:

– placement of the SRC storage tank at the operation position into the heating cell;
– removal of the cap flange and the transportation device crossbeam;
– installation of the special head on the transportation device;
– SRC heating. Temperature monitoring.

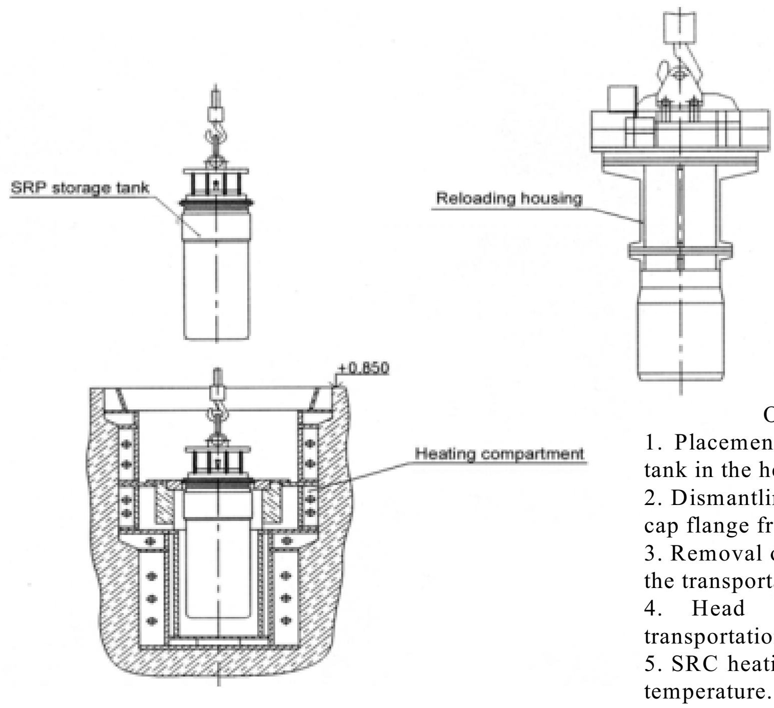
Operations for the SRP receipt at IPPE



Operations:
1. Placement of the cask with the storage tank in the intermediate cell.
2. Removal of the cask cover.

Fig. 8. STAGE III. Cask placement in the intermediate compartment

Operations for the SRP receipt at IPPE



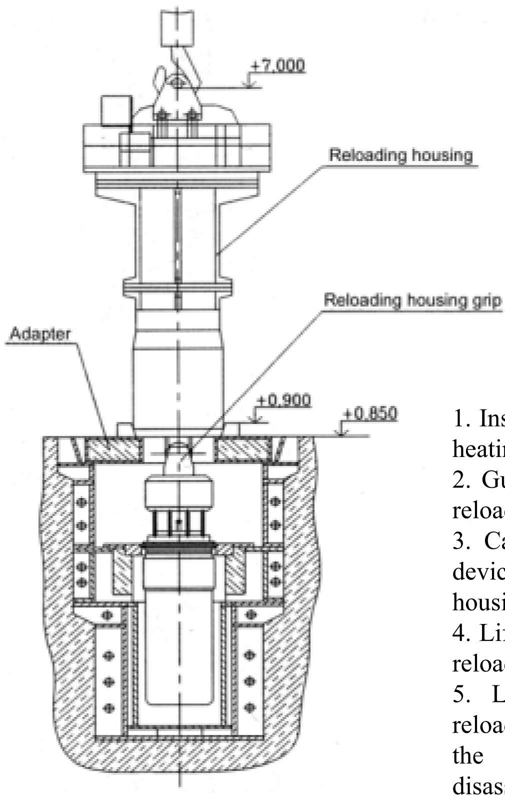
Operations:
1. Placement of the SRC storage tank in the heating cell.
2. Dismantling and removal of the cap flange from the storage tank.
3. Removal of the crossbeam from the transportation device.
4. Head installation on the transportation device.
5. SRC heating. Monitoring of the temperature.

Fig. 9. STAGE V. Loading of the SRC storage tank into the heating cell. SRC Heating.

Stage VI (Fig. 10). SRC unloading from the heating cell. The following operations are to be implemented at this stage:

- installation of an adapter on the heating cell;
- assembly of the reloading housing on the adapter;
- strapping of the SRC using a special head;
- SRC lifting to inside the reloading housing;
- strapping of the reloading housing and its transportation to the loading hatch of the SRC disassembling room.

Operations for the SRP receipt at IPPE



Operations:
1. Installation of an adapter on the heating cell.
2. Guiding and installation of the reloading housing on the adapter.
3. Catching of the transportation device head with the reloading housing grip.
4. Lifting of the SRC to inside the reloading housing.
5. Lifting and transfer of the reloading housing with the SRC to the loading hatch of the disassembling facility.

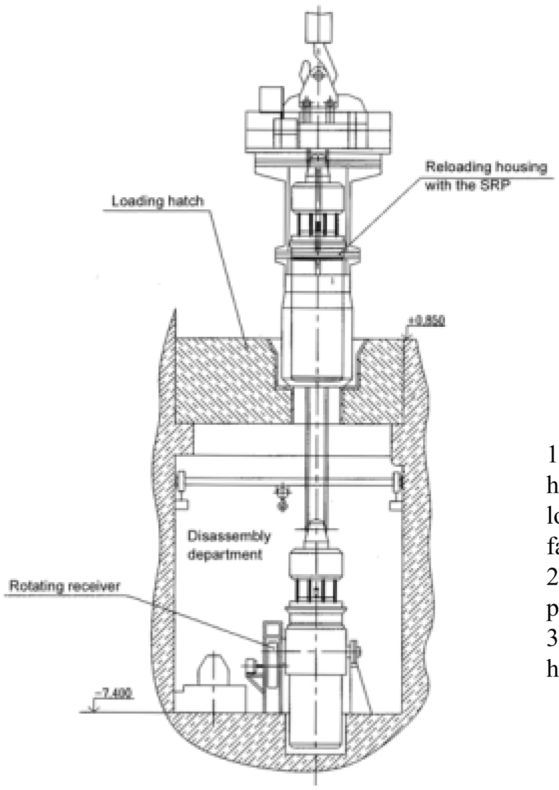
Fig. 10. STAGE VI. Unloading of the SRC from the heating cell

Stage VII (Fig. 11). Placement of the SRC in the rotating receiver of the disassembly bay. The following operations are to be implemented at this stage:

- installation of the reloading housing with the SRC on the loading hatch of the disassembling facility;
- installation (lowering) of the SRC from the reloading housing to the rotating receiver;
- disassembly of the reloading housing.

Fuel elements are removed from the SRC during its disassembling. They are next placed in canisters stored at the canisters storage bay in the disassembling facility. Further operations for preparing fuel elements for delivery to Mayak plant include repackaging of the canisters with the fuel elements from the storage facility to TUK-19 or TK-18 transportation casks. The sequence of the process stages also performed at IPPE to load the canisters with the fuel elements to TK-18 casks is presented below.

Operations for the SRP receipt at IPPE



Operations:
1. Installation of the reloading housing with the SRC on the loading hatch of the disassembling facility.
2. Lowering of the SRC till its full placement in the rotating receiver.
3. Dismantling of the reloading housing grip.

Fig. 11. STAGE VII. Placement of the spent reactor core in the rotating receiver of the disassembling facility

Stage I (Fig. 12). Reloading of the canisters to the reloading housing. The following operations are to be implemented at this stage:

- installation of the reloading housing on the loading hatch of the disassembling facility;
- relocation of the canisters to the storage facility's central cell and the subsequent drawing of the canisters into the reloading housing;
- strapping of the reloading housing and its transportation to the cask with the canisters.

Stage II. Unloading of the canisters from the reloading housing to the cask for the canisters.

Stage III. Unloading of the canisters from the cask and their loading into the intermediate housing.

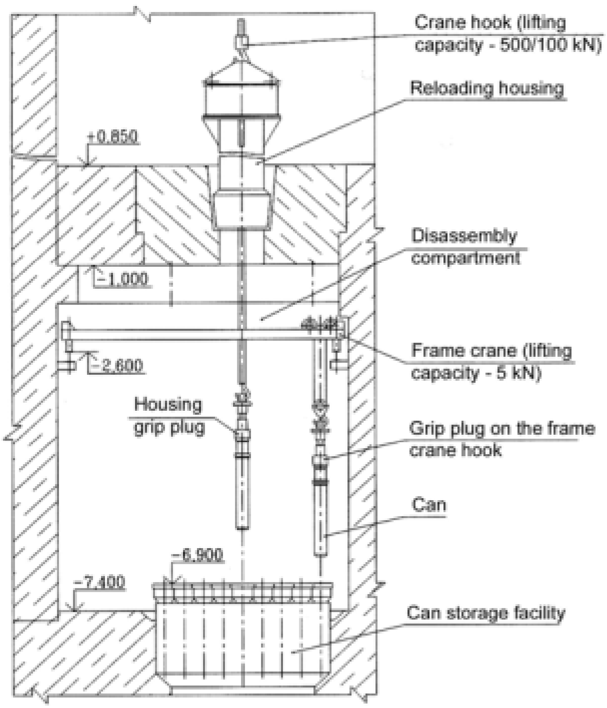
Stage IV. Preparation of the TK-VG-18 railcar for the receipt of the canisters. The following operations are to be implemented at this stage:

- opening of the TK-VG-18 railcar doors;
- removal of the TK-18 cask cover in the railcar;
- assembly of the guiding device on the TK-18 cask.

Stage V. Loading of the cans with the fuel elements into the TK-18 cask. The following operations are to be implemented at this stage:

- installation of the intermediate housing on the guiding device;
- transfer of the canisters with the fuel elements from the intermediate housing inside to the TK-18 canisters cell and fixation of the canisters in the cask cell.

Operations of the SNF shipping for processing



Operations:
1. Installation of the reloading housing on the loading hatch of the disassembling facility.
2. Transfer of the canister to the central compartment and subsequent drawing of the canister into the housing.
3. Transportation of the housing with the canister to the cask.

Fig. 12. STAGE I. Unloading of canisters from the storage facility compartments. Loading of canisters into the reloading housing

Stage VI. Installation of the TK-18 cask cover. The cask sealing and leak-tightness check. Preparation of the TK-VG-18 railcar for transportation[1].

It should be noted that most of the handling operations in any sequence should be performed independent of which SRC management option will be selected for implementation. It will be respectively required to develop and manufacture equipment and tooling (or restore the operability of the existing) used in handling operations.

At present time, it is very difficult to estimate with a sufficient degree of accuracy the cost of implementing any Alfa-class NS reactor SRC management option. In this connection, it is also practically impossible to estimate the time to be spent as it largely depends on two factors: the process cycle of performing any operations and available financial resources.

In order to get the reliable information on the above issues and get the additional data to enable a reasonable selection of the best and most safe Alfa-class NS reactor SRC handling option, it is necessary to undertake the respective feasibility study and a range of analytical and experimental research activities whose content will be disclosed below.

6. Decommissioning of the SRC storage facility

The present state of the SRC storage facility can be described as satisfactory. As noted above, it is necessary to additionally equip the storage facility with a range of systems that

[1] Note. The shipment of one set of fuel elements from one SRC requires 1 train with 12 TK-18 casks.

ensure safe SRC storage fully in accordance with requirements of the current regulations and standards.

The major of the systems are the SRC state radiation and physical monitoring systems, the monitoring system for presence of hydrogen-containing substances in the storage facility room and in the SRC storage tanks.

Currently, six out of eight SRC storage cells available at the storage facility are occupied for storage. In accordance with the NS dislantling plan, three more SRCs will be unloaded from Alfa-class nuclear submarine reactors in Russia's north-west region. Therefore, the storage facility (Building 1B) will be filled and it will be necessary to place one SRC in the LMC reactor refueling building (Building 1A).

Operations for decommissioning of the SRC storage facility can be performed only after it is fully unloaded and SNF from LMC reactors is removed from the SevRAO Branch No.2 site. The following options can be implemented is this case:

- elimination of the storage facility;
- renovation of the storage facility;
- isolation of the storage facility.

Final selection of the SRC storage decommissioning option should be based on the results of a specially developed feasibility study also taking into account the selected SRC management option and the namagement options for the SRW resulting from the SRC disassembling process. Since it is possible to complete operations for the removal (or unloading) of SRCs from the storage facilities of SevRAO Branch No.2 not early than in 5 to 7 years, the development of the design for decommissioning of the storage facilities is not a top-priority issue at present time.

7. Proposals for the first-priority activities on resolution of problems of safe management of SCR of the Alfa-class submarines and the SRC storage facility decommissioning

As noted above, based on provisions of the strategy for management of SNF of dismantled nuclear submarines, the Russian Federation is highly interested in implementation of the comprehensive project for elimination of the interim storage facility for SNF of Alfa-class nuclear submarine reactors.

Implementation of this project will enable not only the elimination of nuclear and radiation hazardous object on the territory of SevRAO Branch No.2 but also the disposition of rather a large amount of highly enriched uranium contained in SNF.

Despite the fact that the stage of the immediate implementation of the given comprehensive project should be preceded by the stage of the feasibility study to identify the best SNF management option, it is possible to formulate a range of tasks (projects) that can be implemented immediately without waiting for the feasibility study results already now. These tasks are as follows:

- development and implementation of a project for bringing the SRC storage facility in compliance with requirements of current regulations and standards;
- development and construction of a cask for transportation of SRCs of the Alfa-class nuclear submarines;
- development of design, engineering and process documentation for additional equipment of the Mayak plant to enable the reprocessing of SNF from liquid-metal cooled reactors.

The expediency and necessity to initiate resolution of these tasks already now are explained by the fact that they should be inevitably solved independent of which SRC management option will be selected as the best one based on the results of the feasibility study being conducted.

Therefore, the following projects are proposed to the international community for discussion and implementation as top-priority activities.

Project 1. Development and implementation of a project for bringing the SevRAO Branch No.2 storage facility in compliance with requirements of current regulations and standards, including:

- development of design documentation for installation of neutron and gamma detectors in the air ducts of the storage facilities, manufacturing and purchase of the instruments required for radiation survey of the SRC tanks;
- calculational evaluation of the radiation potential and power generation in the SRCs of Alfa-class NS which have been unloaded already and are planned to be unloaded in the future;
- performance of a set of R&D activities to determine more accurately the neutronic characteristics of the SRCs located in the storage facilities;
- development of the techniques and design documentation to arrange neutronic monitoring of the SRCs state during the process of their long-term storage, manufacturing, purchase and installation of the required equipment;
- development of the techniques and design documentation to detect the presence of hydrogen-containing substances (moisture, hydrocarbons) in the storage facility rooms and the SRC storage tanks;
- development and production of the safety analysis report (SAR) for SRC long-term storage, with due regard of possible emergency situations and extreme external impacts (earthquake, aircraft fall, etc.) substantiated by necessary calculations.

Approximate schedule of development and implementation of the project for bringing the SRC storage facility in compliance with requirements of current regulations and standards is presented in Fig. 13. The total project implementation time is as follows:

- development of the design for reconstruction of the SRC storage facility with required R&D activities, development of techniques and design documentation, and production of the SAR.

Implementation time – 12 months from the start of the work financing.

Cost of the work – US$ 900,000.

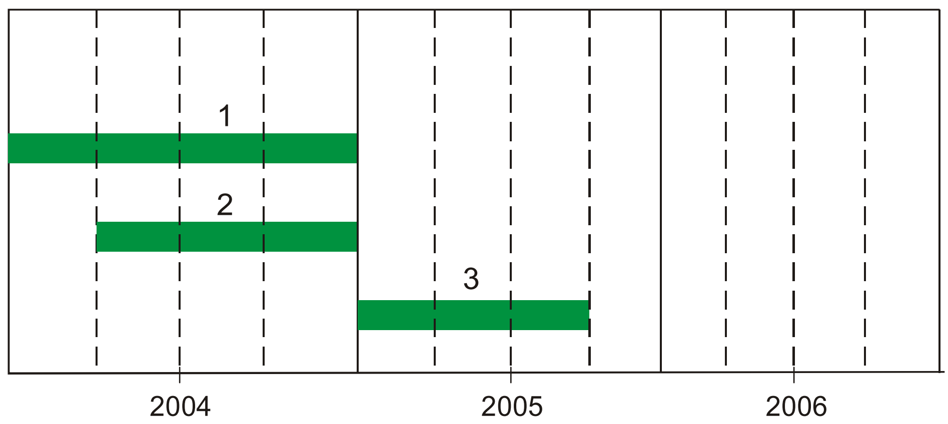
- manufacturing and purchase of required equipment. Reconstruction of the storage facility.

Implementation time – 9 months after the development and approval of the reconstruction design.

Cost of the work – US$ 900,000.

Major participants – Gidropress Experimental Design Bureau, Special Design Bureau of Mechanical Engineering (OKBM), Institute of Physics and Power Engineering (IPPE), All-Russian Research and Design Institute for Power Technology (VNIPIET), Research and Development Institute of Power Engineering (NIKIET), SevRAO.

As a result of the work, design documentation will be produced and the SRC storage facility will be reconstructed in accordance with requirements of current regulations and standards.



1. Development of the SRC storage facility reconstruction design with necessary R&D, development of techniques and design documentation
Cost - US$ 400,000
2. Development of the SAR and the Environmental Effect Assessment
Cost - US$ 500,000
3. Manufacturing and purchase of required equipment. Reconstruction of the storage facility
Cost - US$ 900,000

Fig. 13. Schedule for implementation of the project for bringing the SRC storage facility in compliance with requirements of current Russian regulations and standards

Project 2. Development and construction of the protective cask for transportation of the Alfa-class NS reactor SRCs

Taking into account the fact that the work in this field has already been started (a cask basic design has been developed, the basic design documentation has undergone all required coordination and review stages), the following tasks should be performed as part of this project:

– development of the detailed design and operation documentation;
– development, manufacturing and testing of mock-ups and models of the most critical cask components (sealing joints, dampers, etc.). The update of the design documentation based on the test results;
– manufacturing of a pilot specimen and special rigs, testing in accordance with requirements of the Russian regulatory framework. Update of the design documentation and operational documentation based on the test results;
– cask certification in accordance with Russian legislation;
– cask manufacturing and acceptance tests, cask delivery to the operator.

The approximate schedule of the project implementation is given in Fig. 14. The total project implementation time is as follows:

– development of the detailed design and operation documentation.

Implementation time – 9 months from the start of the work financing.
Cost of the work – US$ 150,000;

– testing of mock-ups and models of separate cask joints based on the General Designer program.

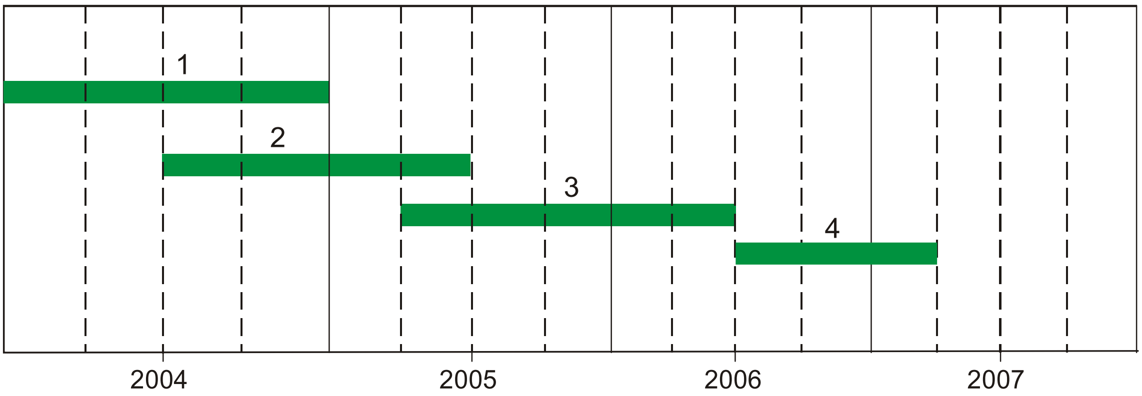
Implementation time – 12 months from the start of the work financing.
Cost of the work – US$ 500,000;

– manufacturing and testing of a pilot cask specimen. Update of design and operational documentation based on the test results. Cask certification.

Implementation time – 12 months from the start of the work financing.
Cost of the work – US$ 1,050,000;

- manufacturing and acceptance tests of delivery pilot casks (2 units), their delivery to the operator.

Implementation time – 9 months after the certification and start of the work financing.
Cost of the work – US$ 1,200,000;
Main participants in the work – Gidropress Experimental Design Bureau, All-Russian Research and Design Institute for Power Technology (VNIPIET), Institute of Physics and Power Engineering (IPPE), Research and Development Institute of Power Engineering (NIKIET), Izhorskiye Zavody Joint-Stock Company.



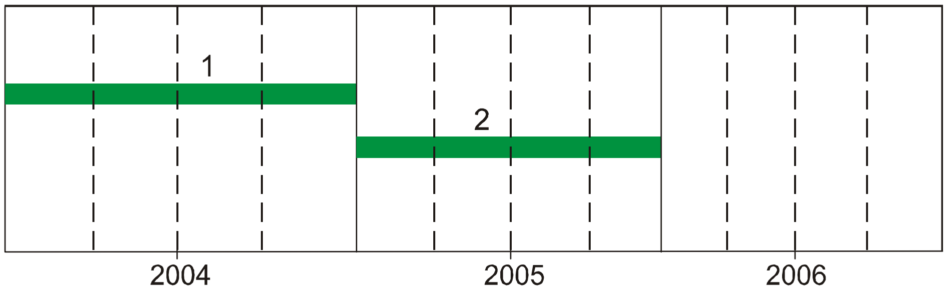
1. Development of detailed design and operation documentation
Cost – US$ 150,000
2. Development, fabrication and testing of mock-ups and models of the most critical components of the transportation cask. Detailed design documentation correction
Cost – US$ 500,000
3. Manufacturing of a pilot specimen. Tests in accordance with requirements of Russian regulations and standards. Update of the detailed design and operation documentation. Cask certification
Cost – US$ 1,050,000
4. Manufacturing, acceptance tests and delivery of two casks to the utility
Cost – US$ 1,200,000

Fig. 14. Schedule for implementation of the project for development of a SRC transportation cask

Project 3. Development of the design and engineering documentation and additional equipment of the Mayak plant to enable reprocessing of SNF from LMC (Pb-Bi) reactors.

Approximate schedule for implementation of this project is presented in Fig. 15.
Project implementation time – 2 years from the start of financing.
Cost of the work – US$ 3,000,000;

Major participants in the activities – Institute of Physics and Power Engineering (IPPE), All-Russian Research Institute for Inorganic Materials, Mayak plant, All-Russian Research and Design Institute for Power Technology (VNIPIET), Fire Protection Research Institute of the Ministry of the Russian Federation for Emergency Situations.



1. Development of design and engineering documentation to support additional equipping the Mayak plant for reprocessing the SNF from reactors of Alfa-class nuclear submarines
Cost – US$ 800,000
2. Production base reconstruction. Technical Specifications approval. Fuel reception and reprocessing licensing.
Cost – US$ 2,200,000

Fig. 15. Schedule of the project implementation for additional equipment of the Mayak plant production base

Project 4. Feasibility study to substantiate the selection of preferred option for safe management of SRC of the Alfa-class submarines, including:

- a set of R & D activities to determine the fuel element state for identifying level of the SRC degradation;
- determination of the major SRC handling system characteristics;
- more accurate determination of composition and characteristics of the SRC disassembling hot cell equipment;
- selection and substantiation of the system for handling the SRW resulting from the SRC disassembling;
- determination of whether it is possible to use available sea carriers or formulation of the basic technical requirements to the newly built sea carrier for transportation of SRC casks.

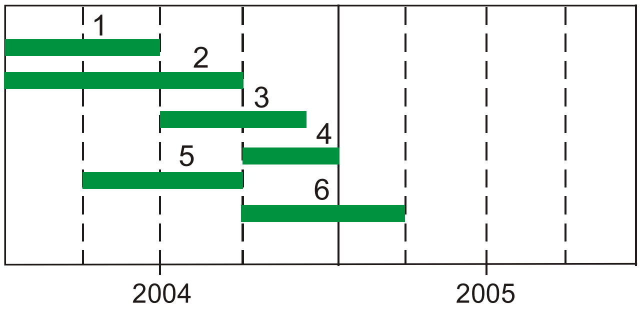
Approximate schedule of the feasibility study to substantiate the selection of the best option for SRC safe handling is given in Fig. 16.

Implementation time – 12 months from the start of the work financing.

Cost of the work – US$ 1,200,000.

Major participants in the work – Gidropress Experimental Design Bureau, Special Design Bureau of Mechanical Engineering (OKBM), Institute of Physics and Power Engineering (IPPE), All-Russian Research and Design Institute for Power Technology (VNIPIET), Research and Development Institute of Power Engineering (NIKIET), All-Russian Research Institute for Inorganic Materials, Mayak plant.

Based on the results of the undertaken feasibility study, the best option for management of the SRC of the Alfa-class NS will be reasonably selected, the major characteristics of the SRC management system components will be determined, and the project implementation time and cost will be estimated. Later, it will be possible to develop a feasibility study and the required design and engineering documentation for the project implementation.



1. R&D activities to determine the fuel element state and extend of the SNF degradation
Cost – US$ 200,000
2. Determination of main SRC handling scheme characteristics
Cost – US$ 300,000
3. Specification of equipment composition and characteristics for the hot cell and SRC disassembling facility
Cost – US$ 250,000
4. Selection and substantiation of the SRW handling scheme
Cost – US$ 150,000
5. Selection and substantiation of the container ship type
Cost – US$ 200,000
6. Development, clearance and approval of the Feasibility Study materials
Cost – US$ 100,000

Fig. 16. Schedule for implementation of the project for feasibility studies to substantiate the selection of the best option of management of SRC from reactors of the Alfa-class nuclear submarines

Conclusion

Currently, there are six SRCs from reactors of Alfa-class nuclear submarines stored at Branch No.2 of SevRAO. It is planned that three more SRCs will be unloaded in the next few years. The storage conditions ensure nuclear and radiation safety. However, efforts should be taken to bring the existing storage facilities in compliance with requirements of current regulations and standards.

The approved "Concept of the Comprehensive Dismantling of Nuclear Submarines, Surface Ships with Nuclear Power Installations and Environmental Remediation of Radiation Hazardous Facilities provides for the complete removal of irradiated nuclear fuel from the SevRAO Branch No.2 site, including the SRCs of the Alfa-class nuclear submarine reactors, and its reprocessing at the Mayak plant».

Major proposals have been formulated for the SNF handling flowchart for NS with LMC reactors. There has been determined the list of the tasks to be solved to implement the strategy for management of SRCs from the retired nuclear submarines accepted in the Russian Federation. Requirements to the site infrastructure and auxiliary systems to ensure safe SRC management have been formulated.

Possible options for management of the SRC have been considered. It was shown that the best SRC management option could be finally selected based on the results of a specially conducted feasibility study. The major fields of activities within the frameworks of this feasibility study have been identified.

Proposals have been formulated for the top-priority projects that can be implemented without waiting for completion of the feasibility study and its results to substantiate the best option for safe management of the SRC of the Alfa-class submarines in accordance to the general concept for NS dismantling accepted in the Russian Federation.