Preparation of RT-1 Plant of FSUE "Production Association "Mayak"
for reprocessing of damaged SFAs from VVR-type reactors of nuclear submarines

Introduction.

During the operation of the Russian nuclear submarine fleet a significant amount of spent nuclear fuel (SNF) had been accumulated in permanent and temporary on-shore storage facilities of the Northwest and the Far Eastern regions of Russia. The storage conditions of these facilities did not fully comply with the applicable safety requirements.

Recognizing its responsibility for the environmental, radiation and nuclear safety of the implemented activities since the beginning of the 2000s the Russian Federation with the support of other countries has started active works on the rehabilitation of "problem" facilities for the management of spent fuel from nuclear submarines (NPS) located in these regions.

One of such projects was the "Gremikha" project providing, among other things, the complete clean-up of the territory of the former naval base from accumulated SNF of first generation submarines - about 900 pieces of VVR SFAs. The activities on the removal of the spent fuel were carried by the Russian Federation, with the technical and financial support from France (CEA) and Italy.

In accordance with the Spent Fuel Management Concept of Russia SNF nuclear submarine is subject to transportation and reprocessing at RT-1 Plant of FSUE "PA "Mayak ". Requirements for the supply of fuel for reprocessing are determined by a Special Industry Standard (OST). The most significant requirements for SNF condition are:

- structural integrity of spent fuel assembly;
- SFA tightness in terms of fuel;
- SFA free retrievability from the transport canister.

Spent fuel assemblies that meet the requirements of OST are called standard and can be reprocessed under the existing technologies.

A considerable part of the VVR SFAs stored in Gremikha did not meet the above requirements, and therefore is was necessary to work out and implement
special measures to enable SFAs transport and reprocessing at FSUE "PA "Mayak".  

Some of non-standard SFAs that were retrievable from a canister have been restored on the storage site in Gremikha and transferred to the category of conditionally standard. Their further reprocessing was carried out according to the standard procedure with minor adjustments of the process. However, some SFAs could not be removed from storage canisters. The additional process preparation was required for their reprocessing at RT-1 Plant of FSUE "PA "Mayak" - organization of a special unit for SFA reloading on the basis of the existing "hot cell".  

Organization of works on the process preparation of RT-1 Plant at FSUE "PO "Mayak "for the treatment of non-standard SFAs from nuclear submarines.  

Development of technical proposals, design documentation, and safety justification.  

To develop and justify technical solutions for process preparation at FSUE "PA "Mayak" for the treatment of defective VVR SFAs in the end of 2009, an international contract between the Atomic Energy Commission of France (CEA), FSUE "Federal Center for Nuclear and Radiation Safety" ("FCNRS") and FSUE "PA "Mayak" (Contract C-6) was concluded. Under this contract FSUE "FCNRS" performed the following works involving subcontractors:  

- Development of Transportation Flow Chart (TFC) for the management of defective VVR SFAs at RT-1 Plant;  
- Development of the Program and survey of existing premises, equipment and support systems at RT-1 Plant with provision for performing works on the acceptance and treatment of defective VVR SFAs;  
- Development of the schedule of works to upgrade the inspected elements of TFC;  
- Development of the technical project of modernization of the hot cell at RT-1 Plant for the treatment of defective VVR SFAs and working design documentation for the hot cell equipment;  
- Development of technologies, regulations and project of organization of works on defective VVR SFAs treatment;  
- Preparation of the technical safety justification of work with defective VVR SFAs, supervisory authorities’ conclusion received.  

At this stage the co-executors of the works were FSUE "PA "Mayak", OJSC "East-European Head Scientific Research and Design Institute for Power Engineer-

**Delivery of defective SFAs from Gremikha to RT-1 Plant of FSUE "PA "Mayak".**

To deliver canisters with defective spent fuel assemblies from Gremikha storage facilities storage Gremikha base to RT-1 Plant of FSUE "PA "Mayak» it was suggested to use the transport vehicles that had been used for the transport of standard SFAs. Thus, for safety reasons, the standard removable part of the cask was replaced with a specially designed sealed baskets (type 1, 2), in which the canisters / cassettes with defective SFAs were loaded (Figure 1)

![Diagram](image)

**Figure 1:** Placement of defective SFAs in the cask (TUK).

The development and manufacturing of baskets, as well as certification of casks including these baskets were performed under an international contract between the Atomic Energy Commission of France (CEA), FSUE "FCNRS" and FSUE "PO" Mayak "- Contract C-5, and the manufacture of equipment (rigs) for
handling the baskets in Gremikha temporary storage facility and at RT-1 Plant—under Contract C-5.1.

The co-executors of this stage of works were OJSC"GI VNIPET", LLC "Spetstehkomplekt."

Contract duration was as follows:
- Contract C-5: 20 months, from December 2009 till July 2011;
- Contract C-5.1: 3 months, from June 2011 till August 2011.

**Transportation Flow Chart of defective SFAs handling at RT-1 Plant of FSUE "PA "Mayak"**

The technical capabilities of RT-1 Plant of FSUE "PA "Mayak" did not allow processing of irretrievable SFAs. For the treatment of such SFAs it was proposed to use an additional "hot cell" located at SFA reprocessing facility of RT-1 Plant. It was called a Cell for Defective Canisters or CDC. This cell was intended for carrying out works on preparation of defective SFAs for reprocessing – SFAs retrieval from transportation canisters and their reloading into special intermediate canisters.

To perform the abovementioned operations it was necessary to perform the following works:
- to develop the technology of defective SFAs preparation in CDC for reprocessing;
- to design, manufacture and install the necessary equipment;
- to equip the cell with additional accessories and tools for remote operations.

In this connection under Contract C-6 the following TFC for handling defective SFAs at RT-1 Plant, as shown in Figure 2.
This TFC includes the following basic operations:

1. Acceptance, temporary storage and transfer to CDC of canisters with defective SFAs:
   - SNF packages unloading and placement of baskets with spent fuel assemblies in the storage pool;
   - temporary technological storage of transportation baskets with spent fuel assemblies in the pool storage;
   - transfer of transportation baskets to CDC.

2. Handling of defective SFAs in CRC:
   - SFA retrieval from transportation canister and reloading into a special intermediate canister;
   - SFA dehydration in intermediate canisters;
   - transfer of intermediate canisters with SFAs from CDC for reprocessing;

3. Handling of reusable elements of the cask and generated solid radioactive waste:
   - transfer of an empty transport basket from CDC for washing with its subsequent transfer for loading into a cask (TUK);
   - transfer of empty transportation canisters for washing and disposal;
   - transfer of SFA structural elements for disposal.

This TFC makes the best use of the existing equipment applied for the treatment of standard SFAs.
Later for the implementation of the developed TFC, in addition to the works on CDC upgrading, which will be described in detail below, a comprehensive survey of the technical state of all elements of the scheme was carried out. It enabled to identify the missing equipment (equipment, tools), to reveal safety deficiencies, to plan and implement the measures to eliminate shortcomings and fit up the scheme.

As a result of the works the following equipment and systems involved in the implementation of the TFC have been upgraded or additionally installed for defective SFA handling:

- equipment for underwater lighting in the storage pool;
- tools and equipment for handling of baskets with defective SFAs in the storage pool;
- equipment for video surveillance of the implementation of transportation technological operations in the transport tunnel;
- control system of mechanisms for transport evacuation of high-level solid radioactive waste;
- crane control system at the basket washing unit;
- local telephone network within the building between individual work areas.

**ell for defective canisters**

A key element of the above TFC providing a possibility for the treatment of defective (including irretrievable) SFAs is a special hot cell equipped with technological equipment, allowing to carry out works on the retrieval of damaged SFAs from transport canisters and their reloading into intermediate cases.

For the organization of this hot cell it was decided to upgrade the existing hot cell intended for works with defective canisters – the CDC cell (Figure 3).
Figure 3: CDC cell (initial condition)

The CDC cell had the following characteristics:

– the cell was confined with shielding walls with inspection windows to provide the biological protection of the personnel in operator’s room. All surfaces of the cell were clad with stainless steel;

– the cell has two levels. The lower level serves as a pool for underwater work under water and is equipped with a trolley to move the canisters;

– the cell dimensions (Length x Width x Height):
  • upper level - 6550 x 5200 x 9650 mm;
  • lower level (pool) - 10600 x 3100 x 5340 mm.

– next to the cell behind a protective wall there is a benchwork room for manual operations, it is connected with the cell by a common pool;

– the cell is connected with SFA reprocessing cells and storage pool by a transport tunnel;

– the cell is equipped with a remote control electro-mechanical manipulator crane with a lifting capacity of 500 kg;

– the cell is served by a remote control bridge crane with a load capacity of 15/3 tons.

The preliminary study of the technology for the treatment of irretrievable VVR SFAs using the upgraded CDC included estimated calculations of radiation exposure of the staff during the performance of the complete cycle of technological
operations. The results of calculations allowed to make a conclusion on the possibility in principle to carry out the technological process of damaged SFA preparation for reprocessing in compliance with the existing requirements and regulations for radiation safety.

After upgrading the CDC cell looked as shown in Figure 4.

![Diagram of CDC cell](image)

Picture 4: CDC cell (after upgrading)

To perform transport operations for the delivery of SNF packages into CDC and removal of empty baskets a crane with a load capacity 15 tons is used.

The operations on reloading of canisters and cassettes inside CDC as well as reloading of retrievable SFAs are performed with the help of internal manipulator with a lifting capacity of 500 kg.
Actually the works on retrieval and reloading of damaged (stuck) SFAs are carried out by the personnel from the benchwork room under water with the use of long-length tools and special equipment and appliances. Depending on the particular situation a variety of techniques can be applied - pulling (pulling force up to 4 tons), pushing and drilling.

For the visual control of performed operations a TV monitoring system is used.

During the design documentation development a number of decisions was adopted that were different from the original intentions. They were aimed at improving the safety of technological operations and equipment reliability, as well as generated waste volume reduction. The most important of them were:

- CDC lower floor division into "dry" and "wet" zones;
- Drilling out irretrievable SFAs together with shroud tubes, i.e. without direct drilling of the fuel composition;
- Modification of heating method and reduction in the number of draining unit module.

Upon the completion of the preparatory operations in CDC defective SFAs can be reprocessed according to the existing technological scheme:

- mechanical grinding of SFA;
- dissolution of the fuel composition;
- clarification and extraction reprocessing of solutions with the precipitation of the target products;
- processing of liquid, solid and gaseous wastes.

**Ensuring safety during defective VVR SFAs treatment.**

In the development of design documentation under Contract C-6 a comprehensive safety analysis of defective fuel assemblies was carried out in each section of the TFC. The parameters of nuclear and radiation safety were calculated and assessed, and the status of explosion, fire and industrial safety was analyzed.

**Nuclear safety.**
The calculations for nuclear safety justification were performed with the use of MCU-RFFI/A code with the DLC / MCUDAT-1.0 data library.

The calculations were made both for normal operating conditions and emergency situations. The following emergency conditions were considered:
- Water filling of the internal cavities of structures containing nuclear material and their surrounding with water reflector;
- CDC pool draining;
- dropping of equipment containing nuclear material during transport;
- falling of objects, equipment, building structures on the structures containing nuclear material;
- natural (earthquake, hurricane, snow load on building structures) and anthropogenic (shock waves) impacts.

The calculation results showed that:
- under normal operating conditions during handling operations in CDC the value of effective multiplication factor (keff) does not exceed 0.48, which is significantly less than the allowable value of 0.95.

If during the retrieval of a stuck SFA from the canister in the travelling CDC platform the SFA is completely destructed, in the most conservative variant keff value would be 0.73. Formation of a solid mass of fuel particles suspended in the water due to the destruction of more SFAs is excluded by technological regulations, as well as through the use of equipment to collect spilled fuel.
- should the CDC dry zone be flooded with water keff value for the equipment contained there with SNF does not exceed 0.69. At the emergency draining of CDC pool keff value will not exceed 0.58.

In case of accidental fall of the equipment in the CDC dry zone keff value does not exceed 0.56. Accidents related to the drop of transported SFA into the CDC pool are also excluded by regulations as the particular transport operations are prohibited with the open valve of the pool.

Thus nuclear safety requirements are met for both normal (keff ≤ 0.95), and for emergency (keff ≤ 0.98) operational conditions.

Radiation safety.
During the execution of works in CDC the protection of the personnel and the environment protection is provided by the following means:
- biological shielding of the cell from ionizing radiation;
- special systems of extraction ventilation from transport tunnels and associated facilities to prevent the intake of radioactive aerosols in the CDC benchwork and operator’s rooms;
- system of air purging from the CDC pool water surface and subsequent purification of radioactive aerosols;
- a layer of water in the CDC travelling platform and pool to protect the staff of ionizing radiation during the performance of manual works on SFA treatment;
- design of manual tools which prevents the impact of ionizing radiation from SFAs (internal air cavities of the tools are filled with water when immersed in the pool, and protective plugs with a minimum height of 300 mm are installed into sealed tubes). The tools are made corrosion-resistant to allow their decontamination;
- purification system of water in the travelling platform, isolated from the pool water, to minimize the emissions of radioactive aerosols in the air;
- the use of additional personal protection equipment by the personnel working in the benchwork room (respirator "Lepestok 200").

The calculations of radiation dose during technical operations in CDC on defective SFA handling were carried out. The program MicroShield v.8. was used for the calculations. The calculation results showed that:
- during remote technical operations in CDC the radiation exposure of the personnel in the operator’s room, is from 0.02 to 0.05 mSv / h, which is significantly less than the allowable value of 6.0 mSv / h, set for the design of the premises of personnel permanent stay;
- in the benchwork room the dose of ionizing radiation may reach 10.6 mSv / h, which is caused by SFA irradiation at its maximum lift in CDC platform during its retrieval and reloading into an intermediate canister. This room belongs to the category of premises for the temporary stay of personnel for whom a permitted value of ionizing radiation dose rate is 12.0 mSv / h.

Thus, at all stages of the works the calculated dose rate does not exceed the limits set by normative documents for the premises of the corresponding destination.

- the analysis of possible emergencies (emergency draining of the CDC pool, termination of power supply, falling of equipment containing radioactive substances during transport) showed that there is no overexposure of personnel located in the operator’s room. The staff should leave the benchwork room. An additional increase in exposure is only possible during the restoration works on the elimination of the accident, which should be taken into account when developing the plans for these works.

*Execution of works on preparation of FSUE "PA "Mayak" to the han-
To perform the works on the preparation of FSUE "PO "Mayak" production to the treatment of defective SFAs in accordance with the developed design documentation in the period from 2011 to 2013 the Atomic Energy Commission of France (CEA) and FSUE "PO "Mayak" concluded and implemented a number of international contracts on the manufacture, supply and installation of equipment for the modernization of TFC and CDC elements.

The works on these contracts were funded by the Atomic Energy Commission of France, acting on behalf of the French government in compliance with the Agreement No. 04-2008 dated March 16, 2009, the Office of Strategy and External Relations (PSRE) under the G8 Global Partnership Program (PMG8).

Under the contracts FSUE "PO "Mayak" performed as the recipient of the technical assistance and the main contractor of the works.

**Contract C-19.1: The procurement of standard equipment and manufacture of optional equipment for the TFC.**

Under this contract the equipment was delivered necessary to perform the following tasks:

- to restore the CDC manipulator performance;
- to improve the reliability of technological mechanisms control (SRW transport control system and canister washing crane control system);
- to provide monitoring and safety of transportation technological operations (TV monitoring system in the transport tunnel, underwater lights);
- to provide labor conditions of the personnel (communication system, air conditioners, self-leveling floors);
- supporting equipment (transportation recipients for SFA canisters; rods, mushroom adaptors, pumps, equipment for tool repair).


**Contract C-19.2: the procurement of standard equipment and manufacture of optional equipment for the production of CDC.**

Under this contract the following equipment was manufactured and supplied:

- equipment for CDC and PRR (travelling platform with a drive, locking device, retrieval device, drilling device, technological equipment and ancillary equipment);
• tools for the manipulator (type 5 gripper);
• electric power and lighting systems;
• dehydration unit;
• CDC CCTV;
• intercommunication and alarm systems.

The main equipment manufacturers and suppliers were LLC SPE "Innovation and Technology", JSC "Diakont", JSC "NTC "Leader".


Contract C-19.3: Installation and setup of TFC and CDC equipment for the handling of defective VVR SFAs.

Under this contract the following works were performed:
• manufacturing and supply of the equipment, not included in Contract C-19.2 (equipment for handling baskets in the storage unit and washing unit (6 items), CDC manipulator tool (12 items), hand tools (19 items), packaging and consumables);
• construction works, installation and commissioning of equipment (mechanical equipment, electrical equipment, instrumentation and control equipment, control mechanisms of CDC, mechanisms control system, tail pieces transportation, and washing unit systems, CCTV system, communications etc.);

Construction, installation and commissioning works were organized in the following sequence:

- preparation work - providing conditions for the construction and installation work on the CDC upgrading:
  • decontamination of equipment and production facilities,
  • dismantling of idle equipment,
  • installation of scaffolds,
  • installation of equipment manufactured and supplied under Contract S19.1;
- installation of equipment manufactured and supplied under Contract C19.2:
  • travelling platform and drive mechanism,
  • drying unit and pipelines,
  • turntable,
  • trap,
  • curtains,
• pool baffle,
• tool stands,
• balance guide,
• electrical equipment (power supply, lighting, intercom, video surveillance, instrumentation and control);
- construction and installation works to repair CDC operator’ rooms (plasterboard paneling, installation of suspended ceilings with light fixtures, construction of polymeric cast-in-place floors, replacement of doors, painting of metal structures);
- equipping CDC and travelling platform with tools and equipment (tools for the manipulator, hand tools, support cylinder, technological platform, cutting, drilling and push-off devices);
- commissioning, adjustment and test run of the installed equipment;
- operational check of the equipment of upgraded CDC and benchwork room with the use of a SFA canister in accordance with the developed Test Program (cold tests):
  • transportation of a canister in the CDC dry zone by crane,
  • removal of a protective plug from the canister using the manipulator,
  • reloading the canister to the travelling platform using the manipulator,
  • removing the platform in the benchwork room,
  • verification of equipment and tools for SFA retrieval from the canister in the benchwork room,
  • removing the platform in CDC,
  • putting a intermediate canister in the drying unit using a manipulator,
  • relocation of the intermediate canister from the drying unit in the transfer cassette using the manipulator,
  • transporting the transfer cassette with the intermediate canister from CDC with a crane;
- Preparation of technical operational documentation and permits:
  • introduction of alterations to the Technological Regulations with regard to the performance of works in the upgraded CDC and benchwork room,
  • development of Standard Operating Procedures on defective SFA handling equipment in the upgraded CDC and benchwork room,
  • introduction of alterations to the Nuclear Safety Provision Regulations.

All works on equipment installation, commissioning and testing were performed by the personnel of the FSUE "PO "Mayak". Co-executors of the stage of works were also LLC SPE "Innovation and Technology" (equipment manufactur-
ing), FSUE "FCNRS" (design supervision of construction and installation works), JSC "Diakont" (installation supervision work on CCTV).


**Conclusion.**

The results of the above works provided the technical possibility of safe transportation and preparation for radiochemical reprocessing of defective SFAs of VVR-type reactors of the first generation nuclear submarines at RT-1 Plant of FSUE "PO "Mayak" which allowed the release the onshore temporary storage facilities of Gremikha from this type of spent fuel and launch the activities on the environmental remediation of the base.