Problems of Dismantling of Multi-Purpose Nuclear Submarines with Liquid-Metal Coolant Reactors

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Some of the retired nuclear submarines found in the North-Western Region of Russia have reactor installations in which metal eutectic (lead-bismuth) was used as a primary coolant – the so-called liquid metal coolant (LMC) reactors. Such reactors were installed in Alpha-class submarines (Fig. 1).

Fig. 1 Alpha-class submarine

Two submarines with LMC reactors and one reactor compartment with spent nuclear fuel (SNF) inside it, cut out of an Alpha-class submarine (unit No. 120), are currently kept waterborne in Murmansk region, waiting for dismantling. Besides, a one-compartment unit (factory No. 900) is afloat in Saida Bay; its reactor together with SNF was mothballed with the use of a special technology.

A distinguishing design feature of Alpha-class submarines is that they are made of titanium alloy. These submarines use a single-reactor nuclear power installation (NPI) as the principal energy source. The key components of the facility – reactor, steam generator, circulation pump and steam turbine unit – have functions similar to those of their counterparts in facilities with light-water reactors (LWR).

Use of liquid metal coolant imparts a number of specific features to the NPI. So, for instance, high steam parameters may be provided at the steam generator outlet (superheated steam) with the pressure in the primary circuit being about one-tenth that in LWRs, which allows using thin-walled components in the NPI.

Liquid metal coolant does not add any special problems to the process of submarine dismantling, but it is necessary to take into account some distinguishing design features of such facilities, which influence the corresponding processes in dismantling. One of such distinctive features lies in the design of the reactor core which together with the shielding plug forms a single demountable unit. Besides, LMC reactors use fuel of high enrichment, which calls for stringent safeguards to meet the non-proliferation requirements.

When an LMC-carrying submarine is decommissioned, initial cooldown is followed by a certain period when the reactor facility is inactive while the coolant is kept hot (at 140-150°C) by heat from an external source (steam from the base or an electric boiler built into the NFI heat transport circuit) or by internal source (running the reactor at the minimum power level).

With the onshore base ready to receive it, the submarine is transferred to the dry dock (No. 10) and is defuelled there. Spent fuel was removed from several Alpha-class submarines following this procedure.

In the two submarines and one RC unit mentioned above, the coolant froze as the base was not prepared to take them in for defuelling and to provide the required heat sources.

The design specifics of LMC reactors require use of special equipment and procedures for preparing and unloading spent fuel, which differ essentially from those employed in defuelling of light-water reactors.

Reactor installations with liquid metal coolant are also distinguished by the fact that with the reactor shut down and the temperature decreasing, the coolant solidifies and forms a monolithic structure, with fuel assemblies and absorber rods found inside it.

For the SNF to be subsequently unloaded, the reactor has to be warmed up from an external (land-based) heat source. The procedure involves simultaneous removal of all fuel assemblies together with control rods from the reactor, which means that the whole reactor core is taken out (so called spent reactor core – SRC).

This operation is carried out with the use of a special container placed above the reactor. With the coolant heated up and kept at a specified temperature, the SRC is pulled into the container by slow controlled steps. When the core is safely inside, the bottom gate of the container is closed. A hoisting crane of dry dock SD-10 transfers the container into building 1A and places it in a storage compartment for initial cooling.

Then the container is disengaged with the SRC and taken out of the storage tank, while the spent core is left in the storage (Fig. 2).

The storage facility made as steel cylinder (storage tank) filled with lead-bismuth eutectic to a certain level and residing in a steel-lined concrete vault which performs the function of radiation shielding.

The storage facility is equipped with an air heating and cooling system, as well as with systems for monitoring the temperature and reactivity state of the spent core. Once the cooling has reached the residual heat level (~ 20 kW), the spent core together with its tank is transferred to a storage place for long-term cooling (building 1B), which is a steel-lined concrete cell (well).

The spent core is cooled by natural circulation of air in the storage cell which is closed at the top by a conical plug. The temperature is monitored by means of a standard thermocouple arranged inside the spent reactor core. There are ten such storage cells in building 1B, 6 of which are already occupied. The time of keeping spent cores in building 1B has not been specified to date.

On completion of spent fuel removal from the reactor, the coolant heating system in the submarine is dismantled, normal protective barriers are restored (the reactor and the hull are sealed) and the submarine is passed on to the dismantling team. At this point, the reactor is filled with a solidified coolant, which serves as an additional protective barrier for the reactor internals. This is very important, as about 99 % of radioactivity remaining after defuelling is concentrated inside the reactor.

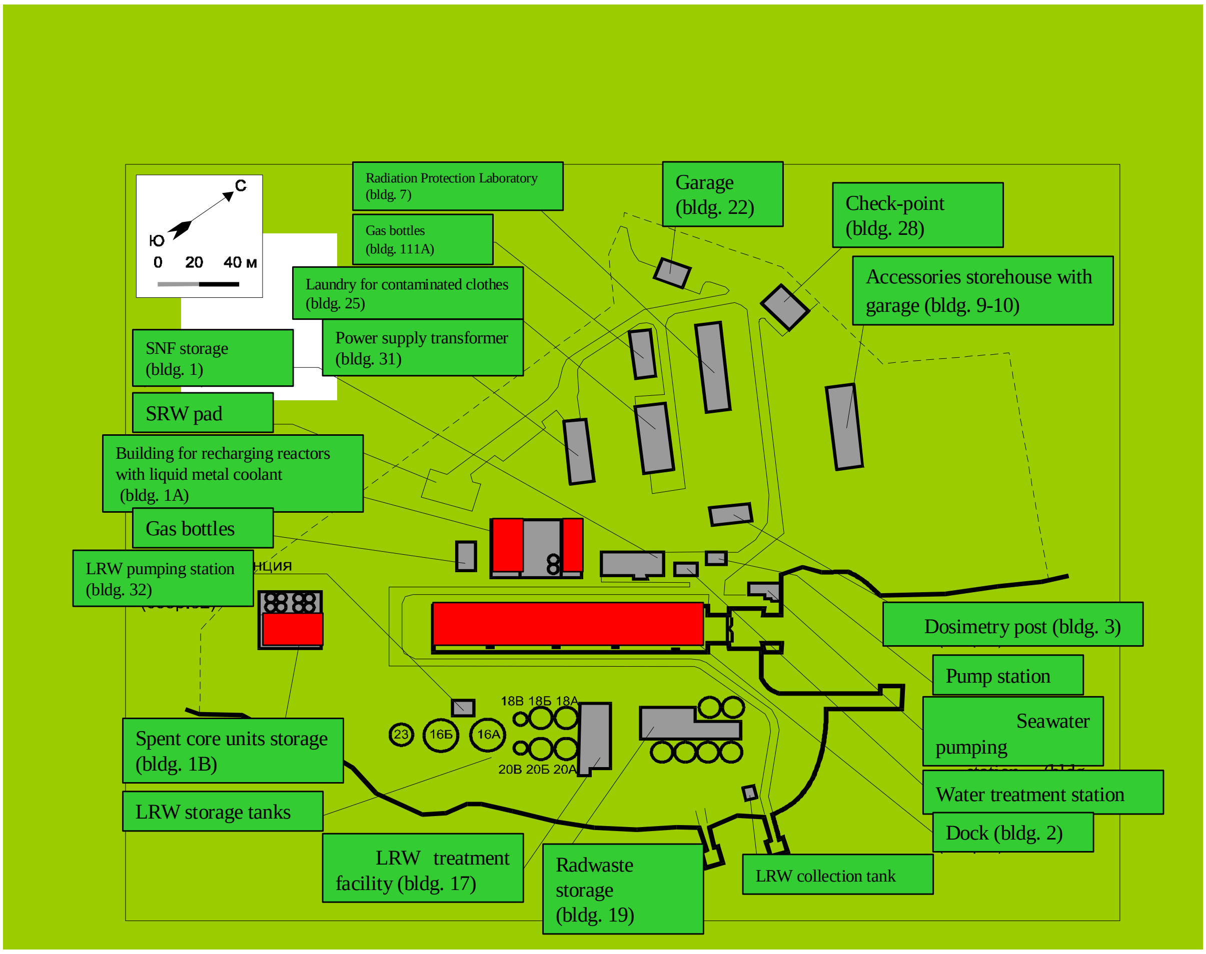

Fig. 2 Layout of the Gremikha site infrastructure

The total activity is determined by the level of radiation from metal structures and coolant. The radioactivity of the eutectic is governed by the radiation from the quick-vanishing polonium-210 ($T_{1/2}$ = 138.4 days), as well as from the long-lived bismuth-210m ($T_{1/2}$ = 3.6 x 10^6 years), bismuth-207 ($T_{1/2}$ = 30.2 years), bismuth-208 ($T_{1/2}$ = 3.65 x 10^5 years) and thallium-204 ($T_{1/2}$ = 3.78 years). The radioactivity of metal structures depends on the radiation from cobalt-60 ($T_{1/2}$ = 5.27 years), nickel-63 ($T_{1/2}$ = 100.1 years) and iron-55 ($T_{1/2}$ = 2.72 years).

A special infrastructure was set up at Gremikha to support the work in accordance with the procedure described above. It includes a dry dock (No. 10) with cranes, a building for storage of “frozen” cores, power supply, inspection and maintenance systems (Fig. 2). This infrastructure has not been used as designed since 1994.

It should be noted that defuelling is but a first step in handling the spent nuclear fuel from the submarines. According to the State Concept for integral decommissioning of Russian nuclear submarines, SNF is to be removed from the North-Western Region and reprocessed. For this requirement to be fulfilled, the LMC reactor cores should be disassembled, with the spent fuel assemblies extracted from the frozen eutectic.

To this end, special capabilities should be provided, including a pad for SRC, systems for heating, drainage and reclamation of liquid metal coolant, hot cells for taking apart the extracted fuel assemblies, a bay for conditioning of large-sized radioactive components, hoisting and transfer equipment, systems for radiation monitoring and provision of safe working conditions, a physical protection system, facilities for dismantling of SRC, power supply and support systems. No less important is appropriate staffing.

In our opinion, it is unrealistic to set up such capabilities and to have them running properly under the conditions of Gremikha, wherefore a more appropriate site should be chosen.

One of the options to be considered is the industrial site of the NRC IPP in Obninsk, where the VT/1 facility with a liquid metal-cooled reactor used to operate and was later decommissioned. This centre possesses certain experience in dismantling one spent reactor core under pilot operation conditions.

In order to dismantle all the SRC from Alpha-class submarines on a full scale, it is necessary to design and build an appropriate infrastructure which will meet all the current requirements placed on such facilities.

A special transport cask should be manufactured in conformity to the regulations for spent nuclear fuel shipment by sea and rail for the purpose of taking the SRC from Gremikha to the SRC disassembling site. An engineering design of such a cask (drawing 438.01) was developed by OKB Gidropress (Fig. 3). Further work on the cask development was suspended due to absence of finance. If this effort is resumed, it will be necessary to produce working documentation, to manufacture and certify the cask for SRC shipment (mass – 41,000 kg, material – special steel of grade 09N2MFB-A).

Thus, the whole package of work on decommissioning of Alpha-class submarines has the following main stages, listed in Table 1.

Table 1

Main phases of dismantling

1.	Submarine delivery and placement in dry dock SD10
2.	Submarine preparation for defuelling
3.	Preparation of the onshore infrastructure for SNF unloading
4.	SRC removal from the reactor, its cooling and installation in a concrete cell of building 1B for storage
5.	Restoration of protective barriers and reactor compartment sealing on completion of defuelling, hull sealing
6.	Submarine removal from the dock, shipment and transfer to the dismantling team (to be selected on a tendering basis)
7.	Submarine dismantling, with the reactor compartment cut out and prepared for long-term storage
8.	SRC shipment and handover for storage (cooling)
9.	Selection of the site and preparation of its infrastructure for SRC disassembling
10.	SRC shipment to the disassembling site
11.	SRC disassembling, SNF shipment to the reprocessing plant, SRW conditioning
12.	Conditioning of large radioactive components (spent core casing, lid, shields, etc.) and their disposal

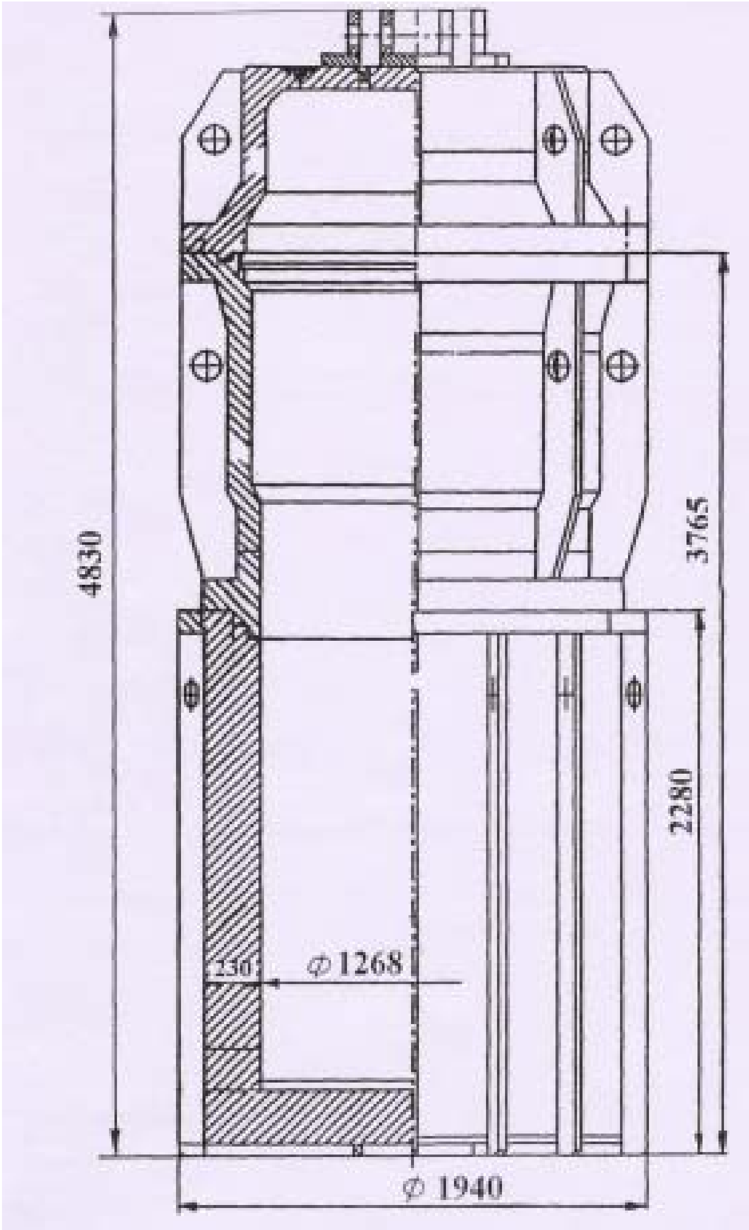

Fig. 3 Shipment cask for spent reactor cores

On assignment from Minatom, several Russian organisations (OKB "Gidropress", NRC IPP, NIKIET, Malakhit, SevRAO and others) are developing the regulatory, technological and operating documents which will specify the components of the infrastructure at Gremikha and their parameters essential to SRC unloading and their arrangement in the storage facility. Spent nuclear fuel removal from submarines to the shore is the top priority step in handling the liquid metal-cooled reactors.

According to the work management and technological procedures, civil experts of SevRAO are expected to carry out the work on SRC handling.

The repairs in the dry dock SD-10 are over by now and it is available for operation; work is underway to fix and certify the special hoisting cranes required for SRC lifting and transfer.

The scope of work planned for the year 2003 includes setting up a system for coolant heating inside the reactor and in storage, providing power supply to the site, restoring the monitoring and radiation safety system to its full capability, providing proper sanitary and living conditions and safety for the personnel exposed to radiation hazards. Personnel training and qualification work is in progress.

Plans for environmental remediation of the coastal base at Gremikha call for removal of accumulated SNF and elimination of the hazardous facilities on its territory. With this in view, it is important to resolve without delay the problem of subsequent handling of the spent nuclear fuel placed for temporary storage in building 1B.

First of all, feasibility studies have to be performed with the aim of identifying the best option for handling the spent reactor cores from Alpha-class submarines in terms of the time and costs involved. Once such an option is adopted, design, technological and regulatory documents will have to be produced for each stage in SRC handling. The associated design work and provision of the appropriate infrastructure are tentatively estimated at US$ 36.0 million.

Given current economic conditions in Russia and considering the funding required for decommissioning of numerous other submarines and for remediation of dangerous sites, such expenditures would be a serious burden to the Russian budget.

So, it may well be expected that slow progress will be made in resolving the problem of SNF management from submarine LMC reactors, with the ensuing necessity for keeping spent reactor cores in building 1B for a long time. This means, in turn, that we shall see further degradation not only of the building structure, but also of the systems for physical protection and control over the facility.

International cooperation and assistance in tackling the problem may be very useful in this situation and would be appreciated. This prompted us to propose implementing the project discussed as an international effort within the Global Partnership Programme.

The tentative schedule and cost estimates for the project are given in Tables 2 and 3.

Table 2

General project schedule

Stage	Work description	Time scale (year, half-year)							
		2003		2004		2005		2006	
		I	II	I	II	I	II	I	II
1.	Feasibility studies to select options for SRC handling from Alpha-class submarines								
2.	Production of design and technological documents on provision of means for safe SRC shipment, preparation of disassembling facilities, treatment and disposal of radwaste generated during SRC disassembling								
3.	Provision of means for safe SRC shipment from Alpha-class submarine, preparation of disassembling facilities								
4.	SRC transfer from their storage place to the disassembling site								
5.	SRC disassembling and preparation of spent nuclear fuel for reprocessing, disposal of radwaste generated in SRC disassembling								

Table 3

Cost estimates

Stage	Work description	Cost, US$ thousand
1.	Feasibility studies to select options for SRC handling from Alpha-class submarines	**1 100.0**
2.	Production of design and technological documents on provision of means for safe SRC shipment, preparation of disassembling facilities, treatment and disposal of radwaste generated during SRC disassembling	**2 800.0**
3.	Provision of means for safe SRC shipment from Alpha-class submarine, preparation of disassembling facilities	**8 200.0**
4.	SRC transfer from their storage place to the disassembling site	**5 300.0**
5.	SRC disassembling and preparation of spent nuclear fuel for reprocessing, disposal of radwaste generated in SRC disassembling	**18 600.0**
	Total:	**36 000.0**

The individual stages of the project identified in Table 2 may be arranged as separate, independent projects. So, for instance, Stage 3 could be translated into a separate project for producing a transport cask to take SRC from the Gremikha storage to the site of their disassembling.

The possibilities of international cooperation in tackling the problem as a whole are not confined to the efforts described above. Both donor aid and expert assistance are essential in dealing with Stages 1, 3, 4, 5 and 7 listed in Table 1. These issues may be discussed in greater detail together with SevRAO personnel.

Provision of a state-of-the-art physical protection system at Gremikha site could be considered as one of the first priority projects.

One of the specific problems yet to be resolved in disposition of Alpha-class submarines is the decision to be made concerning the spent nuclear fuel kept in the reactor of one-compartment unit No. 900 (Fig. 4). This unit (reactor compartment) was treated to make it environmentally safe, with a strong protective barrier provided in the reactor, i.e. the fuel assemblies and control rods are held in a frozen layer of metal coolant, on top of which the reactor is filled with solidified conserving agent.

The reactor compartment is three-quarters felled with bitumen with cement covering above it. In this condition, the compartment may be safely kept for a long time, but as long as spent fuel is inside it, it will be regarded as a nuclear hazard. To sum it up, we need to develop the basic technology and then the procedure for removal and subsequent handling of sSNF from reactor compartment unit No. 900.

One of the options could be removal of the reactor vessel from the reactor compartment with the following long-term storage of the reactor with SNF inside, or further discharge of SRC from the reactor and disassembling of the SRC.

This project could be presented for international in details subject of the results of future discussions.

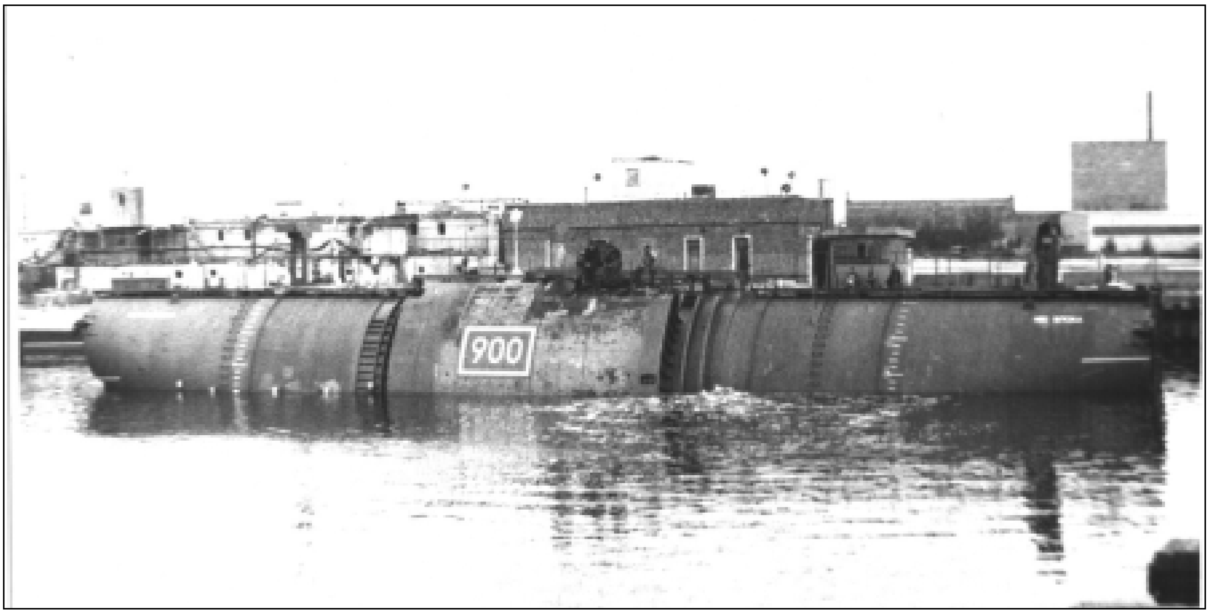

Fig. 4 Waterborne submarine RC unit No. 900

CONCLUSIONS

1. Removal of spent nuclear fuel (spent reactor cores) from LMC reactors of Alpha-class submarines is one of the first priorities in the overall problem of integral dismantling of multipurpose nuclear submarines.

2. Use of the dry dock SD-10 at Gremikha site, Kola Peninsula, is the only option for defuelling the LMC reactors.

3. The Gremikha site infrastructure, required for SRC unloading from reactors and its temporary storage, was not used as designed for a long time (about 10 years). In the year 2000, The Navy passed it over to Minatom for environmental remediation, which is impossible without restoring at least some of the capabilities.

4. The final aims of handling the unloaded SNF lie in extraction of fuel assemblies from the "frozen" core, their dismantling, SNF packaging and transfer to reprocessing, treatment and disposal of solid wastes arising in disassembling of spent reactor cores, and reclamation of the metal coolant.

5. This complex problem may find its quickest and most efficient solution, as described above, within the framework of the Global Partnership Programme through development and implementation of one or several projects. Considering the distinct specifics of individual work stages in tackling the overall SNF management problem, 3 or 4 international projects may be set up and carried out, covering the technical and economic underpinning of the management option choice; provision of casks for SRC shipment; design of facilities for SRC disassembling; development and implementation of a procedure for treatment of large radioactive components resulting from SRC disassembling.

6. With international cooperation, the project for handling spent nuclear fuel from Alpha-class submarines can be developed and carried out before 2005-2006. The total cost of the whole project is estimated at about US$ 36 million. The project promises tangible results, such as elimination of a nuclear hazard site, a reduction in the quantity of nuclear materials in storage and their appropriate protection against proliferation.