DISMANTLEMENT OF THE NUCLEAR-POWERED ICEBREAKERS IN THE ARCTIC REGION

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The article tackles the issue of the dismantlement of the nuclear-powered icebreakers in the Arctic region. It presents the basic approach to the problem and the main technologies used in the nuclear-powered ship dismantlement.

Keywords: *ship dismantlement, nuclear-powered icebreakers, nuclear legacy facility, block package, nuclear safety, radiation safety, radioactive waste.*

In the USSR and the Russian Federation, three generations of civil nuclear-powered vessels with nuclear power units (NPU) have evolved. From 1959 to 1991, nine nuclear icebreakers (NI) and one nuclear-powered lighter carrier were built.

By 2010, active efforts were launched to decommission the nuclear icebreaker fleet (NIF) vessels, in particular, the first stage providing for their transfer into 'cold stack' mode. The age of these vessels with nuclear power units accounted for some 30—35 years.

The USSR and the Russian Navy had five surface ships (SS) with NPU, two of which are being currently dismantled [1].

Data on the nuclear icebreakers and their status

There are five NI that are or were operated within the Russian NIF: 92, 92M (Lenin), 1052 (Arktika, Sibir), 10580 (Taimyr, Vaigach), 10521 (50 Let Pobedy, Rossiya, Yamal, Sovetskiy Soyuz), 22220 (Arktika, Sibir, Ural). The first NI in Russia, which was the only ship of the 92, 92M designs (Lenin), has been decommissioned and upgraded into a museum. The NI of the 1052 designs (Arktika and Sibir) are undergoing the dismantlement process, while the NI of the 10521 designs (Rossiya) is awaiting its dismantlement. The dismantlement operations performed in 2016—2021 at the NI Sibir have provided its end state that had been specified in its decommissioning designs. The ship has been removed from radiation control and excluded from all registers. Its hull structures have been disposed of as scrap metal. Fig. 1 presents the decommissioning schedule for ships with nuclear power units.

Main provisions of regulatory and policy papers on the decommissioning of ships with nuclear power units

Efforts related to the decommissioning of ships with nuclear power units shall be implemented in line with relevant requirements of Federal Norms and Rules in the Field of Atomic Energy Use [2], Radiation Safety Standards [3] and Basic Sanitary Rules for Radiation Safety [4], as well as the

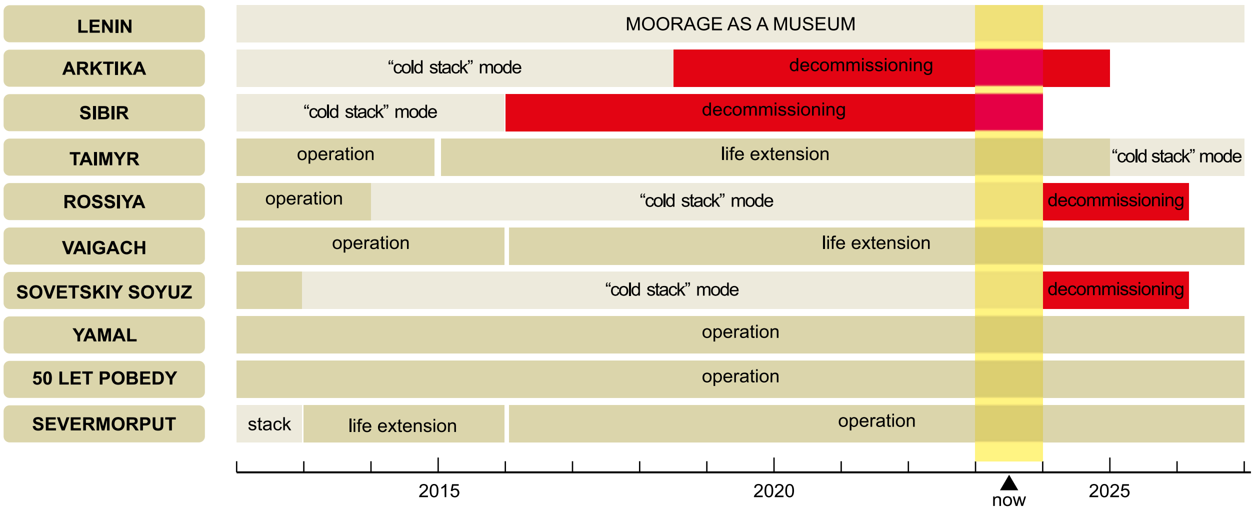

Fig. 1. Decommissioning schedule for ships with nuclear power units

requirements for liquid, solid and gaseous radioactive waste (RW) management, which are regulated by a few regulatory provisions [5]—[7].

According to these requirements, safety measures shall be implemented along the entire life cycle of ships with nuclear power units, including the stages of their design development, operation and decommissioning [2]. These measures are aimed at meeting the principles according to which the established radiation doses for personnel and public exposure and the standards for permissible releases and discharges of radioactive substances (RS) shall not be exceeded, the generated RW amounts shall be minimized and the reuse of materials emitting radioactive radiation or containing RS with an activity exceeding the established limits shall be avoided.

In accordance with Federal Norms and Rules in the Field of Atomic Energy Use [2], the design documentation for a ship with a nuclear power unit shall involve, in particular, the corresponding decommissioning concept describing various options, including possible transitions from one option to another.

The choice of the preferred option shall take into account the following criteria:

- practical feasibility;
- safety of personnel and the population;
- environmental safety;
- cost;
- duration.

When it comes to ships with nuclear power units, the optimal decommissioning option shall meet the following conditions:

- minimal radiation exposure to personnel, population and environmental objects;
- bringing the RW, including the dismantled contaminated structures, to a state considered safe for the population and the environmental objects;
- minimal cost and duration of decommissioning operations, as well as minimal costs required for further maintenance of the block packages (BP).

In 2013, the State Corporation Rosatom approved the concept [8] developed by JSC NIPTB (Research Manufacturing Technological Bureau) Onega. Within its framework, all possible design options for the 1052 NI decommissioning were considered taking into account the technological capabilities of the enterprises performing relevant operations in the Arctic region.

According to the provisions of the disposition concept proposed for ships with nuclear power units [8], the "deferred" decommissioning option consisting of the following stages has been adopted in Russia:

- retirement from the nuclear fleet;
- staking;
- unloading and management of spent nuclear fuel (SNF);
- cutting out the reactor room;
- production of a non-floating reactor unit (NRU);
- production of packages with solid radioactive waste (SRW);
- disposal of the bow and stern ends of the hulls;
- SNF and RW transportation.

The formed NRU is subject to long-term storage (about 70 years).

Aspects considered specific for the decommissioning of ships with nuclear power units

Activity levels, their distribution in the materials of structures and equipment, SRW and liquid radioactive waste (LRW) inventories, as well as personnel exposure levels depend on the adopted designs and, accordingly, may contribute to the selection of different decommissioning approaches.

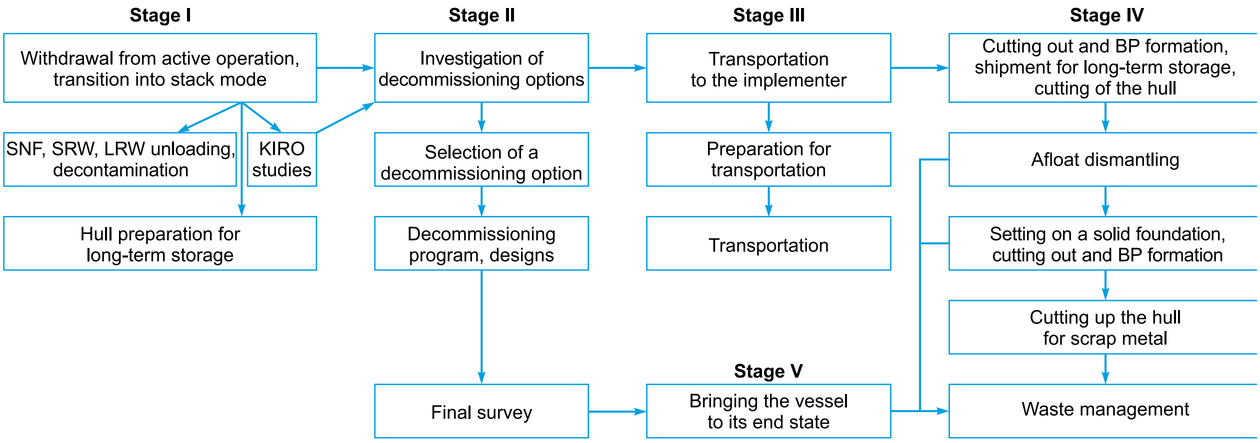

Fig. 2. Decommissioning flow chart developed for ships with NPU

Based on experience at hand, technical condition of the NI, the availability of necessary infrastructure and resources in the Arctic region, the following BP formation options have been defined in the 2013 concept [8]:

- non-floating reactor unit (NRU) sealed by transverse watertight bulkheads and structures of the protective NPU containment (Fig. 3);

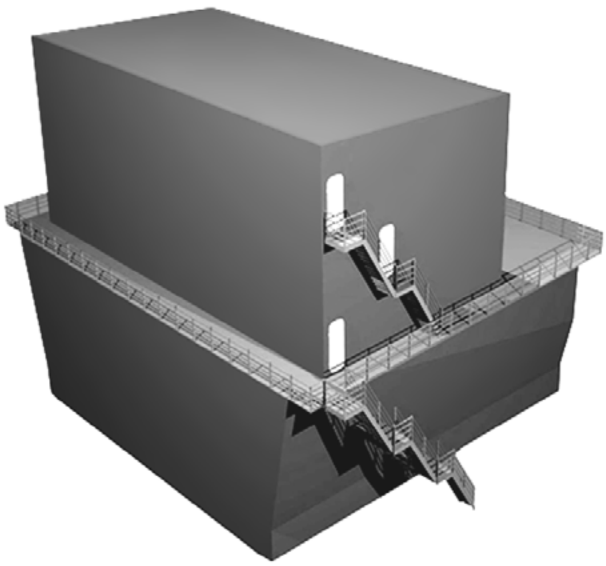

Fig. 3. General appearance of a NRU NI according to option 1 in case of 1052 designs

- cut out block of the nuclear steam generating unit (NSGU) as part of the iron-water protection tank (IWPT);
- NSGU unloaded from the IWPT loaded into a purpose-designed protective container;
- floating unit (FU) sealed by transverse watertight bulkheads.

Fig. 2 presents the flowchart specifying the arrangement of decommissioning operations at ships with NPU in accordance with the 2013 concept [8] and a number of other regulations [5]—[7].

Weight-and-dimensional characteristics of a NRU under the NI 1052 designs:

length, m	17.5
width, m	15.5
height, m	13
weight, t	2,800

In 2016, the Rosatom State Corporation revised the 2013 concept and approved its new edition (the 2016 edition) [9].

Under the new edition, ships with NPU shall be decommissioned provided the unloading of the NSGU equipment with its subsequent loading into the produced BP. Under this concept the hull can be brought to a radiation-safe state and subsequently put for sale to a potential consumer.

Practical decommissioning experience associated with nuclear icebreakers of the 1052 designs

The experience at hand in the decommissioning of NPU vessels is primarily associated with nuclear icebreakers of the 1052 designs, i. e., Arktika and Sibir.

The former one was the lead vessel of these designs. Its construction was started on July 3, 1971 at the Baltic Shipyard in Leningrad. It was set afloat on December 26, 1972 and commissioned on April 25, 1975. The vessel has been laid up since 2008, when the SNF was unloaded from it.

Nuclear icebreaker Sibir is a Soviet nuclear icebreaker of the Arktika class. It was built at the Baltic Shipyard in Leningrad according to the 1052 designs developed by the Iceberg Central Design Bureau and was put into operation on December 28, 1977. In 1993, its mothballing was started, SNF has been removed from its reactors.

The dismantling approach adopted for the nuclear icebreakers of the 1052 designs was developed by JSC NIPTB Onega jointly with the JSC Central Design Bureau Iceberg and JSC OKBM Afrikantov in 2013. It was implemented to dismantle the nuclear icebreakers Sibir and Arktika in 2016—2022.

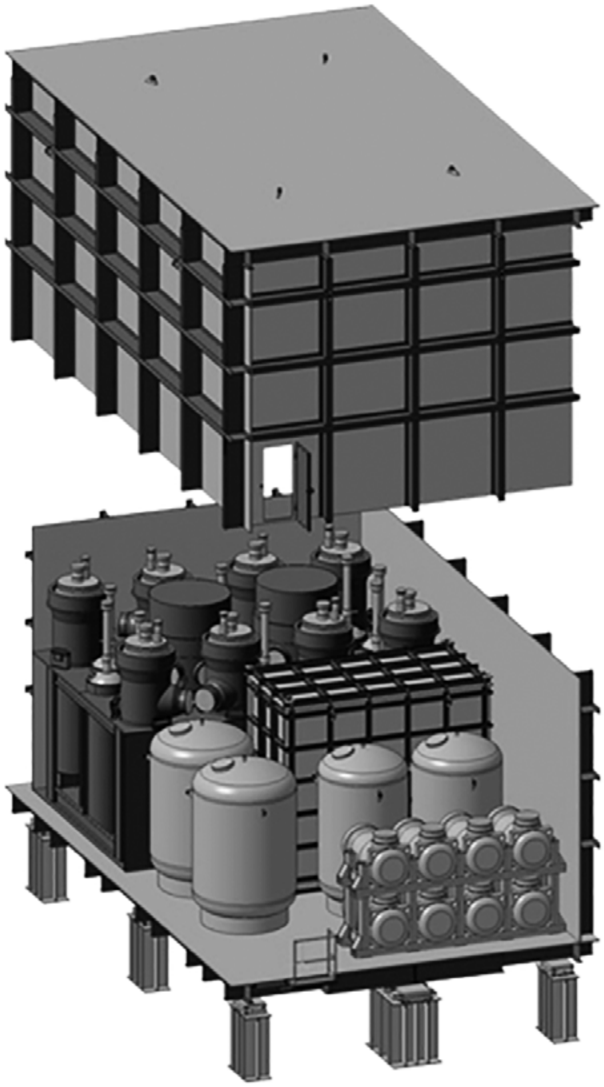

Fig. 4. General appearance of BP for a NI of the 1052 designs

Under the decommissioning process, a concept combining the immediate and the deferred dismantling options was implemented. At the implementor's site, part of the structures and equipment was dismantled, the NSGU was unloaded and then placed into the produced BP (Fig. 4). Tables 1 and 2 summarize the characteristics, the inventory of equipment and NI structures loaded into the NSGU BP.

Table 1. Main characteristics of a BP for a NI of the 1052 designs

Indicator	Value
Load capacity, t	600.0
Maximum length, m	16.32
Maximum width, m	11.70
Maximum height, m	7.54
Weight, t	434.3

Table 2. List of NI equipment and structures loaded into the BP NSGU

Name of the equipment (structure)	Quantity, pcs.	Weight, t
Steam generator (PG-18T)	8	185.3
Volume equalizer	8	38.4
Fission activity filter of the primary circuit (FOA-Ik)	2	8.3
Cooler of the fragmentation activity filter in the primary circuit (KhFOA-Ik)	2	8.7
Assembly of the primary circuit circulation pump in the hydraulic chamber	8	102.5
Circulation cooldown pump	2	4.0
Reactor	2	144.2
Reactor caisson of the iron-water protection tank assembled with lower screens	2	42.8
Bulkhead	4	3.5
Bulkhead of sections 26–29	4	7.4
Platform	1	0.1
Platform	1	0.2
Platform screen	2	1.4
Platform screen	2	2.4
Contour montejus	2	17.7
Drainage montejus	2	8.3
Total weight of the equipment		575.3 t

After the icebreakers were decommissioned, a final radiation survey could be launched. Its findings have required further implementation of the deferred dismantling concept.

Decommissioning of NI Sibir was continued at FSUE Atomflot. Operations associated with the dismantlement and decontamination of its structures, equipment and systems contaminated with radioactive substances were completed, as well as those related to the decontamination of the ship's premises and the management of the resulting RW. The weight of the dismantled equipment amounted to at least 350 t.

To date, NI Sibir has been decommissioned: operations that will enable its complete dismantlement are being implemented by JSC 10 SRZ; the NI Arktika is awaiting the completion of its decommissioning at FSUE Atomflot.

Experience gained from the practical efforts associated with the decommissioning of NI of the 1052 designs can be summarized as follows:

- reactor equipment was dismantled using the element-by-element dismantling option;
- individual levels of personnel exposure did not exceed the basic dose limits established for the Group A of personnel. The collective effective dose accounted for 0.612 man-Sv;

- the cost of an additional contract required to bring the vessel to a radiation-safe state amounts to 250 million rubles;
- the NI decommissioning project adjusted according to the concept (the 2016 edition) was expected to be completed in 1.5 years with no consideration given to the production preparation time, but in practice its duration amounted to 5 years. At the same time, to complete the dismantlement of a vessel according to the concept (the 2016 edition), it was necessary to sell the vessel for its final cutting. The estimated time needed to complete the NI disposition process providing for the production of a BP according to the designs and the concept (the 2013 edition) accounted for 1.5 years excluding the production preparation time. In practice, the final disposition of the vessel was not implemented according to the concept (the 2013 edition)

Specific aspects associated with the disposition of Navy ships

The documentation supporting the decommissioning of ships with nuclear power units has been developed considering the experience in the decommissioning of naval ships and vessels [10]—[12], which is implemented in line with the main provisions of the GOST RV 1901-008-2021 [13], as well as the requirements for the management of LRW, SRW and gaseous radioactive waste (GRW), which are regulated by the SanPiN 2.6.1.2523-09 [3] and the SP 2.6.1.2612 10 [4].

A concept [14] was laid as the basis for this procedure. In keeping with this concept, reactor compartments (rooms), in which the NSGU of the dismantled nuclear submarines and surface ships is located, shall be cut out since they contain radiation-hazardous equipment and handed over for long-term storage to a regional long-term storage facility (LTSF RC) to provide their long-term decay storage (approximately 70 years after the final shutdown).

Based on the experience gained from the dismantlement of nuclear submarines, the following disposal options were adopted for the surface ships (SS) with nuclear power units:

- element-by-element dismantlement of the NSGU equipment from the IWPT caissons and loading of the dismantled equipment into the produced BP meeting the requirements set for units placed into LTSF RC;
- production of a FU with positive buoyancy from the NSGU rooms by cutting out the SGU compartment;
- production of a BP from a reactor installation unloaded from the NSGU premises as part of IWPT with the BP formed on a solid foundation in line with the requirements set forth for the units placed into the LTSF RC Ustrichniy.

In the Northwestern Federal District, no work has been performed yet to dismantle surface ships with NPU. However, certain positive experience has already been gained from the dismantlement of a large nuclear reconnaissance ship (LNRS) Ural in the Far Eastern Federal District at JSC 30 SRZ.

Due to specific weight and size characteristics of the IWPT at surface ships with NPU, they cannot be completely unloaded: no crane equipment required for this is in place at the contractor sites. The results of previous efforts carried out by JSC 30 SRZ can be summarized as follows:

- main NSGU equipment was unloaded (reactor, steam generators, refrigerators and ion exchange filters of the primary circuit);
- the equipment was packaged into protective containers (KZR, KZF1k, transport containers PUTs-2ETs-ST);
- a floating unit of the reactor compartment (RC) was produced;
- the unit was loaded on the slipway No. 2 of the LTSF RC Ustrichniy;
- the ship hull structures were dismantled.

The main weight and size characteristics of the floating RC unit (Fig. 5) when placed on slipway No. 2 were as follows:

maximum length, m	13.10
maximum width, m	29.50
maximum side height, m	8.70
height from slipway to OP, m	2.25
weight, t	2,067

Fig. 5. General view of the floating RC unit

The weight and size characteristics of protective NSGU equipment packages were as follows (Fig. 6):

maximum length, m	5.87
maximum width, m	7.59
maximum height, m	6.50
height from the slipway surface to the pallet, m	1.88
weight, t	223

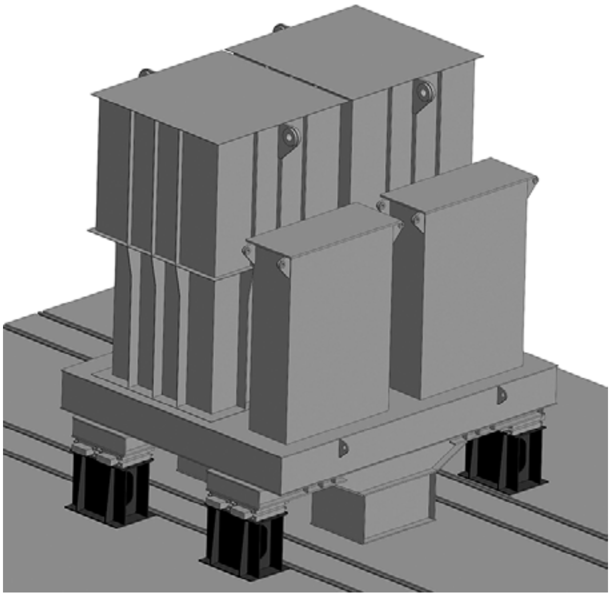

Fig. 6. General view of protective kits for the NSGU equipment

To reduce the area occupied at slipway No. 2 and to ensure the transfer of the BP LNRS Ural to the long-term storage facility, it was decided to produce two separate compact packages from the WP tanks and place them into long-term storage facilities. The hull structures that were not included in the BP had to be cut and dismantled.

JSC NIPTB Onega has developed design and technological documentation providing for work execution in several stages:

1) unloading of the floating RC unit;

2) its movement to the transverse tracks of the slipway No. 2;

3) installation of reinforcements in the internal hull structures;

4) dismantlement of the hull structures under the WPT and installation of temporary support structures;

5) cutting and stage-by-stage lowering of the WPT;

6) production of BP and their transfer for long-term storage;

7) final disposal of the hull RC floating structures that were not included into the BP.

These efforts resulted in two WPT BP tanks with the following weight and size characteristics:

length, m	6.60
width, m	6.00
height (with supports), m	7.00
weight, t	380

Based on the technology developed by JSC NIPTB Onega the company was able to unload the entire WPT and produce BP meeting the long-term storage requirements with no lifting equipment that had to be rented for this purpose (Fig. 7).

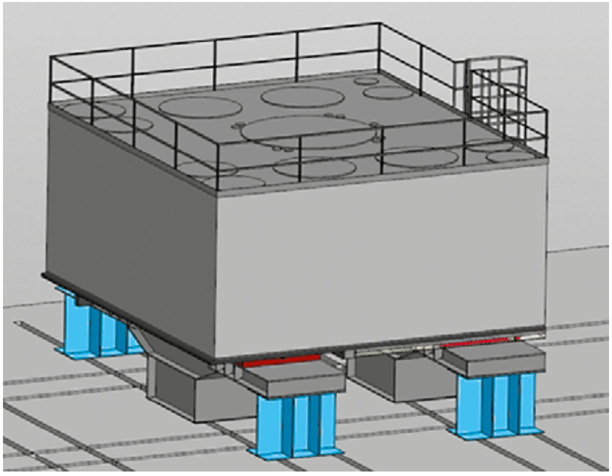

Fig. 7. General view of LNRS Ural

Conclusion

Currently, practical efforts are underway to implement nuclear legacy decommissioning projects.

The concepts supporting the disposition and decommissioning of ships and vessels with nuclear power units are aimed at providing the radiation safety, non-exceedance of the regulatory dose limits set for personnel and public exposure and minimizing the amount and volume of generated RW. In the decision-making on the fundamental designs, the properties of the existing industrial infrastructure, as well as the natural features of the Arctic region are taken into account.

The experience gained from the decommissioning operations should be taken into account in the development of new nuclear designs required for the exploration of the Arctic region.

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