

Accident nuclear submarines Problems of dismantlement and provision of safe isolation

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The inactivated nuclear submarines of the Pacific Navy include those on which radiation accidents took place, i.e. safe operation limits were violated, involving release of radioactive materials and ionizing radiation to beyond the specified boundaries in quantities exceeding the values specified for normal operations.

In accordance with the Federal Law «*On Radiation Safety of Population*» dated 09.01.1996, No.3-FZ, a facility (a nuclear submarine in this case) is qualified as damaged if it has not had effects of the radiation accident eliminated.

At present time, the damaged nuclear submarines (NS) of the Pacific Navy include the nuclear submarine, factory No. 175 (project 675), the nuclear submarine, factory No. 610 (project 671), and the nuclear submarine, factory No. 541 (project 675).

A brief data on the damaged nuclear submarines of the Pacific Navy are presented in Table 1 [2].

Table 1

Damaged nuclear submarine	Accident date	Cause of radiation accident	Accident effects	Location of NS	Planned activities
Nuclear submarine, factory No.175 (project 675)	Aug. 1985	Spontaneous chain reaction (SCR) of the portside (PS) reactor during repairs at the 30 th Ship Repair Plant (SRP) (Chazhma Bay)	Failure of internal structures and equipment enclosures, escape of radioactive products to beyond the reactor compartment. The radiation situation within the reactor compartment is extremely hazardous. Levels of radiation 20 years after the accident: - up to 0.1 Sv/h inside the reactor compartment; - up to 3 Sv/h outside the reactor compartment.	Stored afloat.	Formation of a three-compartment reactor block (RB) with SNF not removed from the starboard (SB) reactor, isolation of the block in the Raz-boynika Bay coastal shelter.

Damaged nuclear submarine	Accident date	Cause of radiation accident	Accident effects	Location of NS	Planned activities
Nuclear submarine, factory No. 610 (project 671)	Dec. 1985	Unrecoverable loss of the PS reactor coolant during the reactor cooldown.	Loss of the FA leak-tightness. Escape of radioactive products into the reactor compartment rooms. The radiation situation within the reactor compartment is extremely hazardous. Levels of radiation 20 years after the accident: - up to 0.075 Sv/h inside the reactor compartment; - up to 1.45 Sv/h outside the reactor compartment.	Stored afloat.	Formation of a three-compartment reactor block (RB) with SNF not removed from the reactors, isolation of the block in the Raz-boynika Bay coastal shelter.
Nuclear submarine, factory No. 541 (project 675)	July 1979	Pressure increase and loss of the PS reactor CPS thimbles leak-tightness.	Escape of the primary coolant into the PS reactor equipment enclosure. As of December 1996, the levels of radiation within NAV exceeded the permissible values and amounted to 3.5 mSv/h.	Slipway of the Far Eastern Plant (DVZ) «Zvezda»	Activities to assure safety of personnel during operations within the reactor compartment. SNF discharge from the reactors in 2007, preparation of the three-compartment block and its transfer to the interim storage point (ISP).

The effects of the accident at the nuclear submarine, factory No. 541, have been practically eliminated; this nuclear submarine will be utilized in 2007 using the technology adopted for undamaged nuclear submarines: unloading of SNF, formation of the three-compartment block and its placement in the interim storage site.

The accidents at the nuclear submarine, factory Nos. 175 and 610, have had highly severe consequences [1, ch.8] and elimination of these requires development and introduction of

special robotic equipment and technologies and preparation of the respective infrastructure. Briefly, I will characterize the technical condition of each of these nuclear submarines.

Nuclear submarine, factory No. 175 [3]

This nuclear submarine was commissioned in September 1965. The nuclear steam supply plant (NSSP) consists of two water-cooled water-moderated reactors of the VM-A type.

In August 1985, the post-refueling operations to install the standard cover onto the PS reactor joint at the 30th SRP in the Chazhma Bay led (due to personnel error) to an abrupt upward movement of a shim rod with the resultant thermal reactor explosion and a fire in the reactor compartment.

The fuel assemblies and the internals were damaged. The process hole was opened on the reactor compartment pressure vessel over the reactors so radioactive materials were released from the reactors not only into the reactor compartment room but also to the SRP's adjoining territory. The vessel structures of the reactor enclosures were deformed.

An additional biological shielding was installed to localize the accident consequences: the pressure vessel of the damaged reactor was filled with gravel and its upper portion was filled with concrete. The standard removable plate was installed onto the reactor compartment vessel hole with a 650-mm high metal box filled with concrete placed atop of it. The gamma radiation dose rate inside the reactor compartment was about 0.25 Sv/h.

The second reactor was not damaged at this nuclear submarine. Now it contains fresh nuclear fuel and the reactor is filled with water (coolant) with the standard cover installed on it and sealed.

Nuclear safety is assured at the nuclear submarine using the following routine methods and means:

- the design absorbers are in the lowermost positions;
- a stop plug preventing the compensating grid movement has been installed onto the compensating grid rod;
- the electric drives of the absorber movement mechanisms and the power switchboard have not been not mounted.

Nuclear fuel can be withdrawn from the SB reactor only given the repair and recovery of the reactor compartment at the nuclear submarine, factory No. 175, to enable the cover removal and installation of refueling equipment, as well as to reduce the radiation levels to acceptable values.

Operations to eliminate the radiation accident consequences have resulted in a somewhat improved radiation situation inside and outside the reactor compartment. Still, it remains extremely hazardous due to a lot of small fragments from the damaged high-level internals thrown out of the reactor into the compartment during the explosion being present in the areas inaccessible for decontamination. The repair to prepare for unloading the «fresh» core from the SB reactor and seal the pressure vessel and the bulkheads is practically unfeasible.

The major source of radioactive radiation is induced activity of the reactor compartment materials and structures and that of fission products. The major dose-forming radionuclides are Co-60 with a half-life of 5.27 years and Cs-137 with a half-life 30.3 years. Some portions of the nuclear submarine's outer hull have the dose rate levels (near the buoy, behind the deck house over compartment 5, etc.) and the surface contamination values (a local patch on the outer hull of compartment 5) abnormally exceeding the average values.

The integrity of the standard biological shielding below the pressure vessel upper deck plating and beneath the reactors has not been lost. So the damaged state of the reactor compartment does not practically result in an increase in the radiation levels on the lower side of the pressure vessel to above the values representative of the undamaged reactor compartments of generation I nuclear submarines.

Nuclear submarine, factory No. 610 [3]

This was commissioned in 1972. The NSSP consists of two water-cooled water-moderated reactors of the OK-300 type.

In December 1985, loss of the primary coolant through the damaged purification system during cooldown of the PS reactor resulted in the reactor drying which resulted in a severe failure (partial meltdown) of the core fuel elements and further loss of the primary circuit leaktightness in the PS reactor CPS thimbles.

Later on, the resumed cooldown of the PS reactor by the spill method in the conditions of continued primary coolant leak resulted in the carrying out of the fuel composition fragments into the reactor compartment room. The activity of the primary water that had escaped into the space beneath the unit through the CPS thimble system reached 8.5×10^{11} Bq/l (2.3×10^1 Ci/l) and governed largely by the fission-fragment activity (Cs-137) released into the coolant from the damaged fuel elements.

The second (SB) reactor was cooled down and put out of operation based on routine procedure. The radiation situation in the reactor compartment was extremely hazardous. Decontamination of the nuclear submarine in 1986 somewhat improved the radiation situation which, while remaining extremely hazardous, stabilized at the level below which it could not be improved using decontamination methods and means available in the nuclear submarine conditions. By late 1986, the activity of the primary water was reduced only to 5.6×10^{10} Bq/l (1.5×10^1 Ci/l).

Following the cooldown and decontamination of the steam supply plant, the bilge and other reactor compartment rooms still had a lot of high-active water that contained corrosive components (decontamination agents).

The nuclear submarine equipment is in a very unsatisfactory condition as the result of the accident, long-term absence of maintenance, impacts of unfavorable climatic conditions and effects of corrosive media. The primary circuit of the PS reactor is leaky. The reactor cores have not been withdrawn.

Nuclear safety is assured at the nuclear submarine in accordance with respective regulations. The following safe holding activities have been performed:

- the reactors of both steam supply plants have been shut down by all standard absorbers: the scram rods (AZ) and the automatic controllers (AR) are in the lowermost position with the slim grids (KR) resting on the lower stops;
- the CPS, the control safety and protection system (USBZ) and other systems have been disconnected from all types of power supplies;
- the CPS mechanism drives have been deenergized, the power cables of the CPS instruments have been disconnected from the terminal boxes and insulated and the reactor compartment has been deenergized;
- the primary circuits of both steam supply plants are filled with highly pure water without corrective additives;
- gas has been removed from the high pressure gas (GVD) system and the valves are closed.

To ensure safe storage afloat, the damaged nuclear submarines, factory Nos. 175 and 610, were subjected to dock examination and repair in 1991 and 1996 respectively.

No buoyancy engineering features of these nuclear submarines has been given further planned repair so their unsinkability is achieved through the use of additional nonstandard (basic) means, including installation of pontoons, filling of the main ballast tanks with a special filler to replace the water therein and supply of air from coastal sources.

It should be considered that the hazards of radioecological incidents continue to exist in storage of the damaged nuclear submarines and their potentiality is implacably growing (because of metal corrosion). So the environmental safety problem with respect to the nuclear submarine, factory No. 175, and the nuclear submarine, factory No. 610, should be solved in the near future. First of all, potentiality of their unauthorized submersion should be excluded. This can be achieved through the placement of them on a hard foundation. It is further required to safely isolate (or remove) the radiation sources inside and outside the reactor compartments and provide for reliable isolation of the nuclear submarines as such.

At present time, these issues constitute an acute problem and require development and implementation of individual technologies, their provision with resources and preparation of the respective infrastructure to be solved.

Obtaining input data and developing requirements to the technology of rehabilitating the damaged nuclear submarines require detailed information on the real (actual) radiation fields inside and outside the nuclear submarine and in its rooms, on parameters (characteristics) of radioactivity and its distribution in saturation of compartments and structures.

For these purposes, preliminary data on the radiation situation at the damaged nuclear submarines were obtained during the examinations:

- of the nuclear submarine, factory No. 175, in 1991, 1996, 1997, 2001 and 2004. The major (prevailing) radionuclides are Co-60 and Cs-137;
- of the nuclear submarine, factory No. 610, in 1990, 1992, 1999 and 2004. The major (prevailing) radionuclide is Cs-137.

The results of the radiation surveys by specialists of FSUE «NIKIET», ZSC «NTTs «Eksperттsentr» and FSUE «OKBM» show that the radiation levels in the reactor compartments are decreasing (e.g. they have decreased from 250 to 180 Sv/h in the reactor enclosure of the nuclear submarine, factory No. 175) but still remain extremely hazardous so

no operations to prepare and unload SNF from the reactors of these nuclear submarines can be performed in near term.

The period of 1996-2000 involved a number of feasibility studies to determine the method (option) for environmental rehabilitation of the damaged nuclear submarines. Based on these, the following decision was taken by agencies in July 2001:

- to continue the design activities for rehabilitation of the damaged nuclear submarines, factory Nos. 175 and 610, the option with their placement in a coastal area above the sea level should be accepted;
- no nuclear fuel should be unloaded from the reactors of these nuclear submarines;
- design approach should ensure reliable isolation of the damaged nuclear submarines during the long-term storage period.

An area near the long-term storage point for the reactor compartments of utilized nuclear submarines under construction on the Ustrichny Cape in the Razboynika Bay (see Fig. 1) was selected for deployment of the site (nuclear submarine storage site) as the result of the surveying work undertaken by FSUE «VNIPIPromtekhologii».



- 1 – storage of three-compartment reactor blocks afloat;
- 2 – Ustrichny long-term storage point;
- 3 – shelter for the damaged nuclear submarines, factory Nos. 175 and 610;
- 4 – FSUE «30 SRZ VMF».

Fig. 1. Layout of the coastal facility for damaged nuclear submarines

It is suggested to prepare the damaged nuclear submarines for long-term isolation in a floating dock (e.g. at PD-41).

One of the problems is the subsequent transfer of the prepared nuclear submarines to the coastal site. To this end, various engineering approaches can be used, including a berth and a transfer dock, a slip, a ship lift and others.

The option using a pontoon foundation was selected by proposal of FSUE «TsKBMT «Rubin». Its implementation requires to:

- create the pontoon foundation to fit the nuclear submarine parameters;
- transfer the nuclear submarine to the floating dock and install it onto the pontoon foundation;
- cut the nuclear submarines to form a three-compartment block on the pontoon foundation and prepare the block for long-term storage;
- float off the pontoon foundation with the reactor block after it is prepared and tow it to the coastal shelter's water area;
- excavate pit with a depth of about 25 m on the coastal site and build the shelter in it;
- build the channel to connect the water area with the reactor block storage (isolation) site;
- move the pontoon foundation through the channel and immobilize it in the shelter;
- close (backfill) the transfer channel.

A diagram showing the reactor block installed onto the pontoon foundation is presented in Fig. 2.

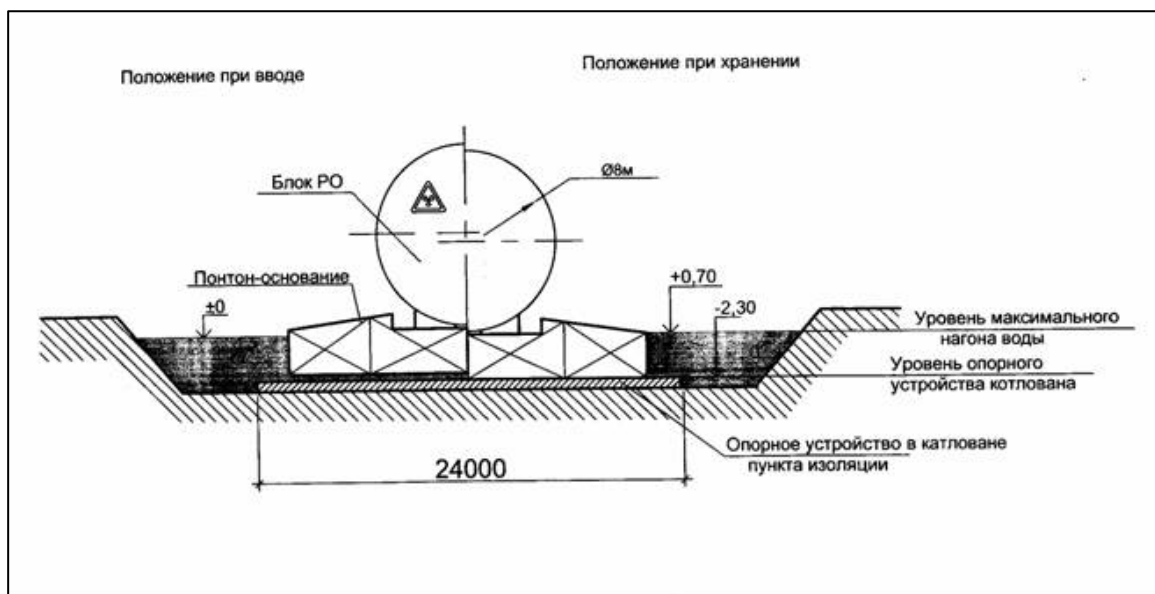


Fig. 2. Pontoon foundation with the reactor unit

It was adopted at the initial stage of developing the designs approaches that the damaged nuclear submarines will be placed in the shelter as the whole (it was suggested to remove only the deck houses and the aft end). To determine if it would be possible to reduce the dimensions of the item to be stored (i.e. the nuclear submarine), FSUE «NIKIET» proposed and in 2004 jointly with ZSC «NTTs «Eksperttsentr» performed a special radiation survey of not only the reactor compartments but also of all compartments of both nuclear submarines.

It was found out as the result of radiation monitoring and spectrometric measurements that increased exposure dose rate (EDR) values were observed only in the compartments adjoining the reactor compartment as they reached their *max* values at the bulkheads common with it:

- at the nuclear submarine, factory No. 175 – up to 0.38 mSv/h;
- at the nuclear submarine, factory No. 610 – up to 0.9 mSv/h,

with the beta contamination being 250-450 part./cm²·min.

The gamma radiation EDR decreases by a factor of 20 to 30 at a distance of 2 m from the bulkhead.

It has been determined that the compartments adjoining the reactor compartments have local sources the levels of radiation from which exceed the permissible values. These sources were largely in the walkways and over the access hatches. The rest of the compartments also have local sources but with a much lower level of radiation – not more than 0.01 mSv/h at the nuclear submarine, factory No. 175, and not more than 0.002 mSv/h at the nuclear submarine, factory No. 610. The average EDR value in these compartments is in the range of 0.002-0.0015 mSv/h. A conclusion has been made based on the survey results that the radiation situation in the end compartments of the damaged nuclear submarines, factory Nos. 175 and 610, makes it possible to perform the operations to form three-compartment blocks from these according to the standards and requirements of effective regulatory documents on assurance of nuclear safety. Performing the operations to form the reactor blocks requires removal or isolation of the local radiation sources from the compartments (except the reactor ones) and the outer hull of the nuclear submarines. In October 2004, agencies made a decision to form three-compartment reactor blocks from the damaged nuclear submarines, factory Nos. 175 and 610. The reduction in the weight and dimensions of the isolated items makes it possible to reduce considerably the dimensions and the cost of the coastal shelter and ease the load on the process equipment for transfer and placement of the blocks. The shelter for the damaged nuclear submarines is designed in accordance with this decision.

The proposed design outline of the coastal shelter for the damaged nuclear submarines is presented in Figures 3,4 and 5.

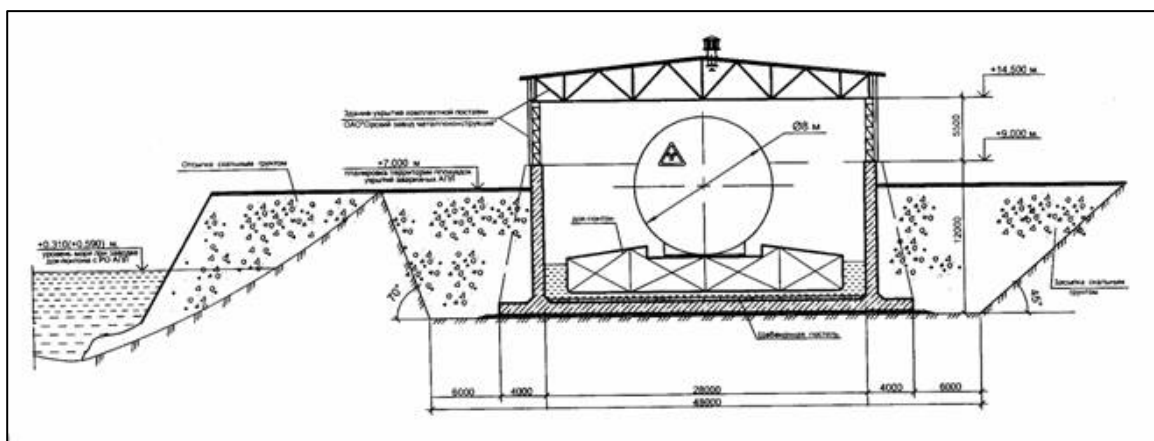


Fig. 3. Coastal shelter for the damaged nuclear submarines

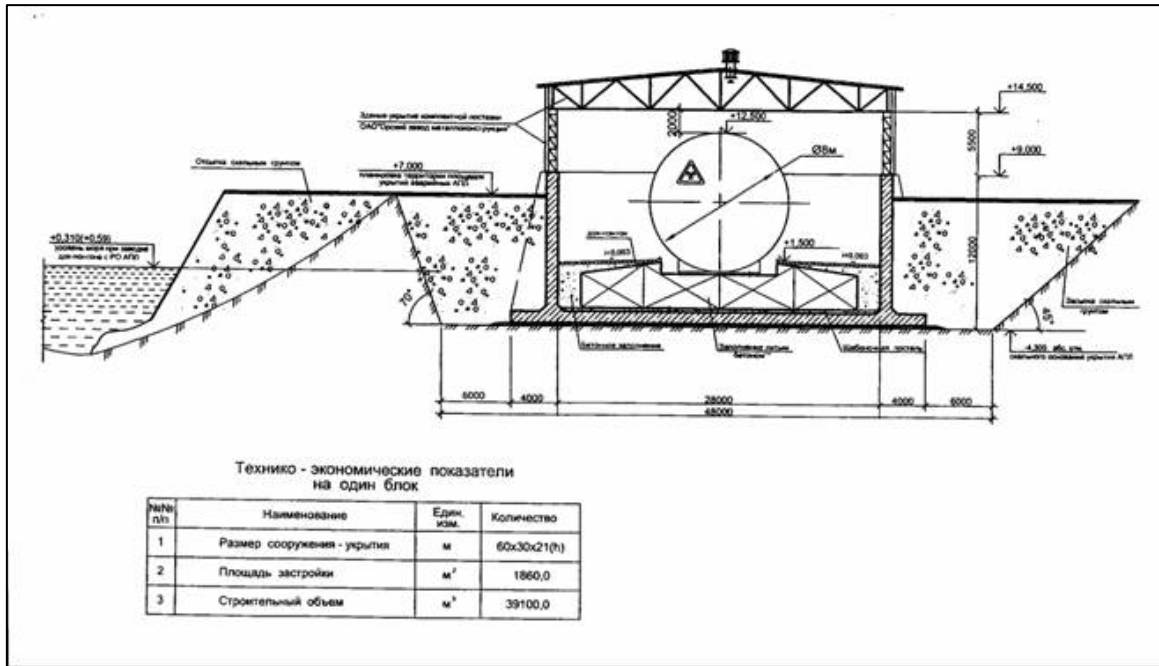


Fig. 4. Coastal shelter for the damaged nuclear submarines

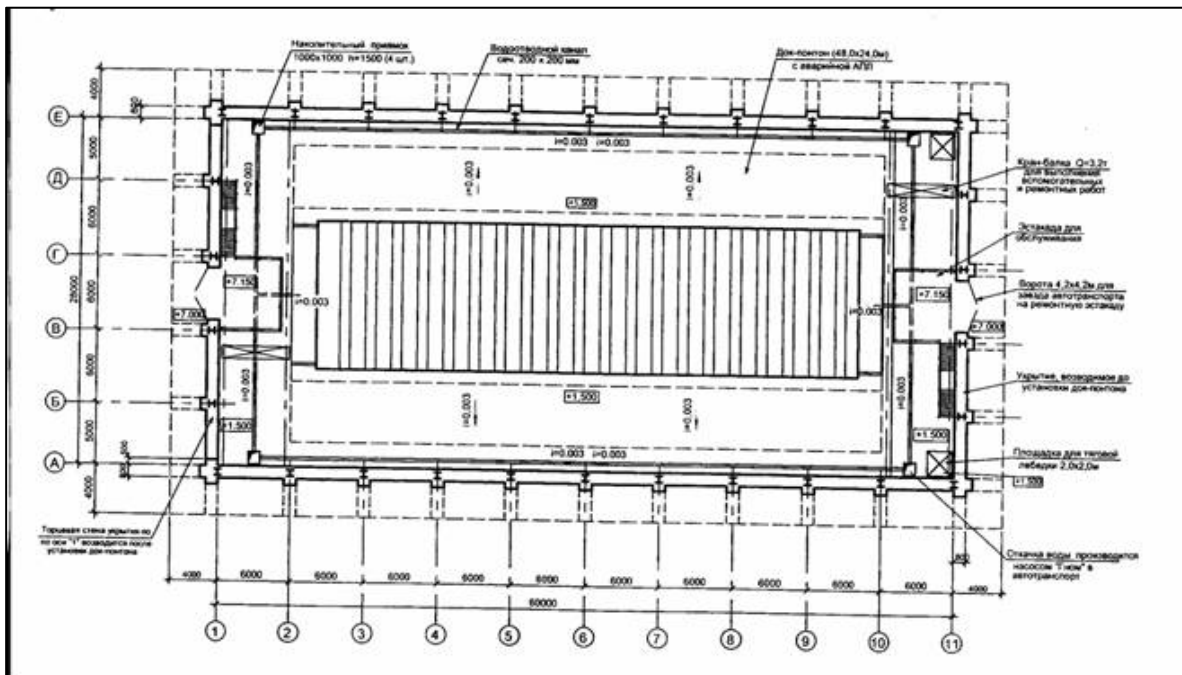


Fig. 5. Coastal shelter for the damaged nuclear submarines (plan)

The shelter is a structure embedded in 3 meters (with respect to the sea level) with reinforced-concrete walls (with a height of 3 m from the elevation of - 3 m) and a bottom onto which the pontoon foundation with the damaged reactor block is installed. A metal structure is installed atop of the walls to form a closed space together with the walls. The free space between the reinforced-concrete walls and the pit walls and the coastal slope are filled with rock up to the elevation of +7 m to form a horizontal platform. The structure's end wall facing the channel is mounted after the pontoon foundation is brought into the shelter. After the pontoon foundation is brought into the shelter by water, it is installed within the structure based on the preset coordinates and submerged till it is placed onto the stone bed with the pontoon foundation in-

ternal structures filled with floated concrete through the holes made in-situ after the pontoon foundation is submerged. After the pontoon foundation is placed onto the hard surface, the transfer channel is dammed at the structure's open end, then the structure's end wall is mounted and the free space is filled with rock.

The operations to install the second pontoon foundation in the shelter are performed in the same way.

It is planned to do the work for environmental rehabilitation of the damaged nuclear submarines on a stepped basis as applied to each nuclear submarine as follows:

- creation of the pontoon foundations;
- placement of the first nuclear submarine onto the pontoon foundation in the dock;
- radiation surveying including the underbody of the nuclear submarines;
- development and implementation of activities to assure safe operations of personnel;
- formation of the reactor block and its preparation for placement in the coastal shelter; implementation of the activities to assure nuclear and radiation safety of the reactor blocks during their long-term storage in the coastal shelter;
- creation of the coastal shelter (the initial stage parallels the formation of the reactor compartment);
- floating off and transportation of the block to the shelter's water area;
- transfer and placement of the block onto the slip in the shelter;
- completion of the creation of the shelter for the first nuclear submarine (stage II).

It is reasonable to take the nuclear submarine, factory No. 175, as the first nuclear submarine to undergo the rehabilitation procedure based on the above stages. Creation of the pontoon foundation is the critical stage that determines the start of the work. A feasibility study (design) for the pontoon foundation has been developed and is currently under consideration and approval. Under certain conditions, the placement of the first reactor block in the dock can be done in 2009 and the second reactor block can be placed in the dock in 2012. Before this, the damaged nuclear submarines will be stored afloat which, as indicated above, is becoming more and more risky.

The second critical stage is radiation surveying of the nuclear submarines on the slipway (in the floating dock). Its results will define the technology of creating safe conditions of personnel operations as well as the technology of preparing the reactor compartment for storage with activities to be undertaken to assure nuclear and radiation safety in the coastal shelter conditions.

The support for the project to rehabilitate the damaged nuclear submarines on the part of international community, especially in the Pacific region, can provide for much faster solution of this pressing problem.

The overall project to create the shelter for the damaged nuclear submarines can incorporate separate subprojects to be implemented based on independent Terms of Reference. For example, the operations presented in Table 2 can be proposed as separate projects.

Table 2

**Overall schedule for creation of the shelter for the damaged nuclear submarines,
Factory Nos.175 and 610**

No.	Description of operations	Duration, years							
		2008	2009	2010	2011	2012	2013	2014	
1.	Construction of the pontoon foundations for the reactor blocks								
2.	Development of working documentation, construction of the shelter pit and the transfer channel thereto, bottom deepening operations								
3.	Development of working documentation and construction of the building for the reactor blocks of the nuclear submarines, factory Nos.175 and 610								
4.	Construction of building for reactor block of the nuclear submarine No.610								

More detailed information on the proposed projects can be delivered additionally.

Provided the work performance dates indicated in Table 2 are met, it will be possible to place the nuclear submarine, factory No. 175, in the dock in 2009. The estimated period for the nuclear submarine cutting, the formation of the reactor block and its preparation for long-term storage is 24 months.

Based on this, the reactor block of the nuclear submarine, factory No. 175, can be ready for placement in the coastal shelter in 2011 and the reactor block of the nuclear submarine, factory No. 610, can be ready for this in 2013.

With regard for the duration of the work to backfill the shelter and the pit, isolation of the reactor blocks of the nuclear submarine, factory No. 175, and the nuclear submarine, factory No. 610, in the coastal shelter can be completed in 2014.

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