Automated system for operational chemical and radiation monitoring of water areas of the Arctic zone of the Russian Federation with flooded underwater potentially dangerous objects

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Abstract. Long-term operational control systems for pollution of the aquatic environment near potentially dangerous underwater objects in ice conditions in the Arctic zone of the Russian Federation are described. The systems are based on the use of bottom stations that measure the levels of radiation and chemical pollution of the aquatic environment and transmit monitoring information via satellite and (or) sonar communication channels. The information transmitting via the satellite communication channel is carried out by the direct ascent of the station itself, and in the case of ice cover, the transmission of information is carried out using a pop-up antenna unit capable of drilling ice. Transmission via the sonar communication channel is carried out between the stations and the receiving unit.

1. Introduction

At the bottom of the seas of the Western Arctic there are currently three nuclear submarines of Russia, five reactor compartments with ship and nuclear power plants, 19 vessels, including a barge with a reactor unloaded from nuclear submarines, 735 radioactive structures and units sunk without hermetic packaging, and more than 17 thousand containers with radioactive waste [1]. Of these, nuclear hazardous facilities include three nuclear submarines and two reactor compartments with spent nuclear fuel unloaded from the ship’s reactors, nuclear submarine order No.421 and a special container with spent nuclear fuel from reactor No. 2 of the first nuclear power plant OK-150 of the Lenin nuclear icebreaker.

The total activity of long-lived technogenic radionuclides in nuclear power plants (NPPs) of the sunken nuclear submarines Komsomolets (Norwegian Sea) and K-159 (Barents Sea) is estimated at ~ 3.6 PBq (~ 0, 1 MKu) and ~ 4, 0 PBq (~ 0, 11 MKu), respectively, which is two times higher than the activity of all the flooded Russian radioactive waste, which determines their potential radioecological hazard [2].

The safety problem of flooded potentially hazardous facilities was first openly voiced after the tragedy with the Komsomolets nuclear submarine, which sank in the Norwegian Sea in 1989. After the work of Russian Emergencies Ministry in 1995-1996 on the localization of torpedoes with nuclear
warheads on nuclear submarines, the question arose about other potentially dangerous objects that were flooded in the waters of the Russian Federation.

For several years, EMERCOM of Russia has been conducting annual surveys of radioactive waste burial sites in the northern and Far Eastern seas, as well as captured German chemical weapons in the Baltic Sea.

As a result of studies conducted in 2013 by the joint Russian-Norwegian group of experts in the Kara Sea (directly in the areas of flooding of solid radioactive waste), areas increased by tens and hundreds of times in comparison with the background of the content of artificial radionuclides in bottom sediments near flooded objects (at a distance of several tens of meters) in the bays of Abrosimov, Stepovoy and Tsivolki on the eastern coast of the Novaya Zemlya archipelago, which is caused by leaching of radionuclides from containers [3]. Observations showed that the walls of the containers underwent severe corrosion and lost their tightness. The rate of release of radionuclides from many objects has a scale of hundredths to tenths of a TBq / year (fractions of a unit Ku / year) with maximum values from 1.1 to 1.8 TBq / year (~ 30-50 Ku / year). Based on the results of many years of research and radioecological monitoring, the Norwegian-Russian group of experts and the IAEA estimated the environmental impact of radioactive pollution in the Arctic region and came to the conclusion that the dumped radioactive waste of the Russian Navy and the Russian icebreaker fleet may remain at the bottom of the sea for some time, but periodic radiation monitoring to detect possible changes in the situation in the areas of their flooding [3].

Given the expansion of oil and gas production in the offshore zone of the Kara Sea, it is necessary to assess the impact of radioactive pollution sources on the environment, including not only obtaining and analyzing the results of field measurements, but also a long-term forecast with modeling of various options for possible emergencies. Forecasts of emergency situations in the areas of disposal of facilities with spent nuclear fuel (SNF) should be carried out both for the Novaya Zemlya Depression and for the bays of Abrosimov, Stepovoy and Tsivolka [3].

Almost all facilities with spent nuclear fuel and radioactive waste (RAW) flooded in the Kara Sea are located at a distance of 10 to 120 km along the northwestern border of the potential hydrocarbon production region, but some of them are located inside the region [3].

2. Systems for automated monitoring of Arctic waters
To solve the problems of reducing the risks of emergence and development of emergencies and increasing the effectiveness of measures to eliminate their consequences during the implementation of large investment projects in hard-to-reach areas of the Arctic shelf, a reliable monitoring system for the status of water areas is required, integrated into a common set of means of warning of emergencies and the rapid development of measures to liquidation of their consequences [2].

At present, multifunctional systems for measuring hydrological and physicochemical parameters of water masses are being developed and being created, both at selected points of the controlled water area and over the water area as a whole.

The integrated water management system (IWMS) in the areas of development of hydrocarbon deposits on the Arctic shelf is described in [4-9].

Using the method of instrumental determination (by means of IWMS) of the level of radionuclide contamination of sea waters caused by the release (leaching) of radioactive substances from flooded objects with SNF and SRW, it allows ranking the Arctic shelf in the areas of operation of oil and gas production facilities by the degree of radiation hazard.

The water area monitoring systems developed at the Russian Emergencies Ministry [2,4-9] are equipped with special bottom stations that are installed near the VET and for a long (several years) time they monitor the radiation level in the environment. If the established values of the volumetric activity of controlled waters are exceeded due to the presence of various radioisotopes in them (as a rule, $^{60}$Co, $^{90}$Sr, $^{137}$Cs, $^{239}$Pu), the bottom stations float to the surface and transmit satellite signals of exceeding the threshold values of the volumetric activity of water at the location bottom station. Most nuclear and radiation hazardous wastes are flooded in the Arctic waters with developed ice cover.
Therefore, the ascent of bottom stations when exceeding the response threshold in the presence of ice is impossible.

One of the solutions to this problem is the development of a system, which is a pop-up antenna unit equipped with a mini-drilling rig that allows ice to pass up to 2.5 meters thick, a satellite modem of the IRIDIUM system and a hydroacoustic communication modem with the bottom station. When a signal is received that the set threshold has been exceeded, the pop-up antenna unit rises to the surface of the water and transmits information to the satellite communication channel.

In the presence of ice cover, the pop-up block reaches the water-ice interface and includes a mini-drilling rig. At the end of the drill is the antenna of the IRIDIUM modem system. When the end of the drill reaches the ice surface, a satellite communication channel begins to work, as well as a hydroacoustic communication channel with the station remaining at the bottom.

Another option is to create a system for transmitting information to the coastal module via a sonar communication channel, which makes it possible to obtain information about the level of pollution at the request of the system operator. This option can significantly reduce the energy consumption from batteries, because no periodic radiation regime. Such a system allows operation without recharging the batteries for several years.

When the controlled object is removed from the coastal module by a distance exceeding the range of the sonar modem, additional bottom relay stations are installed.

The optimal solution is to combine the options considered in one system.

At the same time, the data of the current operational monitoring of the state of the environment near an underwater potentially dangerous object are transmitted through the repeater system, and the pop-up system transmits via satellite channel information about the emergency situation at the facility, which can lead to an emergency in the water area.

The measuring module of the system data is a bottom station (Figure 1), similar to bottom stations [5,6], supplemented by a hydroacoustic modem for communication with the antenna unit. The tasks of the bottom station are long-term operational control of the ecological state of the water area with the automatic transmission of monitoring information and the reception of control commands using sonar and satellite communication channels.

The bottom station or a combination of such stations is installed at the location of an underwater potentially hazardous object and provides long-term operational control of the level of radiation and chemical pollution in the aquatic environment near the object.

If the specified level of pollution is exceeded, the antenna unit floats to the surface and transmits all the accumulated information through the Iridium satellite communication channel to the monitoring center of the Russian Emergencies Ministry.

The subsystem of hydroacoustic communication provides the transmission of monitoring information to the pop-up antenna unit, and also provides reception from the monitoring center of commands for controlling the operating modes of the bottom station, collecting data from the sensors of the bottom station, calling the bottom station to the surface.

Figure 1. Bottom station.
The bottom station uses an EvoLogics S2C M Mini modem with an installation depth of 1000-2000 m, a transmission range of 1000-3500 m and an information transfer rate of 13.9-31.2 kbit / s.

The amount of information when transmitting one gamma-ray spectrum is approximately 500 bits, for a single value of an ion-selective electrode is approximately 260 bits. For an autonomous bottom station that measures the radionuclide composition in water in the amount of 400 spectra and chemical contaminants by 200 parameters, the amount of data to be transmitted during one communication session will be about 300 Kbps. Systems using developed bottom stations are presented in [4,7-20].

The pop-up antenna unit is shown in Figure 2 and 3. The unit has positive buoyancy and is held at the bottom by an anchor with a breaker.

![Figure 2. Antenna unit. General view unit.](image1)

![Figure 3. Top view of the antenna.](image2)

The tasks of the pop-up antenna unit are ascent to the surface of the water area, drilling ice cover to bring the antenna to the surface, receiving monitoring data from the bottom stations via an acoustic communication channel and transmitting information to monitoring centers via a satellite communication channel.

To implement the second version of the system, bottom relay stations are used as an intermediate element (Figure 4).

As relay stations, it is advisable to use the base bottom stations described above, because it has a surface calling mechanism for recharging the power source, a hydroacoustic communication modem and differ only in a set of sensors for monitoring the chemical and radionuclide composition of water.

The coastal module consists of a receiving path, which is a base bottom station installed in the coastal zone and connected by cable to the ground complex.

The base bottom station receives information from the measuring module or relay station, and also transmits a start signal for transmitting the accumulated information from the satellite communication channel.

The ground-based complex is an autonomously working unit that provides duplex communication with the satellites of the Iridium system and generates transmitted information packets.

The above approaches to remote monitoring of the status of underwater potentially hazardous objects can be successfully applied to the tasks of environmental monitoring of the marine environment.

Examples include:
- operational monitoring of water pollution at offshore oil and gas facilities;
- operational monitoring of water pollution in the areas of treatment facilities;
- operational monitoring of radionuclide contamination of the aquatic environment near floating nuclear power plants;
• operational control of natural hydrocarbon sources at the bottom of water areas;
• operational monitoring of the state of the aquatic environment during underwater technological work at facilities containing pollutants.

**Figure 4.** System with relay stations.

3. Conclusion
Automated systems for long-term operational chemical and radiation monitoring of water areas allow ranking the Arctic shelf by the degree of radiation and (or) chemical hazard and timely respond to changes in the radiation situation in areas where underwater potentially hazardous facilities are located and make appropriate decisions that reduce the negative effects of economic activity on the shelf Arctic zone of the Russian Federation.

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