Remote radiation monitoring device

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Abstract. This article is devoted to the issue of the necessity of implementation of a remote radiation monitoring device. The main purpose of the article is to present a model of a remote monitoring device. During the research, the author considers the application areas of the device and presents technical requirements and design descriptions of the monitoring. Moreover, the researcher conducts the spectrometric equipment analysis of the device for accurate measurement of the level of radiation pollution. The device model proposed in the article is capable for secure monitoring for personnel and the public in the event of a radiation accident. The author states the importance of such monitoring device, which is primarily designed for automated radiation monitoring of environmental pollution during the operation of ships with nuclear power plants, ships of nuclear-technological services and ships transporting nuclear materials and radioactive substances.

1. Introduction
The development period of nuclear energy includes a number of major accidents, which include accidents in nuclear submarines: K-8, K-278, K-27, K-219 and the sunken K-159, also at the Chernobyl nuclear power plant, «Fukushima Daichi» and etc [2,6].

In this connection, it is necessary to revise the issue of safety associated with nuclear power plants, and most importantly, arise the question of the development of new methods for remote monitoring and research of environmental pollution [1,10].

Currently, during operations with nuclear technology service ships which equipped with nuclear power plants, transporting nuclear materials and radioactive substances, contact control methods are used. Contact methods have a number of drawbacks: the locality of the measurements, the lack of forecasting ability, exposure to contaminated environment, a high degree of risk for personnel during emergency works, the long time intervals between the moment of contamination and its detection [10].

In the case of emergency, the following main routes of radioactive pollution of the environment are possible:

- release of radioactive substances into the atmosphere;
- radioactive discharge substances in surface water.

The decision making process should be based on the use of unified software tools that provide:
- analysis of the reliability and completeness of the information received [8-18];
- assessment and forecast of the radiological situation;
- analysis of the effectiveness of possible countermeasures in order to prevent negative trends and improve the radiation and environmental situation [9].

The research and development of remote monitoring systems attracts scientists attention, especially, projects of remote radiation monitoring devices that can help to get rid of the shortcomings of existing monitoring devices, and capable for real-time detection and analysis of parameters in large areas remotely and in any weather conditions [1,2].

Nowadays, various technologies have been developed in Russia and abroad that are designed for automated radiation monitoring of environmental pollution during the operation of ships with nuclear power plants, ships of nuclear-technological services and ships transporting nuclear materials and radioactive substances.

In general, radiation-monitoring devices are intended for:

- implementation of continuous radiation monitoring of environmental objects,
- the implementation of automated control of certain parameters of the meteorological situation,
- assessment of the characteristics of the radiation background over a given area in real time with the coordinate reference of the measurement points,
- timely detection of radiation anomalies and ensuring the collection and prompt transfer of data to situational centers on the basis of the Ministry of Emergencies of Russia, the State Atomic Energy Agency «Rosatom» and centers of scientific and technical support, if measured values exceed the radiation conditions of the established threshold values.[1]

Possible emergency situations during the operation of ships and ships with nuclear power plants and ships of nuclear technology support according to the nature of the environmental impact can be divided into 2 main types:

1- Accidents at an existing nuclear power plant;
2- Radiation accidents associated with the storage, transportation and handling of spent nuclear fuel.

The main difference between these types of accidents is the radionuclide composition of the possible release. For the first type the short-lived volatile radionuclides are prevailed and for the second type the long-lived fission products accumulated in the fuel are prevailed. In some cases, activation radionuclides accumulated in the designs of nuclear power plants can make a significant contribution [3]

It should be noted that the short-lived radionuclides presented in the emission have the greatest radiation impact on the personnel of the emergency facility and the population living in the immediate vicinity, within a few days after the accident. And long-lived radionuclides make the greatest contribution to the radiation impact on the environment and the population for several tens or even hundreds of years. In addition, the main route for the transfer of short-lived volatile radionuclides is the air type and for long-lived radionuclides is water transfer [4]

Thus, the different composition of radionuclides in the release and their characteristic behavior after the accident requires different hardware and measurement methods to determine them in the environment.

In an emergency during the operation of ships and ships with nuclear power plants and ships of nuclear technology support, the main output of radionuclides will take place within a few hours, after which it should significantly decrease. In the first hours after the reactor shutdown due to residual heat, it is usually assumed that the core is destroyed in which no more than 10% of the fuel is destroyed. At the same time, radioactive isotopes of noble gases will mainly enter the marine environment. The contribution of long-lived radionuclides to the total activity of radionuclides that left
the reactor one day after its shutdown is less than 1%. After the decrease of the residual heat, it is assumed that the radionuclide yield from the fuel will be no more than 1% per year of the residual activity, accumulated in the core. In this case, radionuclides from this fuel will be released into the environment in accordance with their coefficients:

- 1 for noble gases,
- 0.5 for iodine,
- 0.2 for Sr and Cs,
- 0.05 for the remaining radionuclides [5]

Activation radionuclides, which can be registered in the environment, by the type of their formation can be divided into two groups:

Radionuclides formed in the designs of a reactor installation (shells of fuel elements, screens, reactor vessels and primary pipelines, regulatory authorities). The most significant of these are gamma-emitting radionuclides.

The second group of activation radionuclides includes radionuclides formed in sea water during the operation of a reactor installation.

2. Materials and Methods

One of the most important tasks of radiation monitoring of an object with a nuclear power plant is a reliable confirmation of its subcriticality.

If the reactor is not transferred to a subcritical state, then the fission process continues in it and the neutrons and the associated high-energy capture gamma radiation are emitted. Moreover, the energy of capture gamma radiation for structural materials of the object is more than 3 MeV (for example, for iron this energy is 7.6 MeV), which exceeds the energy of gamma radiation of both natural radioactive elements contained in the environment and the energy of gamma radiation of the main fission products formed in the reactor installation. Thus, by monitoring the level of radiation in the energy region of more than 3 MeV, it is possible to reliably detect the fission chain reaction continuing in the reactor. In this case, measurements must be carried out using a spectrometric device, having a high sensitivity to gamma radiation in the hard range. Such devices are gamma-ray spectrometers with large-sized scintillation crystals [2].

In the case of sea emergency, the following main routes of radioactive pollution of the environment are possible:

- release of radioactive substances into the atmosphere;
- radioactive discharge substances in surface water.
- Decision making based on monitoring results should be conducted with the use of unified software tools that provide:
  - analysis of the reliability and completeness of the information received;
  - assessment and forecast of the radiological situation;
  - analysis of the effectiveness of possible countermeasures in order to prevent negative trends and improve the radiation and environmental situation.

Although, at first glance, for the purpose of accurate detection and measurement of the radiation field, the advantage of helicopter-type devices is visible, their small radius of action and time spent in the air should be taken into account, which may be decisive when conducting accident surveys on ships and ships of the nuclear fleet away from the coast.

In general, an unmanned aerial vehicle is an aircraft without a crew on board. Excluding unmanned airships and cepelines from consideration, we mean an aircraft without a crew on board, using the
aerodynamic principle of creating lift using a fixed or rotating wing, equipped with an engine that can carry a payload sufficient to perform special tasks [9].

3. Results
For remote monitoring purposes, it is possible to use small unmanned aerial vehicles equipped with a spectrometric or dosimetric sensor.

Unmanned aerial vehicles, depending on their mass, time, range and altitude, can be divided into the following classes:

- ultra-small - weighing up to 10 kg, a flight time of about 1 hour and a height up to 1 km;
- small - weighing up to 50 kg, a flight time of several hours and a height of 3-5 km;
- medium - up to 1,000 kg, with a time of 10-12 hours and a height of 9-10 km;
- heavy - with flight altitudes of up to 20 km and a flight time of 24 hours or more.

In addition, an important characteristic of an unmanned aerial vehicle is the method of controlling the device. In general, the following control methods for an unmanned aerial vehicle can be implemented:

- manual operator control (or remote piloting) from the remote control within the limits of optical observability or according to the specific information received from the front-view video camera. With this control, the operator first of all solves the problem of piloting: maintaining the desired course, altitude, etc.;
- automatic control provides the possibility of a completely autonomous flight of an unmanned aerial vehicle along a given trajectory at a given height with a given speed and with stabilization of orientation angles. Automatic control is carried out using on-board software devices;
- semi-automatic control (or remote control) - the flight is carried out automatically without human intervention using the autopilot according to the initially set parameters, but the operator can make changes to the route interactively. Thus, the operator has the ability to influence the result of functioning, without being distracted by the tasks of piloting.

Manual control may be one of the modes for an unmanned aerial vehicle, and may be the only way to control an unmanned aerial vehicle, devoid of any means of automatic flight control.

The last two methods are currently the most demanded by the operators of unmanned systems, since they impose the least requirements on personnel training and ensure the safe and efficient operation of unmanned aerial vehicle systems [8].

One of the most important problems that arise when conducting surveys using a remote radiation monitoring device using spectrometers is the calibration of spectrometers, determining the sensitivity of a detector to a given radionuclide in a certain energy range for a real measurement geometry. Such calibration is a necessary condition for the correct interpretation of the obtained instrument spectors, the identification of radionuclides, and the determination of the absolute values of their activity.

Determining the sensitivity of a detector usually requires the preparation and conduct of special experiments that simulate radiation sources and a specific measurement geometry. The sizes of such sources, as a rule, are large and differ in considerable diversity that is why their production and certification are associated with significant difficulties.

When using the spectrometer for its intended purpose, it is especially important to determine with a given degree of certainty the fact that the measured value of the concentration of radionuclides exceeds the background level. In this case, as the main metrological characteristic of the spectrometer, the detection limit should be used, which represents such radionuclide activity that within a given time will give an increase in the device readings by an amount three times higher than the standard deviation of the background readings made during the same time [7].
The general tasks for obtaining the spectral characteristics of gamma radiation should be the following tasks:

- detection of radioactive anomalies in the air caused by the presence of both technogenic and natural radionuclides when the background (predetermined) threshold value is exceeded;
- determination of the radionuclide composition of the identified radioactive anomaly;
- determination of gamma radiation levels near emergency objects.

Such set of tasks, in turn, presents certain requirements for equipment and a software-algorithmic complex:

- operational registration of radiation levels when performing both operational and long-term monitoring;
- continuous monitoring of the background level of radioactivity;
- visual representation of the recorded data on the operator panel and their interpretation;
- technical diagnosis [8].

Such remote radiation monitoring devices placed on unmanned aerial vehicles can be used during scheduled or one-time work associated with the risk of increased exposure to personnel, as well as during actions in a radiation accident in places where it is not provided (and / or disabled when accidents) stationary system of automated radiation monitoring. (figure 1) (table 1)

Table 1. The main characteristics of the developed and manufactured Russian UAVs

| Name                  | Manufacturer         | Payload, kg / equipment | Flight duration, h | Take-off weight, kg | Range, km | Speed / cruising speed, km/h | Max practical height, m | Length / Height, m | Wingspan, m | Operating temperature range, °C |
|-----------------------|----------------------|-------------------------|--------------------|---------------------|-----------|-----------------------------|------------------------|-------------------|------------|---------------------------------|
| Super cam 100         | "Unmanned Systems "  | camcorder, camera, thermal imager | 2                  | 2.50                | 1000      | 125                         | 3600                   | 0.47              | 1          | -30...+30                        |
| Super cam 350         | "Unmanned Systems "  | camcorder, camera, thermal imager | 4                  | 9.50                | 70        | 120                         | 3600                   | 0.67              | 3.5        | -30...+30                        |
| Photo bot             | "Unmanned Systems "  | camera                   | 4                  | 4.50                | 360       | 120                         | 3600                   | -                 | -          | -30...+30                        |
| Zala 421-04M or Zala 421-12 | ZALA AERO GROUP/Pr. Izhevsk | gyrostabilized video camera (CVK 2), thermal imager on a gyro-stabilized platform (IK-2) digital color camera (installed regularly)< 1 kg | 1.5                 | 4.20                | 25.00     | 130                         | 3600                   | 0.62/0 .25       | 1.6        | -                                |
| ZALA 421-21 helicopter | ZALA AERO Group/Pr. Izhevsk | Light camera           | 0.5                 | 1.50                | 2.00      | 40.00                       | 2 500                   | -                 | -          | -                               |
| ZALA 421-              | ZALA AERO             | Television and photo camera | 1.3                 | 2.50                | 10.00     | 120.00                      | 4 000                   | 0.44/0 .82       | 0.82       | -                                |
| Name       | Manufacturer | Payload, kg / equipment | Flight duration, h | Take-off weight, kg | Range, km | Speed / cruising speed, km/h | Max practical height m | Length / Height, m | Wingspan, m | Operating temperature range, °C |
|------------|--------------|-------------------------|-------------------|-------------------|-----------|-----------------------------|----------------------|----------------|------------|---------------------------------|
| 1 08       | ZALA GROUPPr. Izhevsk | 3                       | 4                 | 2                 | 12.00     | 25.00                       | 50.00                | 2 000          | 57º0.67   | 0.4*1.177                     |
| ZALA 421-06 helicopter | ZALA AERO GROUPPr. Izhevsk | 3.5                    | 2                 | 18.00             | 50.00     | 200.00                      | 3 600                | -              | -         | -                                |
| Zala 421-16 | Aerocon Zhukovsky   | Fixed tv camera         | 0.6               | 0.25              | 44.00     | 72.00                       | 500                  | -              | 0.3       | -30...+50                       |
| Inspector - 101 | Aerocon Zhukovsky   | A front-view or planned-view TV camera with roll stabilization (at least 520 TV lines) or digital camera (10 megapixels); IR camera (optional).0.15 kg | 1                  | 1.30              | 45.00     | 120.00                      | 4 000                | -              | 0.8       | -30º...+50                      |

Figure 1. Model of a device for remote radiation monitoring.

4. Discussion
Finally, it is necessary to state that remote radiation monitoring devices based on unmanned aerial vehicles pose great importance for monitoring process. These devices can be used in the following areas:

- operational radiation monitoring in case of possible emergency situations with offshore facilities incorporating nuclear power plants and radioactive substances;
- radiation monitoring in the areas of basing and servicing ships and vessels with nuclear power plants;
- radiation inspection of sunken ships with nuclear power plants and assessment of their impact on the surrounding marine environment;
• support for the decommissioning of various radiation hazardous facilities, including the lifting of flooded nuclear submarines;
• control of radioactive pollution of the marine environment from coastal facilities of the nuclear industry;
• comprehensive engineering radiation survey of the water areas of the coastal technical bases of the fleet and subsequent constant monitoring of the radiation situation in these water areas;
• control of radioactive contamination of water areas caused by the disposal of radioactive waste in the marine environment;
• radiation and environmental assessments of the environmental impact of projects for the disposal of radioactive waste and rehabilitation of territories and water areas, including the results of comprehensive engineering radiation surveys.

A device for remote radiation monitoring for placement on an unmanned aerial vehicle should include equipment for radiation measurements, a module for transportation, storage, pre-flight preparation, launch, reception and transmission of measurement data [19-25].

Remote radiation monitoring device is a necessary tool in the environmental monitoring system in the areas of operation of nuclear power plants, in the areas of operation of ships with nuclear power plants, ships of atomic-technological services, carrying out the transportation of nuclear materials and radioactive substances.

5. Conclusion
Thus, the device for remote radiation monitoring has a clear advantage over other systems in situations where operational identification of radiation anomalies and their interpretation as point or area sources with known radionuclide composition. The reduction in the overall response time is because it does not require the deployment of the support tools that are necessary when applying contact control methods, allows you to identify an emergency and conduct remote spectral analysis. It makes possible to obtain an image, spectral characteristics of gamma radiation and evaluating the characteristics of the radiation background over a given area in real time in a wide range of gamma radiation dose rates with coordinate reference of measurement points. Also, it allows you to identify an emergency situation, conduct remote spectral analysis and makes it possible to obtain images, spectral characteristics of gamma radiation and assess the characteristics of radiation background over a given plot of terrain in real time in a wide range of gamma radiation dose rates with coordinate reference of measurement points, makes it possible to carry out continuous radiation monitoring of environmental objects and automatically signals when the measured values of the radiation parameters exceed the established threshold values, thereby allowing timely liquidate accidents at facilities and help to reduce the risk of further environmental pollution.

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