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Investigation of radiation formation (plasmoid) in the air environment by radar method

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Abstract. The expediency of using the radar method for detecting radiation contamination at long distances is substantiated in this article. The design of a radar for the detecting of small radioactive formations in the air at the long distances is developed. The dependence of the reflection coefficient of microwave radiation on the wavelength for determining the level of radioactive radiation is established. The investigation results of radioactive contamination in the atmosphere are presented.

1. Introduction

Nowadays in the atmosphere and on the Earth's surface constantly is happening of the radioactive contamination [1-6]. It is due to the development of nuclear power and the increase of the industrial enterprises number that the use of the technologies with the application of radioactive elements [7-9]. The most dangerous are radioactive emissions into the atmosphere [9-14]. Since them are able to move quickly over long distances, especially in strong winds. In this situation, there is a risk of the dropping them in the form of precipitation in areas where there are no special means of protection from radiation. It can lead to mass death of various living organisms [10, 11, 14-19].

The many different devices were developed for environment state control in the world [20-22]. All of them are effectively operating for the radioactive contamination determination near with the source. However, there are a number of difficulties while using these devices. It is associated with the radioactive contamination movement to a great height and long-distance traffic from the source (for example, the nozzle of a pipe, etc.) [21, 23, 24]. It is especially difficult in bad weather conditions. The measurement accuracy is reduced in these cases. Therefore, a number of methods for analyzing the environment radioactive state on based of the measurements results by this devices is not frequency applicable.

It is considered, that of the radar-based methods are the most universal for environmental monitoring. The all risks were associated with the equipment contamination and the personnel irradiation from radiation will be excluded by using these methods. In addition, measurements can be made at long-distance traffic, therefore it is safe [6, 9, 18, 25-27].

The improving of radar characteristics and the expanding of its functionality were required for operating radar for solving tasks of the atmosphere radioactive state control. Therefore, the process of upgrading various radar units, the development of new algorithms for processing information, methods for studying radioactive contamination in the atmosphere and determining the radiation level are the actual tasks now. In addition, the radar station should be multifunctional (solve other tasks besides atmosphere monitoring, for example, moving objects detection, etc.). One of the options for a comprehensive solution to the problem of radioactive contamination investigation in the atmosphere is presented.

2. Radar station and the method for monitoring the radioactive state of the atmosphere

The researchers conducted by various scientists have shown that the radioactive substances are released into the atmosphere afterwards ionization formations are formed in it [20-22]. These ionization formations are called plasmoids [21, 22]. A feature of the plasmoid is the difference in its refractive index and density from other atmosphere air formations [18, 20-24]. Therefore, the plasmoid is able to reflect the incident microwave radiation. The research conducted by the radar method showed that the reflection coefficient of microwave radiation from the plasmoid R depends on the wavelength of incident radiation λ, the value of the exposure dose Pexp, and the spectral composition of the cloud (the presence of radionuclide isotopes, for example, 133Xe, 135Xe, 88Kr, etc. and their concentration). The ionization formation is transformed in a strong wind (it stretches, splits into small parts, etc.). It creates a problem for its research. It is necessary to increase the power of microwave radiation and change the wavelength λ in a wide range (more than an order of magnitude).

We have developed the following radar design with the its main nodes modernization to implement the study of ionization formations in such conditions. The block diagram of the multifunctional radar system developed by us is shown in Figure 1.

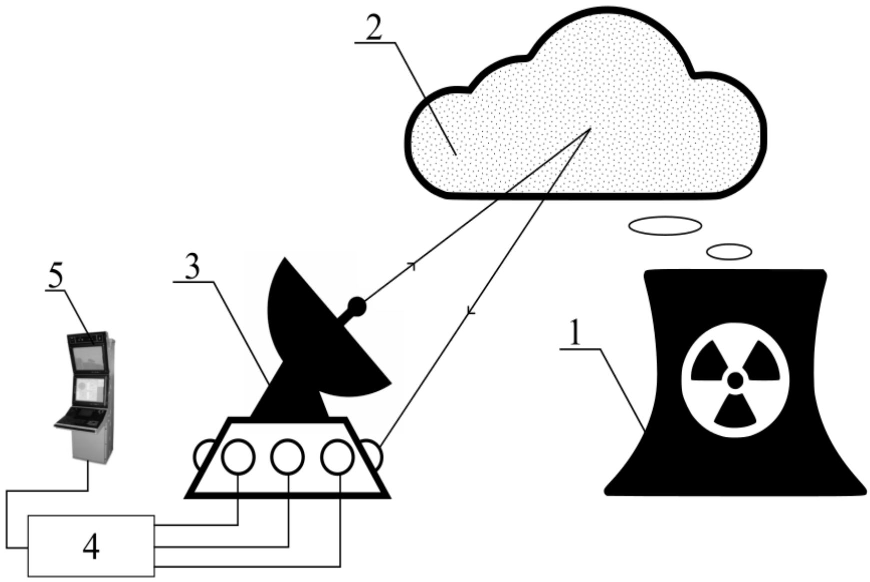

Figure 1. Block diagram of the radar for detecting and investigating radioactive contamination in the atmosphere: 1 – a source of radioactive emissions; 2 – a cloud of ionized particles (plasmoid); 3 – an antenna complex developed by us; 4 – a receiving path with a FOCL developed by us; 5 – device for detecting and processing signals (control case).

The separation of the receiving and transmitting antennas is one of the solutions for radar station modernization. The radiating antenna is a parabolic antenna with a wide directional pattern. The transmitting antenna is mounted on a fixed support that rotates freely in the range of 360 degrees. The scanning angle of the vertical plane is from 10 to 90 degrees. The antenna complex for the radar developed by us is shown in Figure 2.

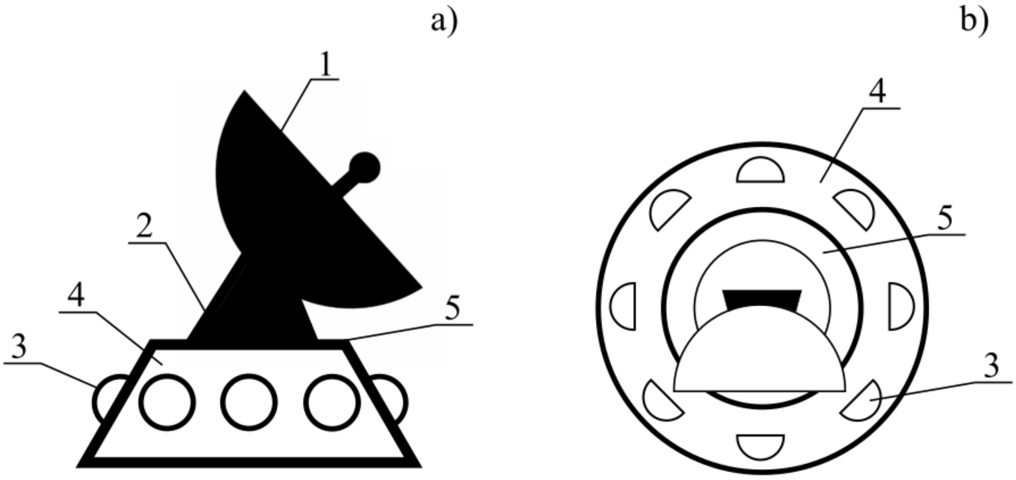

Figure 2. Structural diagram of the radar antenna complex (a – side view, b – top view): 1 – parabolic antenna; 2 – system for scanning the parabolic antenna in the vertical plane, 3 – spiral receiving antennas; 4 – fixed support for mounting spiral antennas; 5 – movable part of the support for rotating the parabolic antenna 360 degrees

In some cases, the radar station may be located on a mobile object. Its receiving paths will be located in areas with high-power interference of various kinds [9, 12, 24-27]. In addition, the spiral antennas receive a low-power reflected signal. Therefore, we use fiber-optic communication lines based on previously made developments of the fiber-optic communication system to exclude the influence of interference on the received signal reflected from the plasmoid in the receiving path of the radar [24, 27, 28].

The main measured value in the study is the reflection coefficient from the plasmoid R, which is determined as follows:

$$R = \frac{P_{ref}}{P_{rad}} \quad (1)$$

where P_{ref} – the amplitude of the reflected signal, P_{rad} – the amplitude of the radiated signal.

Our research and various scientists have shown that the dependence of the reflection coefficient R on the degree of plasmoid ionization (the presence of radionuclides various isotopes and their concentration), taking into account the random distribution of charges in it, can be represented by the following ratio:

$$R \approx 0.2V\Delta\varepsilon^2/\sqrt[3]{L_0^2\lambda} \quad (2)$$

where V – the value of plasmoid, $\Delta\varepsilon^2$ – the average square of the permittivity.

A cylinder can approximate the plasmoid formula. It is due to the fact that the main radioactive emissions into the atmosphere fall from pipes. The form of plasmoid is a torch. The main part (more than 90 %) of the radioactive ions are located in the torch central part, which is close to the cylinder in geometry. Therefore, the volume can be calculated by following formula: $V = \pi r^2 L$ (r – the cylinder radius, L – the cylinder height). In this case, the reduced length can be calculated be following formula

L_0 = 0.2 L [29]. The value of $\Delta\varepsilon^2$ can be estimated taking into account the presence of various ions in the plasmoid, using the following ratio:

$$\Delta\varepsilon^2 = \sqrt{\sum_i \left(\Delta\varepsilon_i^2\right)^2} \quad (3)$$

The value $\Delta\varepsilon_i^2$ can be estimated for ions corresponding to a certain isotope, using the following ratio:

$$\Delta\varepsilon_i^2 = \left[\frac{\lambda N_i q_i^2}{\pi c^2 M_i}\right]^2 \quad (4)$$

where N_i – the concentration of ions, q_i – charge of ion, M_i – mass of ion.

Using the ratios (2), (3) and (4) allows in some cases to define the concentration and type of ion (isotope) take into account the experimental measured dependencies R (ratio (1)) for different values of λ. Then the level of radiation in the plasmoid can be determined by using calibration tables.

3. Results of experimental investigations and discussion

Figure 3 shows, for example, the dependences of the change in the values R from the exposure dose P_{exp} of plasmoid, which is educated the ions from the ^{16}N isotope at the polygon for different values of the wavelength λ of the microwave radar signal. These isotopes most often are released in the atmosphere with oxygen during the emissions.

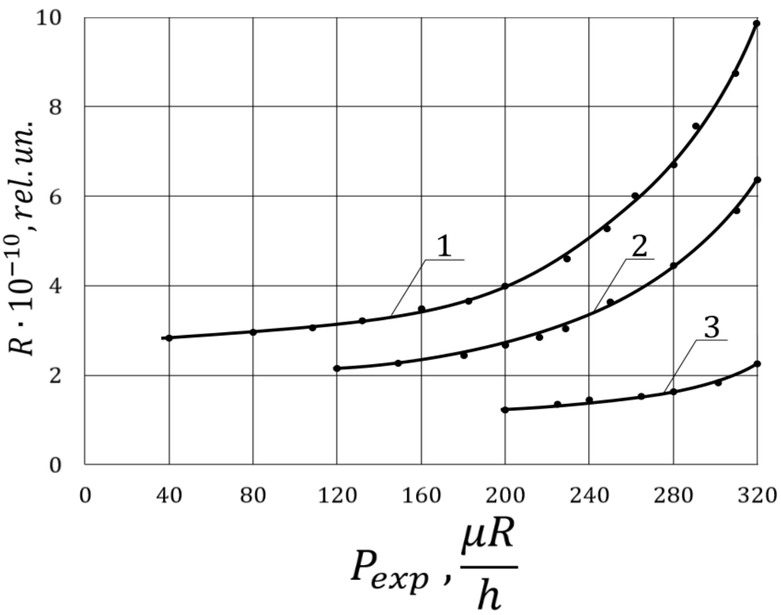

Figure 3. The dependence of the reflection coefficient R from the power of the exposure dose P_{exp} for different wavelengths λ of microwave radiation. Graphs 1, 2 and 3 correspond to the values of the radiation wavelength λ in cm: 8; 5; 2.

These dependences are further necessary for compiling calibration tables. The obtained results (see figure 3) are coincide with the results in [20-23], that shows the reliability of the developed radar.

Figure 4 shows, for example, the dependence of the reflection coefficient R of microwave radiation for the plasmoid (formed from ^{16}N isotope ions) from the wavelength λ.

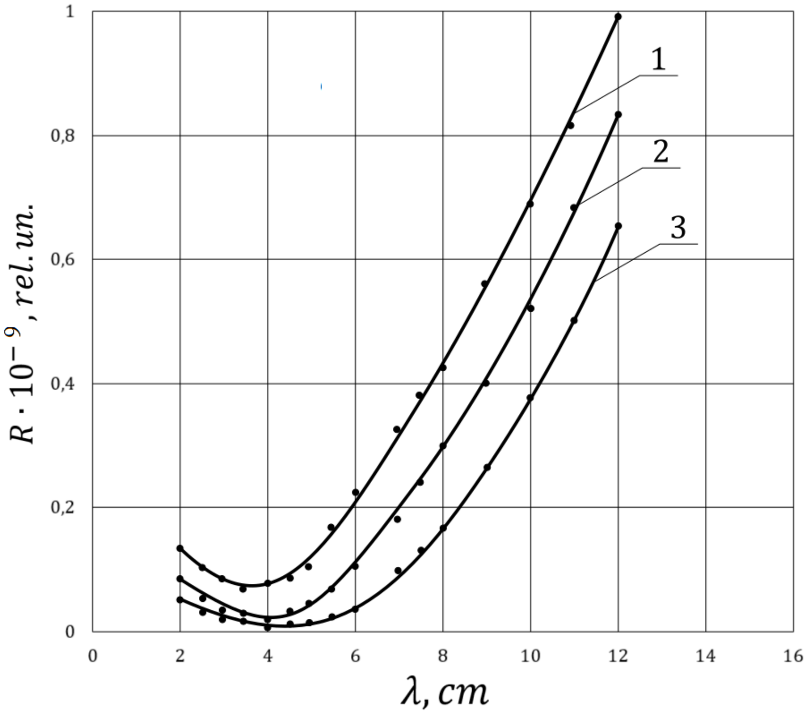

Figure 4. The dependence of the reflection coefficient R from wavelength λ. Graphs 1, 2 и 3 correspond to the values of ^{16}N isotope ions concentration N_i in cm^{-3}: 10^{10}; 10^{9}; 10^{8}.

The analysis of the obtained dependences showed that the ions concentration N_i has a significant influence on the minimum point position (the value of λ, from which the continuous increase in the reflection coefficient of microwave radiation by the plasmoid begins). In addition, the value λ is different for each type of ion. Therefore, it is necessary to develop a parabolic antenna with a wavelength adjustment step of 0.1 cm or less for realization of the more detailed investigations of these dependencies in the minimum vicinity. It will significantly expand the research possibilities of the plasmoids physical properties with using of the radar.

4. Conclusion

The obtained results are showed, that the any possibilities of radar method for radioactive contamination investigation in the atmosphere are not fully studied.

The results of experimental researchers of plasmoids were formed by ^{16}N ions allowed us to establish a minimum error of 10 % of the method developed by us during of the exposure dose determining. This result (with accuracy 10 %) meets the requirements of services which are responsible for environmental monitoring and radiation safety.

Of particular interest for research is the determination of the presence of ^{131}I ions in the plasmoid. It is the most dangerous isotope in the operation of nuclear reactors [15, 30]. Its presence characterizes of poisoning zone at the nuclear electrical station. It will be a continuation of our work.

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