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Monitoring of radioactive contamination in the atmosphere using radar systems

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Abstract. The necessity of monitoring the state of the environment is justified. Various methods of environmental monitoring were analyzed. The radar method for monitoring radioactive contamination in the atmosphere was considered in detail. The monitoring data using radar stations were processed and analyzed. The efficiency of this method was estimated. Recommendations were proposed to expand the monitoring capabilities using radars to assess the environmental situation.

Keywords: radar systems, radar station, radioactive contamination, environmental monitoring, plasmoid, atmosphere, microwave radiation

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Мониторинг радиоактивных загрязнений в атмосфере с использованием радиолокационных систем

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Аннотация. Обоснована необходимость контроля за состоянием окружающей среды. Проанализированы различные методы экологического мониторинга. Подробно рассмотрен радиолокационный метод для мониторинга радиоактивных загрязнений в атмосфере. Обработаны и проанализированы данные мониторинга с использованием радиолокационных станций. Оценена эффективность данного метода. Предложены рекомендации для расширения возможностей мониторинга с использованием радиолокационных станций для оценки экологической ситуации.

Ключевые слова: радиолокационные системы, радиолокационная станция, радиоактивное загрязнение, мониторинг окружающей среды, плазмоид, атмосфера, СВЧ излучение

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Introduction

The deterioration of ecology and emergence of different negative factors for various reasons led to a decrease in the quality of the air environment [1–4], that affects the person health [5–8]. For various reasons, pollution is formed in the air environment, which must be determined by various methods [9–16]. Due to the constant increase in the number of industrial enterprises, the study of radiation formations in the air is extremely important for humans, especially in high-risk areas, such as places located in close proximity to radiation-hazardous objects. The amount of radioactive substances released into the atmosphere is also increasing every year [17–23]. These dangerous substances get into the air masses and can be transported over vast distances, and thus get to the ground and to water bodies in the form of precipitation. This is confirmed by various studies [18–27].

Many methods have been developed to control the radiation situation and respond to emergencies in a timely manner [2, 5, 7, 9, 11–14, 21, 23, 24, 26, 28]. Over time, most of them have become obsolete, and the remaining ones have a number of disadvantages [17-20, 28–31]. Among the various methods, the radar method is the most optimal, since it is remote, which is important when working with radioactive particles. It should be noted that the radar method of studying the state of the environment is a direct measurement of the degree of ionization of air masses containing radioactive elements (pollution level). This is extremely important, especially when taking measurements in difficult conditions.

Materials and Methods

The principle of the radar method of finding radioactive particles consists of several points. First, radioactive substances are released into the atmosphere. Next, a plasmoid is formed in the atmosphere, which can change locations with the help of air masses. This plasmoid can be detected using a radar station that is located at a fairly safe distance from the object under study. Radiation directed at the plasmoid is reflected from it and then enters the receiving path of the radar station. Due to the fact that the reflected signal has a small power, the signal is amplified in the receiving path and transmitted to the control panel using fiber-optic communication lines. Fig. 1 presents a block diagram of the operation of the radar station.

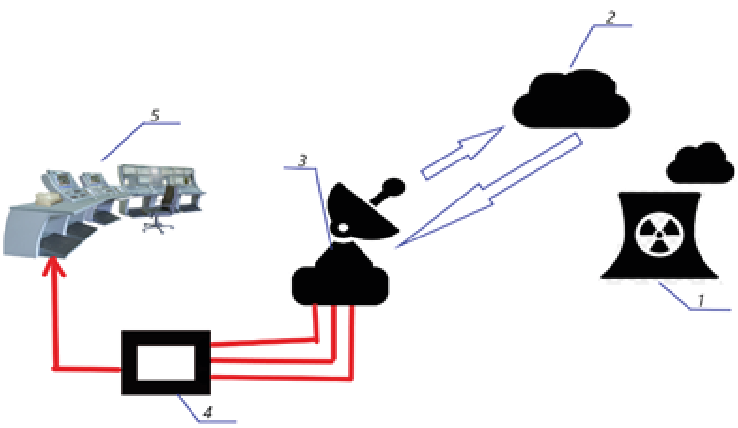

Fig. 1. Structural diagram of the radar operation: radiation-hazardous object *1*, plasmoid *2*, radar antenna complex *3*, radar receiving path *4*, remote control *5*

An important feature of the plasmoid is that the refractive index of ionization formations and the density are quite different from the parameters of air formations in the atmosphere. This fact indicates the ability of the plasmoid to reflect the microwave radiation that hits it from the radar station. The reflection coefficient R depends on the degree of ionization of the plasmoid. Taking into account the fact that the distribution of charges in the ionization formation is random, it is possible to represent the reflection coefficient R from the plasmoid in the form of formula (1):

$$R \approx \frac{0.2V\Delta\varepsilon^2}{\sqrt[3]{L_0^2\lambda}}, \tag{1}$$

where V is the plasmoid volume, $\Delta\varepsilon^2$ is the average square of the dielectric constant of the ionization formation, L_0 is the reduced plasmoid length, λ is the wavelength of microwave radiation.

The layered structure of the ionization formation can be described by changing the value of the permittivity of the atmosphere in the plasmoid, which was formed as a result of the release of radioactive elements. In this case, the permittivity of the medium ε can be estimated using the formula (2):

$$\varepsilon = 1 - \frac{4\pi N_e e^2}{m_e\left(\omega^2+\nu^2\right)} - \frac{4\pi N_+ e^2}{M_+\left(\omega^2+\nu^2\right)} - \frac{4\pi N_- e^2}{M_-\left(\omega^2+\nu^2\right)}, \tag{2}$$

where N_e is the electron concentration, N_+ is the concentration of positive ions, N_- is the concentration of negative ions, ν is the frequency of collisions, ω is the radiation frequency, $M_+ = M_-$ is the mass of ions, m_e is the electron mass.

A layer-by-layer change in the permittivity value of the atmosphere leads to a corresponding change in the electric field strength and conductivity in comparison with the airspace, which does not contain contamination by radioactive particles.

In order to determine the parameters of the plasmoid, it is necessary to describe its shape. Thus, a mathematical model is compiled. Often radioactive contamination enters the atmosphere with the help of pipes that have the shape of a cylinder. Therefore, the volume of the plasmoid is found using the formula (3) of the volume of the cylinder.

$$V = \pi r^2 L, \tag{3}$$

where r is cylinder radius; L is the height of the cylinder.

The radar method provides advantages in the ability to detect ionization formations in almost any weather conditions. The detection distance is quite large. In comparison with other methods for detecting radioactive substances in the atmosphere, the radar method has proven itself as a method with only one significant drawback. In the presence of a strong wind, it is difficult to detect and study the plasmoid, since the plasmoid is prone to rapid dispersion. It breaks down into smaller particles that are difficult to detect.

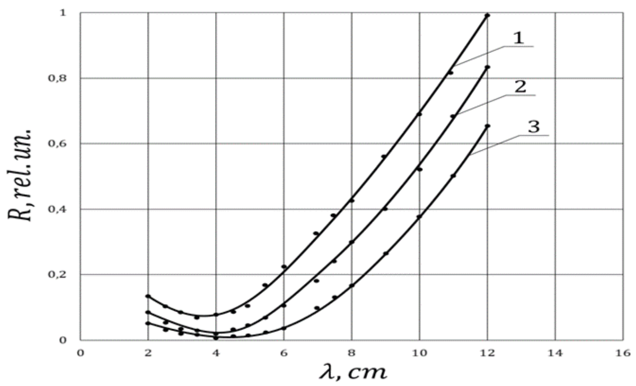

Fig. 2. Dependence of the reflection coefficient R on the wavelength of radiation λ at different levels of concentration of ions of the isotope ^{16}N in the atmosphere

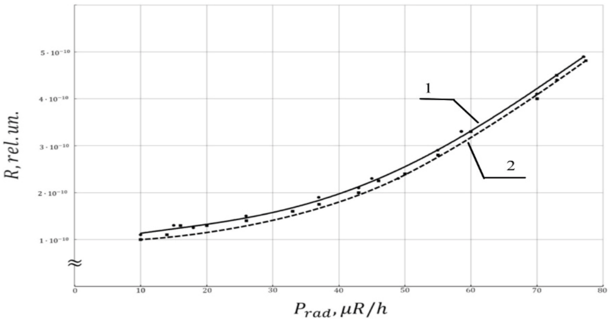

Fig. 3. Dependence of the reflection coefficient R on the power of the exposure dose of radiation for different wavelengths λ of microwave radiation

Graphs 1 and 2 correspond to the values of 8 cm and 5 cm of the radiation wavelength λ

Results and Discussion

The main objective of the study of a cloud of radioactive particles is to estimate the dependence of the reflection coefficient R of the electromagnetic wave on ionization formations on the wavelength of radiation λ. During the study of ionization formations formed from ions of the nitrogen isotope ^{16}N, the following dependences R(λ), shown in Fig. 2, were obtained at different concentration levels.

The analysis of the dependencies shows that different levels of nitrogen ion concentration in the plasmoid correspond to their own schedule. The higher the concentration of ions, the higher the reflectivity of the ionization formation, with increasing concentration, the dependence $R(\lambda)$ is located higher. In addition, it can be noted that all dependencies have a characteristic shape, an important feature is the presence of a minimum reflection coefficient at a certain value of λ. Starting from this value, there is a continuous increase in the reflection coefficient with an increase in the wavelength of the microwave radiation λ.

Moreover, it can be established that the minimum reflection coefficient R is achieved at different λ for each type of isotope ions of radioactive elements. Thus, after conducting an additional study of various plasmoids formed as a result of the release of pollutants in the presence of radioactive particles, it will be possible to determine which isotope ion formed the plasmoid and what its concentration is.

Another dependence was also revealed, which was obtained experimentally — this is the dependence of the reflection coefficient R from the plasmoid on the irradiation power of the P_{rad}, which is shown in Fig. 3.

A change in the value of the wavelength λ makes it possible to estimate the exposure dose in various areas of the plasmoid with an error of about 10%.

Conclusion

The use of the proposed methodology during environmental monitoring makes it possible to more effectively detect ionization formations resulting from the release of radioactive elements into the atmosphere. This is especially true on mobile objects, where the radar complex, in addition to monitoring the state of the atmosphere, will monitor the air situation. In the future, it is possible to develop a complex that will not only detect ionization formations, but also determine their composition.

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