

Multifunctional method for remote monitoring of the environment in the area of nuclear facilities

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Abstract. In a paper the method for remote monitoring of the radiation characteristics of the environment in the area of the nuclear power plant is considered. To solve this problem, the need to use remote methods of environmental monitoring is justified. A method is proposed for determining radioactive formations in the atmosphere using a radar station. Using the methodology for determining radioactive formations in the atmosphere by changing the reflection coefficient of an electromagnetic wave from a given formation is justified. Calculation of changes in the reflection coefficient of an electromagnetic wave from a radioactive formation in the atmosphere for different climatic conditions is calculated. The results of studies of radioactive contamination in the atmosphere are presented. The advantages of the method developed by us in comparison with others are noted. The directions of scientific research to expand the functionality of the method developed by us are determined.

1 Introduction

The world experience shows that more and more electric energy is required for the sustainable development of society in various directions every year. Especially it is required in industry, services and personal life [1-7]. It happens against the background of a decrease in stocks of various types of fuel and environmental degradation [7-13]. One of the solutions to this complex problem (increasing the volume of generated electric energy with minimal environmental impact) is the development of nuclear energy [14-21].

The nuclear power plant (NPP) is a source of increased radiation hazard during operation. Special attention is paid to monitoring the radiation situation on the territory of the NPP, so in the area of its location, including the atmosphere [6, 9, 22-27]. Various methods are used to detect radioactive substances and emissions into the atmosphere. Remote methods are considered the most promising and safe. It is especially advisable to use them to determine the pollution of the surface layer of the atmosphere by potentially dangerous objects, including radioactive ones. The

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radar method has several advantages over gamma-ray telescropy, thermal imaging, spectroscopy using laser radiation of various ranges, etc. [26-33]. The radar method surpasses these methods in detection range, sensitivity, data processing time and spatial resolution [24-43].

The most radar methods are based on measuring the secondary effects of radioactivity, that is reduces the effectiveness of monitoring the state of the environment, especially at long ranges, under bad weather conditions significantly. Therefore, the development of new and improvement of the used radar methods operating in a wide range of weather conditions is an extremely urgent task. One such solution may be proposed by us the radar method for remote monitoring of the environment with direct measurement of the degree of ionization of the air volume irradiated by a radioactive release.

2 Methods

The previous experiments of earlier [26, 34-40, 44-46] are showed that in the event of atmospheric contamination with

a radioactive impurity in it due to ionization of the air, ionization formations appear - plasmoids. The transverse dimensions of these formations depend on the area of contamination (general case). The shape of the plasmoid is transformed in the presence of wind. Numerous experiments have made it possible to establish that the sizes of plasmoids can vary from several tens of meters to thousands of meters in the transverse direction to radioactive release and up to several hundred meters in height. A feature of these formations is their resistance to various external influences (humidity, wind, etc.).

The Ionization formations (plasmoid) need to be considered ion-ion rather than electron-ion formations. It can be explained that the oxygen in the atmosphere is 10^{13} times greater than the positive ions at a radiation dose rate of 1 R/h. Capture of ions of water molecules by radioactive ions will lead to ion-drop formations. These formations will have different concentrations depending on the height H . Figure 1 shows the concentration of positively charged water droplets depending on the height H .

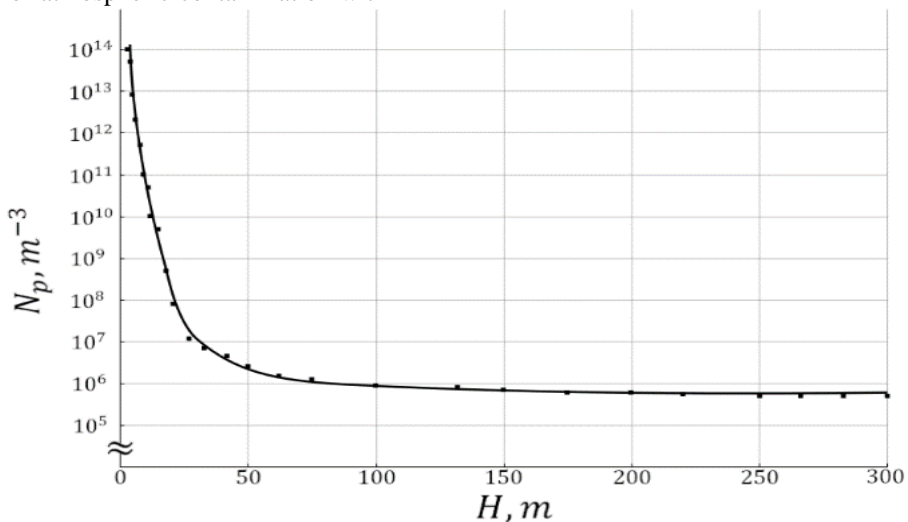


Fig. 1. Dependence of change of concentration N_p of positively charged water drops on the height H above the Earth 's surface.

Analysis of the distribution of carriers shows that there is a rather shallow decline with an increase in height. This means that the plasmon formed by the radioactive contamination will have a layered structure. It will

provide good stability of the plasmon under various weather conditions.

It will change the permittivity value ϵ of the atmosphere in the region of radioactive contamination. The value of ϵ can be estimated by the following formula:

$$\epsilon = 1 - \frac{4\pi N_e e^2}{m_e(\omega^2 + \nu^2)} - \frac{4\pi N_+ e^2}{M_+(\omega^2 + \nu^2)} - \frac{4\pi N_- e^2}{M_-(\omega^2 + \nu^2)} \quad (1)$$

where ν – the impact frequency, ω – the electromagnetic wave frequency, $M_+ = M_- = M_i$ – the ion mass, m_e – the electron mass, N_e – electron concentration, N_+ – positive ion concentration, N_- – negative ion concentration.

will change the effective electric field (the intensity of the electric field changes) and conductivity compared to a part of the air without radioactive contamination.

Figure 2 shows the dependence the intensity of the natural electric field of the atmosphere on the level of radioactive contamination.

The change in the value of the air space in which the plasmons are formed

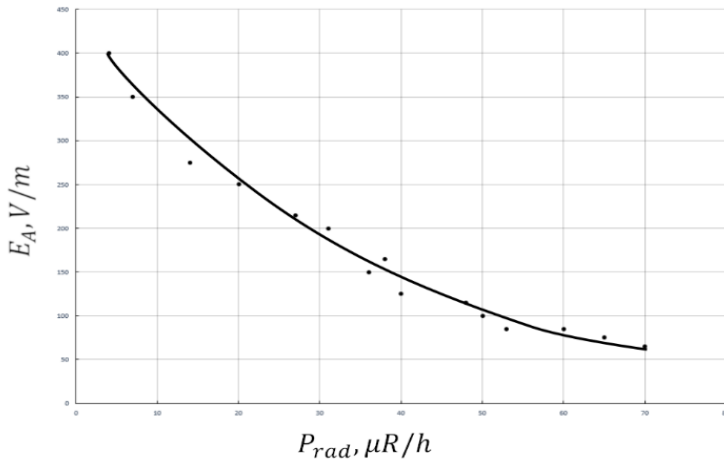


Fig. 2. Dependence of the change in the intensity E_A of the electric field of the atmosphere at the height of 100 m on the power P_{rad} of the exposure dose of irradiation.

The results show that it is necessary to solve the problem of estimating the reflection coefficient R of the electromagnetic wave from the plasmoid as a function of the wavelength of the radar radiation in order to measure the level of radioactive contamination of the atmosphere. This issue did not explore in detail earlier. The heterogeneity of the spatial distribution of positively charged

ions was not discussed in detail. Our research solves the problem associated with the determination of the dependence $R(\lambda)$. Figure 3 shows a structural diagram of the implementation of our remote method of detecting radioactive contamination.

The reflection coefficient R can be calculated by the following formula:

$$R = \frac{F_{\text{ref}}}{F_{\text{rad}}} \quad (2)$$

where F_{ref} – the amplitude of the reflected wave, F_{rad} – the amplitude of the emitted wave.

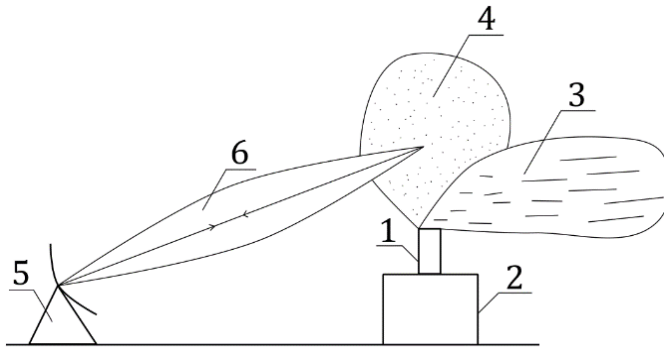


Fig. 3. Structural diagram of remote monitoring of the radiation state of the environment: 1 – nuclear power plant; 2 – ventilation stack; 3 – radiation emission flare; 4 – plasmoid; 5 – radar station; 6 – electromagnetic radiation (incident and reflected wave).

To estimate the value of R from the formed plasmoid, we will use the following assumption. Electromagnetic wave with wavelength λ is incident on interface, one of which is air, the other is ionized layer of air. The formula can be applied to describe the reflection coefficient R as a jump of the derivative at the air interface and the ionized layer whereas the edge of the radial ion distribution has a sharp character:

$$R = \frac{\lambda_0 e^2}{4M\omega^2} \left(\frac{dN_k^+}{dr} \right) \quad (3)$$

where N_k^+ is the concentration of charged droplets.

If the exposure dose rate from the contaminating surface is recorded as uniformly distributed with the surface density q_0 ($K = \pi q_0 K_r$) and calculated for (3) the radial derivative, the following formula can be obtained:

$$R = K^{1/4} \frac{\lambda_0 e^2}{8M\omega^2} \left(\frac{G}{k_r} \right)^{1/4} \left(2 \frac{k_c^p N_k^s + k_c^m N_k^g}{k_r} \right)^{1/2} \frac{1}{\varphi^{3/4}} \frac{d\varphi}{dr} \quad (4)$$

where the values of $\frac{d\varphi}{dr}$ и φ are calculated at the boundary of the radioactive contamination area.

It is possible to solve the system of equations obtained using (4) by measuring the reflection coefficient R at several wavelengths λ_0 . We can calculate the value K . It allows us to determine the value q_0 . This value contains information of air pollutants concentration.

3 Results

The dependence the reflection coefficient R on different wavelength values R was calculated for the test exposure dose in order to justify the use of the formula (4) for detecting radioactive contamination and determining the degree of its danger by the value of q_0 . The calculation results were compared with the experiment. Figure 4 shows as an example the dependence the reflection coefficient R on the wavelength λ for $P_{\text{rad}} = 34 \mu\text{R/h}$.

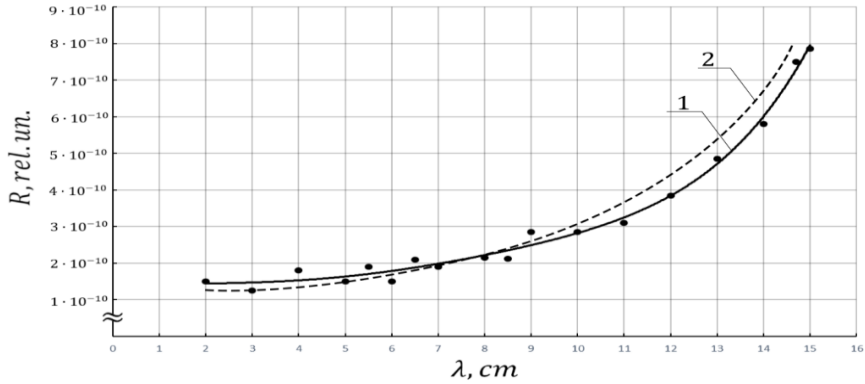


Fig. 4. The dependence the reflection coefficient R on the wavelength λ of microwave radiation. The line 1 is an experimental dependence. The line 2 is the results of R value calculation.

Analysis of the obtained dependencies shows that the nature of the change in the calculated and experimental dependence of the reflection coefficient R on the wavelength λ of microwave radiation coincides. The difference between numerical results and experimental results is explained by the fact that (4) does not take into account the heterogeneity of the spatial distribution of positive ions. This value is quite difficult to predict, so an average value was taken. The difference of results is

not more than 5 %, which allows to use (4) to determine the area of radioactive contamination and its degree of danger.

The change in R values from the power P_{rad} of the exposure dose for different wavelength values λ of the microwave radiation signal of the radar was investigated in order to confirm the validity of the use of the remote method of radiation monitoring of the atmosphere. Figure 5 shows one such dependence as an example.

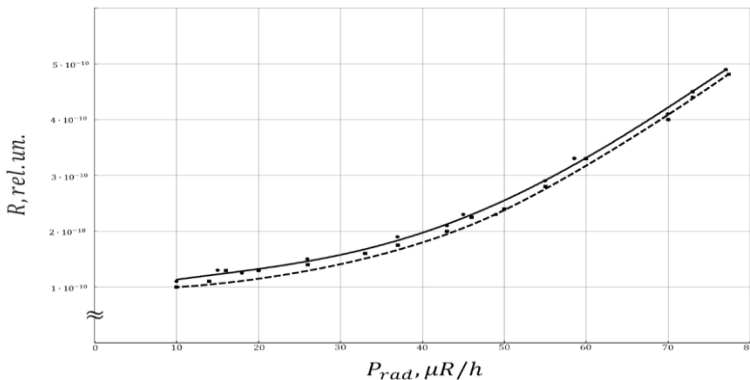


Fig. 5. The dependence the reflection coefficient R on the power P_{rad} of the exposure dose for different wavelengths of microwave radiation. Graphs 1 and 2 correspond to the value of λ : 8 cm and 5 cm.

The obtained results are the same as those obtained by various methods in other works [24, 34-40, 44-47]. This fact

confirms the feasibility of using the method proposed by us.

In addition, samples from experimental atmospheres were tested in

a mobile laboratory. For this, the nuclear magnetic spectrometers is designed for express control were used [48-51]. The obtained research results also coincided with the data obtained by our developed radar method.

4 Conclusion

The results showed that the reflection coefficient $R \sim P_{\text{dis}}$ (emission power) at low P_{rad} values. It allows to determine the cause of the release.

We have found that the reflection coefficient $R \sim P_{\text{dis}}^z$ in general, where the value of z varies from 0.22 to 0.55 taking into account the temperature and humidity conditions.

It is necessary to use radar with tunable λ from 1 to 10 cm, with a power of not less than 4 kW in a pulse in order to carry out a reliable study of the atmosphere, as well as the surface of the Earth, on which radioactive contamination may be present, near the NPP. In this case, plasmoid studies can be performed at distances greater than 300 km. These distances are not available for other remote environmental monitoring methods. This allows you to effectively monitor the state of the atmosphere and predict the possibility of rainfall over long distances. This is especially important when carrying out various long-term works (for example, construction and others) [52-55].

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