Remote environmental monitoring in the area of a nuclear power plant

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Abstract. The article considers a method for remote monitoring of the radiation characteristics of the environment and agricultural land in the area of the nuclear power plant in this paper. A method is proposed for determining radioactive formations in the atmosphere and at the surface of the earth using a radar station. The results of studies of radioactive contamination in the atmosphere and on agricultural lands are presented.

1 Introduction

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, manufacture and processing of agricultural products and personal life [1-9]. Analysis of the society development trend [1-5] and the state of the environment [10-15] shows that electric energy is frequently in large volumes in a small part of the territory. There are large cities, industrial enterprises, tourist areas or intensive agriculture in these places. These territories have often a difficult environmental situation. Therefore, the most appropriate is the search for solutions to the problems of increasing the production of electric energy using environmentally pure methods. It is advisable to use nuclear and solar energy to solve this problem given the large volumes of required power [16–25]. Other types of renewable energy sources cannot provide the necessary power. The exception is hydropower, but it requires large areas and water resources [26-29]. Great damage is done to agricultural territories (they are flooded) when implementing hydraulic engineering projects.

A comparative analysis of the possibilities of nuclear and solar energy showed that the first is universal. Solar energy requires areas with high solar activity and large areas. In addition, the power of the solar power plant and nuclear power does not make sense to compare [30-35]. Therefore, in most countries, for example, France, preference is given to nuclear energy [20, 21, 30, 32].

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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 [30, 32, 36-39]. 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 radar method has several advantages over gamma-ray telescope, thermal imaging, spectroscopy using laser radiation of various ranges, etc [32, 36-42]. The radar method surpasses these methods in detection range, sensitivity, data processing time and spatial resolution [36-44].

Most radar methods are based on measuring the secondary effects of radioactivity, that is reduces the effectiveness of monitoring the state of the environment and earth surface, 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.

The main purpose of this paper - to investigate Industrial symbiosis (IS) economic efficiency parameters in context of regional sustainable development.

2 The multifunctional radar control method

Previous experiments [32, 36-39] showed that in the event of atmospheric contamination with a radioactive impurity, ionization formations — plasmoids — arise in it due to ionization of the air. 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.).

In fig. 1 shows as an example the concentration of positively charged water droplets depending on the height H.

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 $\varepsilon$ of the atmosphere in the region of radioactive contamination. The value of $\varepsilon$ can be estimated by the following formula:

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

(1)

where $\nu$ – the impact frequency, $\omega$ – the electromagnetic wave frequency, $M_i = M_e$ == $M_i$ – the ion mass, $m_e$ – the electron mass, $N_e$ – electron concentration, $N_+$ – positive ion concentration, $N_-$ – negative ion concentration.

The change in the value of the air space in which the plasmoids are formed 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.
Fig. 1. Dependence change of concentration $N_p$ of positively charged water drops on the height $H$ above the earth surface.

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

![Graph of Fig. 1](image1)

**Fig. 1.** Dependence change of concentration $N_p$ of positively charged water drops on the height $H$ above the earth surface.

$$N_p, m^{-3}$$

$$H, m$$

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 $\lambda$ of the radar radiation in order to measure the level of radioactive contamination.
of the atmosphere. In fig. 3 shows a structural diagram of the implementation of our remote method of detecting radioactive contamination.

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).

The reflection coefficient \( R \) can be calculated in this case by the following formula:

\[
R = \frac{F_{\text{ref}}}{F_{\text{rad}}}
\]  

(2)

where \( F_{\text{ref}} \) – the amplitude of the reflected wave, \( F_{\text{rad}} \) – the amplitude of the emitted wave.

We will use the following assumption to estimate the value of \( R \) from the formed plasmoid. Electromagnetic wave with wavelength \( \lambda \) 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 \( R \) whereas the edge of the radial ion distribution has a sharp character:

\[
R = K^{1/4} \frac{\lambda e^2}{8\pi \omega^2} \left( \frac{\varphi}{k_r} \right)^{1/4} \left( 2 \frac{\kappa^2 N_k^2 + \kappa^2 N_{k^2}}{k_r} \right)^{1/2} \frac{1}{\varphi^{3/4}} \frac{d\varphi}{d\rho}
\]  

(3)

where the values of \( d\varphi/dr \) and \( \varphi \) are calculated at the boundary of the radioactive contamination area.

It is possible to solve the system of equations obtained using (3) by measuring the reflection coefficient \( R \) at several wavelengths \( \lambda_0 \). We can calculate the value \( K \). It allows us to determine the value \( q_0 \). This value contains information of air pollution concentration.

3 Results of experimental studies and discussion

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 (3) 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. In fig. 3 shows the dependence the reflection coefficient \( R \) on the wavelength \( \lambda \) for \( P_{\text{rad}} = 34 \mu\text{R/h} \) (it is a typical pollution level of agricultural land in the zone of nuclear power plants).
The dependence the reflection coefficient \( R \) on the wavelength \( \lambda \) of microwave radiation. The graph 1 is an experimental dependence. The graph 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 \( \lambda \) of microwave radiation coincides. The difference between numerical results and experimental results is explained by the fact that (3) 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 (3) to determine the area of radioactive contamination and its degree of danger.

In addition, samples from experimental soil samples were tested on nuclear magnetic spectrometers designed for express control [45–47] in a mobile laboratory. The obtained research results also coincided with the data obtained by our developed radar method.

4 Conclusions

The results obtained made it possible to establish that, at small the reflection coefficient \( R \approx P_{\text{dis}} \) (the emission power) values of \( P_{\text{rad}} \). It allows us to determine the reason for the outlier.

It is necessary to use radar with tunable \( \lambda \) from 1 to 10 cm, with a power of not less than 1 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. Plasmoid studies can be performed at distances greater than 300 km in this case. These distances are not available for other remote methods for monitoring the state of the environment and territories. It allows to effectively monitor the state of the atmosphere, to predict the possibility of precipitation, which is extremely important not only when the crop is ripe, but also when carrying out various works (for example, construction) [48-51].

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