TECHNIQUE FOR THE DETECTION OF RADIOACTIVE POLLUTION OF THE ENVIRONMENT BY AIR GLOW ANALYSIS

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This paper presents a technique for detection of radioactive environmental pollution by measuring air glow in the microwave region.

Recently information about observations of air glow in areas with radioactive environmental pollution appeared in literature. Analysis of these data shows that the connection between visible glow and meteorological situation takes place.

This paper discusses some peculiarities of the ionization of air due to radioactive irradiation. It is shown that radiation can exist not only in the visible range, but also in the microwave range. Possible channels of the interrelations between the air glow and meteorological conditions are also considered.

It is known[1–4] that in the boundary layer of the atmosphere exposed to ionizing action, for example, by electric breakdown, there can occur certain conditions providing for long afterglow of the atmosphere. These conditions are primarily connected with the water content in the atmosphere both in vapor and in aerosol or liquid-drop phases. Regardless of the type of ionizing action there are three stages of water transformation in the atmosphere providing stable and long afterglow of the air, namely,

– vaporization of water from liquid–drop phase,

– decomposition of water vapor molecules,

– occurrence of a number of physicochemical reactions[5], forming a long afterglow.

Although the role of the first stage at radioactive irradiation of the atmosphere is not important because of small energy contribution, one can assume that both the causes of air glow and the connections of the glow with meteorological conditions are determined by the course of the second and third stages.

Regarding the first stage of aggregative-physicochemical transformations of H_2O, the following comment is necessary. In the atmosphere the conditions of water vapor supersaturation often take place although for a short time. During the process of ionization this must result in reverse course of H_2O transformations at the first stage. In this connection one can expect some changes in the atmospheric glow during such periods (at summer nights).

It should be noted that as a result of the processes of excitation and ionization[6]

$$H_2O \quad \begin{matrix} H_2O^+ \text{ (a)}; \;\; H + OH^+ \text{ (b)}; \;\; H^- + OH \text{ (c)}; \\ H_2O^* \; H + OH \text{ (d)}; \; H_2 + O \text{ (e)}, \end{matrix} \qquad (1)$$

as well as due to the fast ion-molecular reactions

$$\begin{matrix} H_2O^+ + H_2O \rightarrow H_3O^+ + OH \;\; \text{(a)}; \\ OH^+ + H_2O \rightarrow H_3O^+ + O_2 \;\; \text{(b)}; \end{matrix} \qquad (2)$$

in combination with the process of dissociative neutralization of ion of oxonium

$$H_3O^+ + e \quad \begin{matrix} H^+ + H_2O \;\; \text{(a)}; \\ H_2 \; (2H) + OH \;\; \text{(b)}, \end{matrix} \qquad (3)$$

the formation of free hydrogen atoms via channels of reactions (1b), (1d), and (3a) as well as hydroxyl OH (reactions (1b), (1c), (1d), (2a), and (3b)) occurs. These components are active in the microwave range. Such phenomena are of interest in two aspects.

First, even at a weak level of radioactive background generation of radio waves can be observed, and they can be easily detected at a large distance from the source of radioactive pollution. Second, using an additional microwave irradiation of air exposed to ionizing radiation one can increase the efficiency of radioactive background and detect it.

In addition to the frequency of 1420 MHz the above problems may be solved for H also at frequencies of 1612, 1665, 1667, and 1721 MHz (see Ref. 7). These frequencies correspond to hyperfine transition (see Ref. 7) in molecule of OH radical, which occurs similar to hydrogen practically in all reactions of water decomposition, for example, (1b), (1c), (1d), (2a), and (3b).

It should be noted that, in contrast to the H_2O molecules, the other air components require for their decompositions, as a rule, larger energy.

Let us estimate the feasibility of detection of the above–mentioned microwave radiation in the case of practical realization of proposed microwave method. Intensity of radiation (of a spectral line) is determined by the probability of radiative transition A_{nk} and can be calculated by the formula[8]

$$S = \hbar\omega_{nk} A_{nk}, \qquad (4)$$

where $\hbar\omega_{nk} = E_n - E_k$ is the quantum energy.

According to Ref. 9 the energy of hyperfine splitting of stable levels of hydrogen atoms (the fundamental term is $^1H(^2S_{1/2})$, the electron term is $^2S_{1/2}$, quantum numbers of total momentum are F and $F'(1, 0)$) for $\Delta\nu(F, F') = 1420.\,405\,751\,7$ MHz is $\Delta E(F, F') = 47.3797 \cdot 10^{-3}\text{cm}^{-1} \simeq 10^{-24}$ J, the probability of transition A_{nk} is equal to $3 \cdot 10^{-15}\text{s}^{-1}$ (see Ref. 10). In this case the radiation intensity $S' = 10^{-24} \cdot 3 \cdot 10^{-15} = 3 \cdot 10^{-39}$W.

In the case when air humidity $\varphi = 100\%$, water molecules make about 3% of the total volume of mixture "air + H_2O", that correspons to 10^{18} H_2O molecules per 1 cm^3 if converted into concentration. Let us assume that only 10% of H_2O molecules are decomposed, this approximately corresponds to $2 \cdot 10^{17}$ atoms of hydrogen. It follows that exitance from 1 cm^3 is about $6 \cdot 10^{-22}$ W.

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Current experience of nuclear power stations operation evidences that the size of a cloud over the nuclear object is about 0.5 km^3 (d = 1000, h = 600 m), then it is easy to calculate that its radiant power is equal to $3 \cdot 10^{-7}$ W. Let us try to answer the question, whether is this radiation level sufficient for detection with modern instrumentation.

Sensitivity of modern detectors in decimeter and cantimeter wavelength range $P_{min} = 10^{-13}$–10^{-14} W (see Ref. 11). Comparison of such a sensitivity reached yet in 1967 year with the radiation level from the cloud allows me to argue that radiation of atomic hydrogen may be recorded with the modern radars. However, it is important to keep in mind two circumstances. First, strength of the electric field of electromagnetic wave reduces proportional to squared distance from the radiation source, i.e. measurements should be performed near the nuclear power object. Second, stationary nature of the background radiation and minimum level of noise (even with regard to atmosphere) corresponding to the frequency range of 10^3 to 10^4 MHz (Ref. 12) increases reliability of reception of signals at the frequency of 1420 MHz.

Radiation of hydroxyl OH can be detected similarly.

It is also known from radiophysics that propagation of microwave radiation in a medium with varying dielectric constant ε the radio waves reflection takes place. (This fact is used in radio–location.) The water vapor has large dielectric constant ε and therefore its decomposition is accompanied by a change of the dielectric constant ε of the medium. This can be an additional criterion in radio–location of environmental pollution. Use of laser radiation could not yield the same result in this case.

Thus, the air glow over the objects of nuclear power is not the prime cause of troubles in these objects but the result of these troubles and can be used as a good indicator of increasing radioactive background.

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