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DISTRIBUTION OF NEUTRONS IN THE EARTH ATMOSPHERE FROM PLANE RADIOACTIVE SOURCE

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The question of the spatial distribution of fast and thermal neutrons in the Earth's atmosphere is considered. The fields of fast neutrons from a flat radioactive source with a source energy not exceeding 1 MeV are correctly described by the age theory. The effect of atmospheric in homogeneity affects the height of the source, exceeding 20-25 km. The flux density of slow neutrons falls almost to zero at a distance of about two parameters of the atmospheric in homogeneity.

Keywords: neutron flux, Earth's atmosphere, heterogeneity, quasi-diffusion.

1. From the point of view of the problem of pollution of the Earth's atmosphere and the control of it, it is of interest to know the spatial-energy distribution of neutrons in the atmosphere and some of its functional that determine side effects, such as secondary gamma radiation, from radioactive sources of various types.

The intensity of the interaction of neutrons with air depends on the density of air molecules, which is different at different heights. In this regard, in the upper layers of the atmosphere, the non-uniformity of the atmosphere will exert on the distribution of neutrons. The effect of in homogeneity is significant at those altitudes at which the neutron mean free path turns out to be comparable with the characteristic size of the atmosphere in homogeneity. For the model of an exponential atmosphere with a characteristic parameter h = 8 km, this occurs at altitudes of 20-25 km above the Earth's surface. By the nature of the interaction with air molecules, neutrons can be divided into two broad categories: fast and thermal. The fast neutrons include those neutrons whose energy significantly exceeds the thermal energy of the movement of air molecules. In this case, we can assume that neutron scattering occurs on immobile molecules. Thermal neutrons are those neutrons whose energy is comparable to or even less than the thermal energy of air molecules. In this case, when considering the scattering of neutrons by air molecules, it is necessary to take into account the thermal motion of the latter.

2. The neutron flux density at a height z, moving at a speed in the direction in the stationary case, is described by the Integral-Differential Boltzmann equation:

$$\vec{\Omega}\, grad\, \psi\left(z,\upsilon,\vec{\Omega}\right)+\sum\nolimits_z(z,\upsilon)\psi\left(z,\upsilon,\vec{\Omega}\right)= \\ =\iint \sum\nolimits_s\left(z,\upsilon'\to\upsilon,\vec{\Omega}'\to\vec{\Omega}\right)\cdot\psi\left(z,\upsilon',\vec{\Omega}'\right)d\upsilon' d\vec{\Omega}' + \\ +S\left(z,\upsilon,\vec{\Omega}\right), \quad (1)$$

where $\sum\nolimits_s\left(z,\upsilon'\to\upsilon;\vec{\Omega}'\to\vec{\Omega}\right)$ – twice the differential cross section of neutron scattering, $\sum\nolimits_z(z,\upsilon)$ – the total cross section for the interaction of neutrons with air, $S\left(z,\upsilon,\vec{\Omega}\right)$ – the density of sources of thermal neutrons.

3. The spatial-energy distribution of fast neutrons for an exponential atmosphere from a flat mono energetic source, which are solutions of equation (1) in the age approximation, has the form [1]:

$$\psi_{epi}(z,\tau)=\frac{\exp\left[-\int_0^\tau a^2(\tau')\,d\tau'\right]}{(4\pi\tau)^{1/2}}\cdot \\ \cdot\exp\left[-\frac{\left(1-e^{-\lambda z}\right)^2}{4\tau\lambda^2}\right], \quad (2)$$

$$a^2=3\sum\nolimits_{tr}\cdot\sum\nolimits_a;\quad \sum\nolimits_{tr}=\sum\nolimits_t-\frac{2}{3}\sum_{l=1}^{N}\frac{\sum\nolimits_i}{A_l};$$

$$\lambda=\frac{1}{h};\quad d\tau=\frac{dE}{3\xi\sum\nolimits_s\cdot\sum\nolimits_{tr}\cdot E};$$

$$\xi=\frac{1}{\sum\nolimits_s}\sum_{i=1}^{N}\sum\nolimits_{si}\left[1-\frac{(A_i-1)^2}{4A_i}\ln\frac{(A_i+1)^2}{(A_i-1)^2}\right],$$

where A_i is the atomic weight of the *i*-th scattering element, *N* is the number of elements, and are the integral cross sections for scattering and absorption, respectively, is the transport cross section. The density of fast neutron fluxes in (2) is normalized by the condition that one neutron occurs at a time unit at the origin (at z = 0).

It is easy to show that for energies much lower than the energy of the source neutrons, this distribution follows the well-known Fermi spectrum. Deviations from this spectrum, exponentially obtained in [2], are apparently caused by such effects as the non-pointless of the source in space, the presence of impurities in the air, and the presence of chemical bonds in the scattering molecules.

4. Obtaining an analytical solution of the kinetic equation (1) in the case of thermal energy of neutrons,

even for the simplest models of scattering is difficult. The spatial-energy distribution of neutrons in this energy region was obtained by us numerically using the [3] program complex, which was based on a nonlinear iterative method for solving the kinetic equation, called the [4] quasi-diffusion method. The source of thermal neutrons is determined from the following physical considerations. When scattering of fast neutrons with energy E_{gr}, some of them fall into the thermal region. The choice of the boundary of the E_{gr} between fast and thermal neutrons is conditional. The energy E_{gr} should satisfy the only requirement $E_{gr} >> T$ (T is the equilibrium temperature of the medium in energy units). For each neutron with energy $E> E_{gr}$ there is a certain probability to pass due to scattering on the atoms of the medium to the state with $E <E_{gr}$. The further behavior of neutrons with $E <E_{gr}$ is determined by the thermalization equation. The sources in this equation are those neutrons with $E <E_{gr}$, which were located in the region $E'>E_{gr}$ before the last collision. The density of thermal neutron sources is determined by the total effect over all energies $E'>E_{гр}$. and is given by the expression:

$$S\left(z,E,\vec{\Omega}\right)=\iint\limits_{E'>E\text{гр}}\sum\nolimits_{s}\left(z,E'\to E,\vec{\Omega}'\to\vec{\Omega}\right)\cdot \cdot\psi_{epi}\left(z,E',\vec{\Omega}'\right)dE'd\vec{\Omega}' \qquad (3)$$

where (3) gives both spatial and energy distribution of thermal neutron sources.

When calculating the source of thermal neutrons, we will use the expression (2). Substituting (2) into formula (3), we obtain:

$$S\left(s,\upsilon\right)=\sum_{i=1}^{N}S_i(z,\upsilon) \qquad (4)$$

where $S_i\left(s,\upsilon\right)=S_i(\upsilon)\chi(z)$,

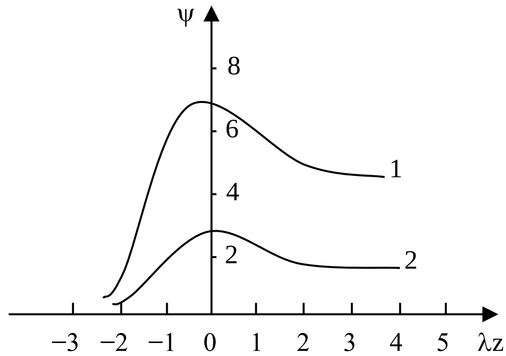
$$\chi(z)=\frac{1}{(4\pi\tau_T)^{1/2}}\exp\left[-\lambda z-\frac{(1-e^{-\lambda z})^2}{4\tau_T\lambda^2}\right], \qquad (5)$$

$$S_i\left(\upsilon\right)=\frac{1}{2\pi\xi\sum_s}\int\limits_{\upsilon_{\min}}^{\upsilon_{\max}}\sum\nolimits_{S_i}\left(\tau,\upsilon'\to\upsilon\right)\frac{d\upsilon'}{\upsilon'}.$$

We take out from the sign of the integral in terms of speed, since the age of neutrons depends on speed only through magnitude. The change in u in the region from υ_{min} and υ_{max} (near energies ~ 1 eV) is small, T means the age of neutrons with energy E_{gr}.

The Earth's atmosphere in the calculations of the neutron fields was assumed to consist of nitrogen and oxygen with a temperature corresponding to the height H of a flat monoenergetic source of fast neutrons.

The spatial distribution of slow neutrons, obtained with allowance for the thermalization effect, for height H = 40 km is shown in Figure.



1 - the result of the calculation of this work;
2 - the result of [5], excluding the thermalization effect

Figure. The spatial distribution of slow neutrons

The distribution of thermal neutrons obtained in [5], without taking into account energy exchange in collisions, is also given there for comparison.

The large difference in the results is explained by the overestimation of the effect of neutron absorption in work [5]. Compared to this distribution, our graph is shifted to higher energies. This is due to the strong absorption of slow neutrons by nitrogen molecules. The average energy of slow neutrons in the Earth’s atmosphere was approximately constant in space and equal to 0.2 eV.

5. **Conclusions.** The fields of fast neutrons from a flat radioactive source with a source energy not exceeding 1 MeV are correctly described by the age theory. The effect of atmospheric in homogeneity affects the height of the source, exceeding 20–25 km.

The fields of slow neutrons are essentially determined by the thermal motion of air molecules.

The thermalization effect in an inhomogeneous atmosphere can be described in the one-group approximation if the average neutron energy is set equal to 0.2 eV.

The flux density of slow neutrons falls almost to zero at a distance of about two parameters of the atmospheric in homogeneity. The asymptotic value of this density in the direction of the Earth’s axis is significantly different from zero. The maximum of the spatial distribution is shifted in the direction from the source to the Earth by a value of the order of h = 8 km.

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АНЫҚТАЛМАҒАН РАДИОАКТИВТІ КӨЗДЕРДЕН ЖЕР АТМОСФЕРАСЫНА НЕЙТРОНДАРДЫҢ ТАРАЛУЫ

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Жер атмосферасына шапшаң және жылулық нейтрондардың кеңістікті таралу мәселесі қарастырылды. Нейтрондардың жас теориясына 1 МэВ аспайтын энергия көзі кезіндегі жазық радиоактивті көзден шапшаң нейтрондар өрістерінің дұрыс сипаттамасы беріледі. Атмосфералық әртектілік әсері көздің 20-25 км астам биіктігіне ықпал етеді. Баяу нейтрондар ағынының тығыздығы атмосфералық әртектіліктің екі параметріне жуық қашықтықта нөлге дейін төмендейді.
Кілт сөздер: нейтрондар ағыны, Жер атмосферасы, гетерогендік, квази-шашырау.

РАСПРЕДЕЛЕНИЕ НЕЙТРОНОВ ОТ НЕОПРЕДЕЛЕННЫХ РАДИОАКТИВНЫХ ИСТОЧНИКОВ В АТМОСФЕРЕ ЗЕМЛИ

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Рассмотрен вопрос пространственного распределения быстрых и тепловых нейтронов в атмосфере Земли. Теорией возраста нейтронов дается корректное описание полей быстрых нейтронов от плоского радиоактивного источника при энергии источника не превышающей 1 МэВ. Эффект атмосферной неоднородности влияет на высоту источника свыше 20–25 км. Плотность потока медленных нейтронов снижается почти до нуля на расстоянии около двух параметров атмосферной неоднородности.
Ключевые слова: поток нейтронов, атмосфера Земли, гетерогенность, квази-рассеивание.