Modeling of Albedo Neutrons at Low Orbiting Satellites Altitudes

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Abstract. In a series of space experiments there was reported on the short increases of the neutron background cont. It was concluded on the possible correlation of these increases with thunderstorm activity on the Earth [Bratolyubova-Tsulukidze L.S. at al., 2004]. Recent studies show the principal possibility of detection of neutrons from thunderstorms [Grigoriev A.V., Drozdov A.Yu., et al., 2010]. However, confirmation of thunderstorm neutrons detection at orbital altitudes is connected with many difficulties [Drozdov A.Yu., Grigoriev A.V., et al., 2010]. One of them is influence of the albedo neutrons. In this work we make a modeling of the albedo neutrons within the Monte-Carlo method by Geant4 toolkit. The source is neutrons, produced by galactic cosmic rays (GCR) in the atmosphere. The main features of the simulation are spatial distribution of the source, spanning up to 100 MeV spectrum of the source, account of gravity, MSIS-90 atmospheric model. The result of the modeling are spectrum and flux of the albedo neutrons on different altitudes. Also, we estimate the neutron leakage and the minimum altitudes from which the neutrons can reach low orbits altitudes.

Introduction

In 1985, Indian scientists first observed the effect of neutrons generation during a thunderstorm at ground-based experiments [Shah at al., 1985]. Experimental data were previously published on observation of neutrons produced by intense electrical discharges passing through polymer fibres [Stephanakis at al. 1972]. Scientists have suggested that the generation of neutrons is due to deuteron-deuteron interaction. This made it possible to make an assumption that a similar mechanism of neutrons generation has place during the thunderstorms. Kuzhevsky [2004] suggested that the generation of neutrons during the thunderstorm is caused by the deuteron-deuteron interaction. He made the calculation, showing the conditions under which this mechanism provides the detection of the neutrons in the ground-based experiments. Also, an increased neutrons count, which is not connected with the activity of the cosmic rays (CR), was observed in a series of some space experiments [Bratolyubova-Tsulukidze et al., 2004]. The authors made the assumption that the observed increase may also be connected with thunderstorms. Babich [2006] refuted the results of Kuzhevsky’s calculation and proposed his own model for the generation of neutrons from the thunderstorms. The neutrons, generated during thunderstorms, are born as the result of photonuclear interaction of gamma rays, formed by runaway electrons with atoms of atmospheric nitrogen.

Until now, there is no clear evidence that the observed increase of neutrons cont at orbital altitudes are caused by thunderstorm neutrons. Recent studies show only the principal possibility of detection of neutrons from the thunderstorms [Grigoriev A.V., Drozdov A.Yu., et al., 2010]. However, solid confirmation of thunderstorm neutrons detection on orbital altitudes is connected with many difficulties [Drozdov A.Yu., Grigoriev A.V., et al., 2010].

The total flux of neutrons, detected at the satellite, is the contribution of albedo neutron flux from Earth, local neutron flux, produced by CR, and neutron flux from other sources (for example neutrons from thunderstorms). The local neutron flux depends on the mass of the satellites [Panasyk at al., 2000]. In the case of small satellites, the local neutron flux is small and has no effect on the total flux. As opposed to the local neutron flux, albedo neutron flux does not depend on characteristics of the satellite. The information about albedo neutrons needs to separate the influence of other sources of neutrons on the total neutron flux.

This paper presented the modeling by Monte-Carlo of the albedo neutrons at altitudes of low orbital satellites (200 km to 450 km) on the basis of data on albedo neutrons which are born in the
Hess at all [1959] published a review article, which presented in detail the neutron energy spectrum produced by CR (from $10^{-8}$ MeV up to $10^{4}$ MeV) obtained on the basis of many experimental data. This work also presented in detail the neutron energy spectrum at low energies (from 0.001 eV up to 10 eV). Soberman [1955] published the detailed distribution of the neutron flux, depending on the altitude of neutron observation. Furthermore, his work shows the distribution of neutron flux, depending on latitude. These data are shown in Figure 1.

More detailed calculations of the neutron energy spectrum were made later by Hess [1961], who used multigroup diffusion theory, by Nwekirk [1963] who used approximate solution of the kinetic equation and by Lingenfelter [1963] who used multigroup diffusion theory and taking into account variations in solar activity cycle. These works were made generally for determining the contribution of protons and electrons produced by the albedo neutrons in the Earth's radiation belts. The results of calculations of the neutron leakage can differ up to 3-5 times, depending on the latitude in works of different authors. The average value of neutron leakage was 17%.

Figure 1. a) The neutron energy spectrum. Two curves shown for different altitude of measurement of the spectrum. b) The neutron energy spectrum at low energies. c) Dependence of the neutron intensity on the altitude of observation. Different curves correspond to different latitudes of observation. d) Dependence of the neutron intensity on latitude of observation. Different curves correspond to different altitudes of observation.
Monte-Carlo simulation

To solve this problem we have written a program which uses the libraries of the Genat4 package, which implements the Monte Carlo method. The environment of the model is the spherical shell value with inner radius equal to the radius of the Earth and the thickness of 500 \( \text{km} \), the atmosphere, consisting of nitrogen and oxygen molecules, as well as atomic nitrogen and oxygen, was set in the volume. To determine the concentrations at different altitudes, the atmospheric model MSIS-90 was used. Concentrations were constant in the layers of 1 \( \text{km} \) thickness at an altitude up to 10 \( \text{km} \); 2 \( \text{km} \) thickness at an altitude from 10 \( \text{km} \) to 30 \( \text{km} \); 10 \( \text{km} \) thickness at an altitude from 30 \( \text{km} \) to 100 \( \text{km} \), and 50 \( \text{km} \) thickness at an altitude from 100 \( \text{km} \) to 500 \( \text{km} \). The single neutron source is volumetric spherical shell layer, the thickness of 2 \( \text{km} \), divided into sectors of 10 degrees latitude. The sources were determined at altitudes from 4 \( \text{km} \) to 30 \( \text{km} \). Thus, it was determined 13 spherical shell layer sources in global spherical shell of the environment of the model. The intensities of the sources are determined in accordance with the data on the altitudinal and latitudinal distribution of albedo neutrons described by Soberman \[1955\]. The neutron energy spectrum of the sources is determined in accordance with the data about the neutron energy spectrum described by Hess at all \[1959\] in the range from \(10^{-9}\ \text{MeV}\) to \(10^{2}\ \text{MeV}\). The angular distribution was isotropic.

All 13 sources were modeled separately. The program detected the neutrons at the time of its occurrence and at the time of passage of the altitude level of low orbital satellites. In this case, there were selected altitudes from 50 \( \text{km} \) to 450 \( \text{km} \) in steps of 50 \( \text{km} \).

The calculations take into account the elastic interaction of neutrons with elements of the atmosphere. Cross section of interactions determined by the libraries Genat4 package. At the low-energy neutrons are strongly influenced by gravity. The program is taking into account its influence.

In each of the 13 sources were simulated \(10^6\) neutrons. The amount of the total flux of neutrons at low orbital satellite altitudes, derived from the result of the calculation of neutron flux from each source, given the dependence of altitude distribution of albedo neutrons. The calculations were performed on the supercomputer SKIF-MSU "Chebyshev" Moscow State University.

The simulation results of the source spectrum are shown in Figure 2.

In each of the 13 sources \(10^6\) neutrons were simulated. The amount of the total flux of neutrons at low orbital satellite altitudes is obtained from the result of the calculation of neutron flux from each source, given the dependence of altitude distribution of albedo neutrons in atmosphere. The calculations were performed on the supercomputer SKIF-MSU "Chebyshev" of Moscow State University.

The simulation result of the spectrum of the model source is shown in Figure 2.

**Figure 2.** The example of the neutron energy spectrum in the form of the energy per nucleon. “Model spectrum” is a form of the spectrum which is used to determine the source of neutrons if the program. “Produces spectrum” is the form of the spectrum obtained as the result of the program work.
Results and discussion

Spectra of albedo neutrons at different altitudes registration were obtained as the result of the calculation. These spectra are displayed in Figure 3.

Shape of the spectrum does not vary much with altitude of the neutrons detection. There is a levelling of the spectrum in the range from 1 eV to 10 MeV. At the altitude of 50 km observed increase in low-energy neutrons, as compared with the spectrum of the source. These phenomena are caused by the interaction of neutrons with the Earth's atmosphere as a result of the passage of neutrons to the orbital altitudes. However, at altitudes above 50 km observed increase in low-energy neutrons, but less rated.

The shape of the spectrum does not vary much with altitude of the neutrons detection. There is a leveling of the spectrum in the range from ~1 eV to ~10 MeV. At the altitude of 50 km it can be observed the increase of low-energy neutrons amount, as compared with the spectrum of the source. This phenomenon is caused by the interaction of neutrons with the Earth's atmosphere as a result of the passage of neutrons to the orbital altitudes. However, at altitudes above 50 km is observed increase of low-energy neutrons amount, but less than increase of its at the altitude of 50 km.

Figure 4 shows the dependence of the albedo neutrons flux on the latitude observations at different altitudes of observation. The flux is calculated from the assumption that the average generation rate of the albedo neutrons in atmosphere is 4.6 neutron / sec·cm². To illustrate changes in the latitudinal variation with altitude of observation in Figure 4b the data were normalized at the value of 0 degree latitude. This Figure shows the increase of the neutrons flux in the polar latitudes in comparison with the equatorial latitudes one.

Decay of neutrons, reaching orbital altitude, may contribute to the formation of Earth's radiation belts. We called these neutrons - neutron leakage. Figure 5a shows the ratio of detected neutrons and the number of neutrons generated from the altitude of the generation. Knowing this dependence, it is not difficult to determine the percentage of neutron leakage. According to data, the percent of neutron leakage on the 50 km is equal to 17%, which corresponds to the result obtained in the sixties. However, at altitudes of observation more than 200 km, this value falls below 12% and decreases with height. Figure 5b shows the effectiveness of the generation of albedo neutrons at different altitudes. According to data, the significant contribution (more than 10% percent of total neutron albedo flux) to the albedo neutrons flux of orbital altitudes has the neutrons birthed at altitudes from 16 km to 24 km.

Figure 3. a) The neutron energy spectrum. There are present the spectrum of the albedo neutrons source and several spectra of the albedo neutrons on the different altitudes. b) Detail view of the Figure 3a at the low energy range.
Figure 4. a) Latitudinal dependence of the neutron flux. Shown are the curve of the source neutrons, and the curves of the albedo neutrons on different altitudes. b) The same as on figure 4a, but each curve is normalized at the value of 0 degree latitude.

Figure 5. a) The ratio of the amount of neutrons obtained the detection altitude and the amount of the neutrons source. b) The ration of the amount of neutrons obtained the detection altitude and the amount of the neutrons produced by single spherical shell source.

For example, the 17% of the neutrons are achieved the altitude 50 km. The 1.7% albedo neutrons were born on the 16 km single spherical shell. Thus, this single source is producing 10% of the albedo neutrons.

Conclusion

As a result of the simulation there were obtained albedo neutrons spectra at altitudes of low orbital satellites. There is a leveling of the spectrum in the energy range from ~1 eV to ~10 MeV. There has been increasing of low-energy part of the spectrum, and this increase tends to reduction with enhance of altitude. The latitudinal dependence of the albedo neutrons is determined. It was found some change in the latitudinal dependence in the direction of relative neutrons flux increase at the polar latitudes. Neutron leakage is 17%, but at altitudes above 200 km, the number of neutrons,
reaching orbital altitude, decreases to 12% and decreases with height. It is shown that a significant
contribution to the albedo neutrons flux of orbital altitudes have the neutrons birthed at altitudes from
16 km to 24 km.

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