Neutron component of the radiation dose related to thunderstorm activity

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There exist a number of experimental data favouring the idea of the connection between thunderstorm activity and rises of neutron count rate, registered in on-ground [1,2] as well as space experiments [3]. The current view on the problem of thunderstorm neutrons origin assumes their generation in photonuclear reactions of the TGF radiation and atmosphere components [4]. Such neutron radiation could be of considerable importance in the region of the neutrons generation (on altitudes of 10 – 20 km). In the present study we perform a numerical simulation of the thunderstorm neutron radiation near the generation area. The modeling includes generation of the neutrons from TGF and further propagation with account of interaction with background nuclei. On the basis of modeling results we obtain estimates of the absorbed dose for various configurations and altitudes of the neutrons source.

1. Overview

It is now of common establishment that thunderstorm activity can be accompanied by brief and powerful emissions of γ-radiation, called TGF (Terrestrial Gamma Flashes). This radiation is thought to generate neutron bursts through photonuclear reactions on the atmosphere components (TNF's, "Terrestrial Neutron Flashes" [4], [5]). The amount of neutrons can be substantial so that the correspondent neutron flux is detectable on low orbit [6]. While being possibly responsible for rises of neutron count rate, registered in a number of on-ground [1], [2] as well as space experiments [3], these neutrons are of interest at low atmospheric altitudes. They are thought to contribute to the radiation environment provided by thunderstorm activity along with electron and gamma components, which have been shown to be potentially meaningful for the aviation flights [7]. Taking into account the high penetration power of neutron radiation, one may expect also a reasonable neutron dosimetric hazard.

2. Modeling

The modeling was carried out using Geant4 package. For the detailed consideration of neutrons propagation it is first needed to obtain the initial spatial and energetic distribution of neutrons, generated by the bremsstrahlung gamma-rays of the TGF. Thus, the modeling of propagation of the γ-rays through atmosphere was carried out and the result of interaction of atmospheric particles with γ-rays providing the neutron yield constituted the thunderstorm neutrons source. At the next step, propagation of neutrons through the atmosphere was simulated. In the modelling, the MSIS-90 atmospheric model was used.

2.1. Modeling of the thunderstorm neutrons source

The point γ-ray source was used for the input because currently there is no enough information about spatial structure of the TGF source. The spectrum was taken in accordance with the usual RREA bremsstrahlung generation scheme. Photons with energy less than 10 MeV have no possibility to generate neutrons due to photonuclear reaction threshold, thus γ-rays between 10 MeV and 30 MeV were only adopted.

We considered 10 km, 15 km and 20 km altitude of γ-ray source. For each case, propagation of 10^9 photons was modeled. The generated neutrons were detected in the whole calculation area, and obtained was the array of neutrons parameters which was used for the subsequent calculation as the initial conditions.

2.2. Modeling of the thunderstorm neutrons propagation

During neutron transport modeling the neutrons were registered by spherical detectors, arranged in a space lattice. The number of neutrons registered at different detectors was converted to the total neutron fluence at a given point (detector). The fluence was calculated with assumption that γ-source generates 10^{17} photos. Only ~30% photons have enough energy for generate neutrons. Also, the number of generated neutrons form 10^9 photons was used for calculation of neutron fluence.

3. Calculation of the radiation dose

The radiation dose was found for the each point by means of the formula:

$$D = \int_{E_{min}}^{E_{max}} K(E)\Phi(r,E)dE, \qquad (1)$$

where $\Phi(r,E)$ is the differential energy neutron fluence, $K(E)$ – the Kerma equivalent of neutrons in specific tissue matter, r - coordinate of observation point. In the investigation, the soft biological tissue (SBT) and the bone biological tissue (BBT) Kerma equivalent was used [8].

The formula (1) can be transformed to:

$$D = \frac{1}{S}\sum_i K(E_i), \qquad (2)$$

with E_i being the energy of the i-th neutron. The sum is over all neutrons which were caught by spherical detector during the simulation. The $\frac{1}{S}$ coefficient of the summation is needed to convert the neutron flux on the scale of the spherical detector into the local value in accordance with the definition.

A particular result of simulations is presented on Figure 1 in the form of equivalent dose map, and in Table 1. The axis coincides with the vertical.

Table 1. Neutron equivalent dose (Sv). The γ-source is located at 10 km and is isotropic.

Source		10 km iso			
Distance from the axis, km		0	2	4	6
Height, km	6	4,7E-08	2,3E-08	4,3E-09	6,8E-10
	8	1,7E-06	4,0E-07	3,9E-08	4,0E-09
	10	6,5E-05	2,0E-06	1,1E-07	1,1E-08
	12	2,2E-06	6,5E-07	8,8E-08	1,3E-08
	14	2,0E-07	1,2E-07	3,9E-08	1,0E-08
	16	4,1E-08	3,2E-08	1,7E-08	6,5E-09
	18	1,5E-08	1,2E-08	7,9E-09	3,8E-09
	20	5,6E-09	5,9E-09	3,6E-09	2,6E-09

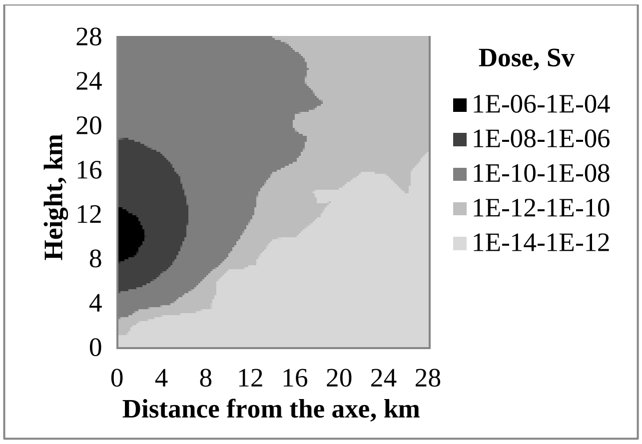

Figure 1. The visualization of the thunderstorm neutron radiation action. γ-source is located at 10 km and is isotropic.

4. Conclusions

The thunderstorm neutron radiation dose at an aircraft due to single TGF event can amount to substantial, but far not crucial value (6.5×10^{-5} Sv). Neutron radiation produced by TGF does not affect the radiation environment at the Earth surface. However, the neutron radiation can be observable on 3-4 km altitude (for example, on mountains). In the case of TGF location several kilometres higher than 10 km, the civil aviation is safe because of strong neutron flux attenuation. But due to possible multiplicity and close local spatial distribution of the γ-sources the thunderstorm neutron radiation can be significantly higher than the indicated value.

Experimental measurement of neutron equivalent dose in flights can be adopted for investigation of the γ-flashes in the atmosphere. For this aim we may propose using of airplane or meteorological rocket facilities.

5. Acknowledgments

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6. References

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