Neutron bursts associated with lightning cloud-to-ground discharges

V I Kozlov, V A Mullayarov, S A Starodubtsev, A A Toropov

Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy of SB RAS, Yakutsk, Russia

E-mail: v.kozlov@ikfia.ysn.ru

Abstract. We consider bursts in the neutrons registered by the Yakut spectrograph of cosmic rays and the electrostatic fluxmeter ($\pm 50$ kV/m). Bursts were observed during a significant change in the field, which changes abruptly from -16 kV/m to 18 kV/m during negative lightning. It was found that during the positive lightning have not been observed bursts of neutrons, despite that the electric field changes abruptly from 10 kV/m up to -30 kV/m during the lightning discharge.

1. Introduction
The first experimental reference to neutron generation during lightning discharges was made by Indian physicists in 1985 [1]. At the present time, this phenomenon is being registered by modern ground installations both in the mountains [2] and at sea level [3]. Despite a relatively long history of observations of neutrons associated with lightning and a large number of theoretical studies, the question of the origin of these neutrons is still open [4]. One of the theories [3] assumes that the neutrons are generated in the lightning channel due to the synthesis of deuterium contained in water vapor in the atmosphere. According to another theory [5] (actively developed in the last decade), the neutrons are generated by a complex mechanism of interaction between bremsstrahlung (produced by relativistic runaway electrons, which can occur during a thunderstorm) and the atmosphere.

We present experimental results of the registration of the neutron component during the nearest thunderstorms in the years 2009-2011. The neutrons were detected with the Yakutsk cosmic ray spectrograph (Yakutsk, 61° 59.362’ N; 129° 41.874’ E) on the standard neutron monitor 24-NM-64 (altitude 94 m above sea level, geomagnetic cutoff threshold of 1.65 GeV). In the immediate vicinity of the monitor the electric field sensor (an electrostatic fluxmeter - our own design) was installed to register the electric field and its variations during thunderstorms. The electrostatic fluxmeter was calibrated in an artificial electric field and has a measurement range of $\pm 50$ kV/m. The second electrostatic fluxmeter is located 4 km from the monitor, on the building of the institute. Both fluxmeters allow us to register lightning discharges within a radius of 10-15 km. In this paper we have used one-second resolution data. In the course of two storms a high-speed video (300 fps) was recorded.

2. Results and discussion
An example of bursts of neutrons during lightning discharges is shown in Fig. 1. Fig. 1 shows two curves: the count rate of the neutron monitor (top panel) and the electric field strength. The time is
UTC. During the lightning discharges some typical jumps are observed in the electric field, after which the field is restored to its original value in seconds and tens of seconds.

Figure 1. An example of neuron bursts at the moment of lightning discharges during the thunderstorm on June 26, 2010. Bottom panel indicates variations of the electric field; top panel depicts the level of neutron count rate.

Figure 2. The dependence of the neutron monitor count rate $N$ from time during a thunderstorm June 26, 2010 from the atmospheric electric field strength $E$, due to lightning discharges.

Study of the dependence of the neutron monitor counting rate of the surface tension of the atmospheric electric field during lightning discharges shows that short bursts of neutrons on the average recorded in excess of the threshold electric field strength of $-16$ kV/cm, and, with increasing field is observed increasing the amplitude of bursts. Fig. 2 is an example of such dependence obtained for the storm June 26, 2010. The data of measurements and their statistical errors at the level of $\sigma$; line shows the level of linear count rate of the monitor before the storm, dashed line is approximation of the measurements by the formula $N=1.01 \cdot \exp(-E/2517.33)+13390.48; R^2=0.74$ is the degree of correspondence between the approximating curve and the measurements.

During the summer seasons of 2009-2011 thirty nine thunderstorms were registered in the vicinity of the neutron monitor. In nine of them the neutron flux level was up by a fairly significant value. When a thunderstorm cloud passes over the observation point at the earth surface, relatively slow (from tens of minutes to hours) variations of the electric field are registered. Depending on the electrical structure of a thundercloud, these variations can be divided into four main types. The first type is associated with the clouds where a positive charge dominates in the upper part, while a negative charge dominates at the bottom (the so-called cloud of positive polarity). The second type of field variations occurs with the same clouds, but has an additional compact positive charge at the bottom. The third type is associated with the clouds where a negative charge is dominating in upper part, while at the bottom - a positive charge dominates (a negative polarity cloud). The fourth type of variation is associated with the clouds of positive polarity with the upper positive charge and the lower negative charge shifted relative to each other. The variations of the second type are the most frequently observed (total frequency 36.6%). All the cases (100% probability) of observations of bursts in the neutron component are correlated to this type of thunderstorm cloud structure. It should also be noted that the bursts in the neutron component were mainly observed in the second half of thunderstorms, just after the compact positive charge concentrated in the bottom of the thundercloud had passed over the observation point (Fig. 1). It is believed [6] that a compact positive charge is primarily associated with very strong upward flows, in which there is an intense separation of charges at the height of a storm cloud. This cloud structure is observed at the peak of a thunderstorm.
Figure 3. The bursts of neutrons observed during the thunderstorm on June 11, 2011. Top panel indicates the count rate of the neutron monitor; bottom panel - the atmospheric electric field strength. Pictures mark certain cloud-to-ground negative lightning strikes and corresponding photos showing the places of strikes. The distances between the neutron monitor building and the points of strikes: 1 - 6.2 km; 2 - 5.8 km, 3 - 6.2 km.

Figure 4. The thunderstorm of June 12, 2011 with positive lightning discharges that had no response in the neutron component. Pictures mark certain discharges and corresponding high-speed video shots. The distance between the neutron monitor building and the place of the strike in all three cases is 4.1 km.

As mentioned above, in the course of two thunderstorms, a high-speed video was recorded. It allowed us to determine the location of the lightning strikes (or the distance to the neutron monitor) and to correct the polarity of the lightning. In the first thunderstorm, observed on June 11, 2011, the cloud-to-ground lightning discharges, which were negative discharges (the main return discharge occurred in the direction from the ground to the cloud), caused an increase in the neutron flux (Fig. 3). For this storm, the distance between a lightning strike and the neutron monitor, lies in the range of 5.8 - 7.1 km. During the second storm, observed on June 12, 2011, lightning discharges occurred mainly in the opposite direction (positive discharges, Fig. 4). The discharge of this type had no effect on the neutron component despite the fact that the lightning strikes were located 4.1 km from the neutron monitor (a strike to the 240 m high television tower in the center of Yakutsk, Fig. 5). That is, the lightning discharges occurred 2 km closer to the neutron monitor as compared with the lightning strikes during the thunderstorms of June 11, 2011. Three videos of lightning discharges at the television tower were made.

Fig. 6 shows the location of lightning strikes during the thunderstorms of June 11 and 12, 2011, and the distance in kilometers from these strikes to the neutron monitor.

The analysis of experimental data has revealed that the increase in the counting rate in the neutron component during the nearby thunderstorms is not random and is directly related to lightning discharges in the vicinity of the neutron monitor. The picture of neutron intensity variations is consistent with the one given in [4]. In certain events the counting rate increased up to 21% (2688 neutrons per minute) above the background level. As was noted above, all the peaks in the neutron component occurred during the nearby thunderstorms in which a thunderstorm cloud had a certain type of charge distribution (in the upper part - a positive charge, at the bottom - negative, but containing a compact positive charge at the bottom of the cloud). It should be noted that not all the
nearby thunderstorms of that kind had a response in the neutron component: only 9 of 16 thunderstorms were accompanied by bursts of neutrons.

**Figure 5.** Spatial location of the points of lightning strikes during the thunderstorms of June 11, 2011 and June 12, 2011 relative to the neutron monitor. Distance (in km) to the neutron monitor is given for each point of the strike.

**Figure 6.** The scheme of the points of lightning strikes of June 11, 2011 the distance to which was determinable, as well as the areas of lightning strikes the distance to which was not defined (only the azimuth was known), which were clearly beyond the edge of the terrace.

3. **Conclusion**
The short neutron flux bursts were registered during the short-distance (5-7 km) lightning discharges. The bursts were observed during a significant change in the electric field (down to -16 kV/m and more), which abruptly changed up to +18 kV/m at the time of lightning discharges. The increase in the neutron flux reached 21% of the average level for the data of one minute resolution. It has been found that positive cloud-to-ground lightning (carrying positive charges) does not significantly affect the neutron intensity in spite of the fact that the positive lightning strikes may be closer to the neutron monitor in comparison with the negative lightning strikes, while the electric field may change abruptly in a wider range (from +10 kV/m to -30 kV/m).

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**References**
[1] Shah G N et al. 1985 *Nature* 313 773
[2] Chubenko A P et al. 2008 *J. Phys. G: Nucl. Part. Phys.* 35 085202
[3] Kuzhevsky B M 2004 *Moscow Univ. Phys. Bull.* 5, 14 (in Russian)
[4] Gurevich A V et al. 2012 *Phys. Rev. Lett.* 108 125001
[5] Babich L P 2007 *Geomag. Aeron.* 47 664
[6] Chalmers J A 1967 *Atmospheric Electricity* (2nd Edn.) Oxford (Pergamon) 515