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Variations in the Neutron Flux during Thunderstorms

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Abstract—The results from the registration and analysis of sporadic variations of atmospheric thermal neutron flux during thunderstorms are reported. Measurements were performed in Moscow and at the Baksan Neutrino Observatory of the Institute for Nuclear Research of the Russian Academy of Sciences. The neutron flux was detected by unscreened scintillation en-detectors based on ^{6}LiF + ZnS (Ag) compound targets with signals selected according to pulse shape. Reductions of 5–10% in the neutron flux due to shower precipitates during thunderstorms are detected. No incidents of increased neutron flux during thunderstorms were detected over four summer seasons. The upper limits for the integrated and pulsed flux of neutrons from thunderbolts are estimated.

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INTRODUCTION

To the best of our knowledge, the registration of an increase in the neutron flux during a thunderstorm was first reported by the authors of [1]. In recent years, a number of works have been devoted to the results from registering the neutron flux during thunderstorms, obtained by the Aragats [2], Tien-Shan [3], Yakutsk [4], and Yangbadjing (Tibet) groups [5]. Data from neutron monitors (NMs) were analyzed in these experiments, while information from ^{3}He counters was also used in [3]. The authors of [5] assumed that the experimentally observed increase in the neutron flux was the result of photonuclear reactions in the lead contained in NMs, while the authors of [6] ascribed the effect to the photonuclear reactions in the atmosphere. These and other experimental results were analyzed in detail in [7] with allowance for possible contributions from photonuclear reactions or X-ray and γ-radiation. Below, we report the results obtained during thunderstorms at the Neutron-MEPhI and Neutron-BNO installations.

DETECTORS: THE NEUTRON-MEPhI AND NEUTRON-BNO INSTALLATIONS

The neutron flux was registered by a thermal neutron detector based on an inorganic scintillator with ^{6}LiF + ZnS (Ag), deposited as thin layers on the base of a light-reflecting cone with a PMT positioned at its vertex. Thermal neutrons produce the reaction ^{6}Li(n, α)^{3}H + 4.78 MeV, while α-particles and tritons produce scintillations in ZnS that are detected by the FEU-200 photomultiplier. The efficiency of neutron registration is ~20%. More detailed data on the detector can be found in [8]. PMT signals are detected and fully digitized using standard rapid flash ADCs (FADCs).

The shape of a pulse from a neutron differs from the background pulses caused by relativistic charged particles and electromagnetic noise pickup. This allows us to select neutron signals according to pulse shape under conditions associated with pulsed electromagnetic noise during a thunderstorm. Information on neutron count rate N ~ 400/5 min and the count rate of rejected pulses is displayed every 5 min. In addition, the arrival time for each pulse is stored with an accuracy of 10 ms. Each the Neutron installations consists of four en-detectors that operate under a variety of physical conditions determined by thicknesses of absorbers. The detector scintillator area is 0.75 m^2 in the MEPhI installation and 0.36 m^2 in the BNO installation. In this study, we used the data from exterior detectors with maximum sensitivity to variations in the flux of atmospheric neutrons (i.e., situated under the minimum amount of absorber). The set of detectors in the MEPhI installation includes a thunderbolt sensor as well.

THUNDERSTORMS AND THE EFFECT OF HUMIDITY

Let us first note that the nuclei of hydrogen atoms in water molecules are very effective moderators and absorbers of neutrons. The effect of a decrease in the neutron flux in the environment during and after rainfalls was detected long ago in experiments with unshielded neutron detectors [9, 10]. Figure 1 shows the reduction in the neutron flux (corrected for baro-

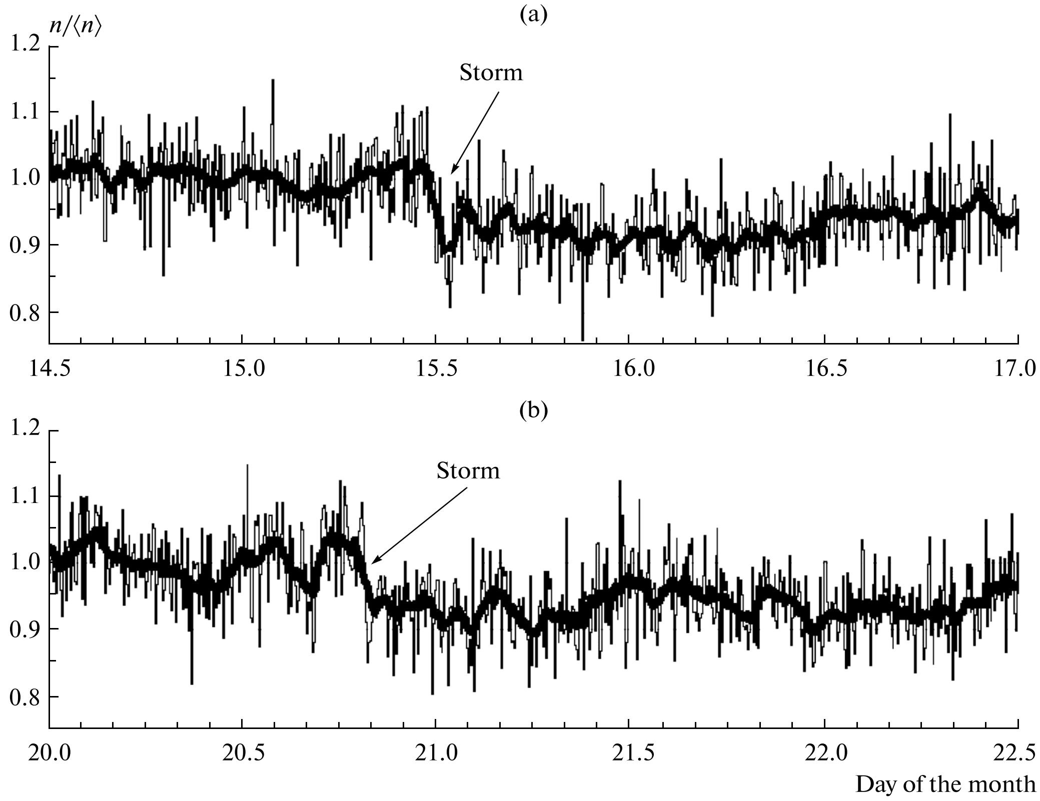

Fig. 1. Variation in the neutron count rate as a function of time for two thunderstorms: (a) July 15, 2011, and (b) July 20, 2012.

metric pressure) during two thunderstorms after prolonged dry periods, as registered by en-detectors at the National Research Nuclear University (MEPhI) on July 15, 2011, and July 20, 2012. The fine lines show the variations at 5-minute intervals. The statistical error of each 5-minute interval is 5.4%. The bold lines show the sliding-average smooth over each hour interval. The first shower started at noon on July 15, 2011 (panel (a)), and the second shower occurred at around 19:00 hours on July 20, 2012 (panel (b)). In both cases, we observed an approximately 10% reduction in the neutron count rate. One feature of event (b) is that a thunderbolt struck the experimental building at a distance of about 10 meters from the en-detector. Fortunately, however, our data collection system was not damaged, and no statistically significant rise in the neutron count rate was detected even in this extreme case.

UPPER LIMIT FOR THE INTEGRAL NEUTRON FLUX FROM THUNDERBOLTS

As there were no statistically significant rises in the neutron count rate during thunderstorms in our experiment, we can use the direct current (DC) method to determine at our level of accuracy the upper limit for the integral 5-minute neutron flux from thunderbolts. A conservative estimate of the upper limit of the integral 5-minute neutron flux at the 95% confidence level is $N_f < 240$ neutrons m^{-2}. In the actual experiment, the number of thunderbolts was as high as four over five minutes, allowing us to set a more rigid limit on the flux from one thunderbolt: $N_f < 60$ neutron thunderbolt^{-1} m^{-2}.

UPPER LIMIT FOR THE PULSED NEUTRON FLUX

It is clear that using the DC procedure yields somewhat rough estimates. To improve our estimates and search for neutron flashes from thunderbolts, we can use the concept of cluster analysis in its simplest form: searching for an anomalous number of neutron clusters over a specified time interval. We use the following search algorithm: If the number of pulses N in temporal window T exceeds preliminarily specified number n, the absolute time of the appearance of a neutron cluster is fixed, and the unit is added to corresponding bin m on the temporal axis: $Cm = Cm + 1$. For the thunderstorm day at Baksan (July 17, 2014) we performed a search with parameters $T = 10^{-2}$ s, $n = 1$, and $m = 1440$ min (day length). We analyzed the flux of pulses with a total $N = 2.9$ s^{-1} from three detectors ($S = 1.08$ m^2). The excess neutron flux at $m = th$ would lead to the anomalous number of cluster events Cth.

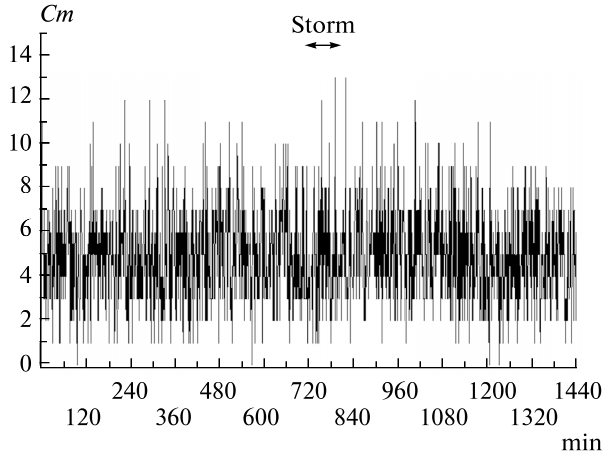

Fig. 2. Number of binary clusters detected per minute.

Figure 2 shows the behavior of *Cm* as a function of time. The established distribution of cluster frequency with an average magnitude of 4.9 is described by a Poisson distribution. We end up with maximum value $Cm = 13$. The fraction of events with number of occurrences $Cm < 14$ is 99.9% for a Poisson distribution with an average of 4.9 and a number of inputs of 1440. If we assume that the maximum deviation from an average of eight was purely random, we can accept number nine as the upper estimate of the cluster flux, which corresponds to 18 neutrons (tertiary clusters constitute a 0.03 fraction of the number of binary clusters) per each possible thunderbolt per minute (a conservative case). Allowing for the efficiency of registration and the area of three detectors, we find $N_f < 83$ neutron thunderbolt^{-1} m^{-2}. This estimate is comparable to the one obtained using the DC method but at a considerably higher confidence level.

CONCLUSIONS

There is a 5–10% reduction in the thermal neutron flux during thunderstorms, due to an increase in the absorption of neutrons in water-saturated soil. We estimate the upper limits of the integral thermal neutron flux associated with thunderbolts at N_f (95% c.l.) < 60 neutron thunderbolt^{-1} m^{-2} using the DC method, and at N_f (99.9% c.l.) < 83 neutron thunderbolt^{-1} m^{-2} using the results from cluster analysis. Our procedure differs from others by the complete digitalization of detector signals. This could have been the reason why no event exceeding the background thermal neutron flux during thunderstorms was detected, not even when a thunderbolt struck the facility housing the detectors.

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REFERENCES

1. Shah, G.N., et al., *Nature*, 1985, vol. 313, p. 773.
2. Chilingarian, A., Bostanjyan, N., and Vanyan, L., *Phys. Rev. D: Part. Fields*, 2012, vol. 85, no. 8, p. 085017.
3. Gurevich, A., et al., *Phys. Rev. Lett.*, 2012, vol. 108, no. 12, p. 125001.
4. Kozlov, V., et al., *J. Phys.: Conf. Ser.*, 2013, vol. 409, p. 012210.
5. Tsuchiya, H., et al., *Phys. Rev. D: Part. Fields*, 2012, vol. 85, no. 9, p. 092006.
6. Chilingarian, A., Bostanjyan, N., Karapetyan, T., and Vanyan, L., *J. Phys.: Conf. Ser.*, 2013, vol. 409, p. 012216.
7. Babich, L.P., et al., *JETP Lett.*, 2013, vol. 97, no. 6, p. 291.
8. Sten'kin, Yu.V., *Nuclear Track Detectors: Design, Methods and Applications*, Sidorov, M. and Ivanov, O., Eds., Nova Sci. Publ., 2010, ch. 10, p. 253.
9. Bercovitch, M., *Proc. Int. Conf. Cosmic Rays*, Calgary, 1967, part A, p. 267.
10. Eroshenko, E., Velinov, P., et al., *Adv. Space Res.*, 2010, vol. 46, p. 637.

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