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Sporadic variations of thermal neutron background measured by a global net of the en-detectors

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Abstract: We report here in brief some results of observation and analysis of atmospheric thermal neutron flux sporadic variations during cosmic ray Forbush-decreases and thunderstorms. The results obtained with unshielded scintillation neutron detectors show in both cases prominent flux decreasing correlated with geomagnetic cutoff or with meteorological precipitations after a long dry period. Also, dependence of registered Forbush-decrease on an absorber thickness above the detector is presented. No evidences for the "thunderstorm neutrons" effect were observed during two summer time periods of data recording.

Keywords: Forfush decrease, neutrons, en-detector, thunderstorm

1 Introduction

In the frame of cosmic ray physics dealing with interaction of primary cosmic rays with the Earth, a low energy neutron flux is one of constituents of secondary cosmic flux in atmosphere side by side with electromagnetic and high energy hadron components. Atmospheric neutrons appear as a result of nuclear and photonuclear reactions of hadrons and gammas with atomic nuclei of atmosphere elements. Hence any factor modulating both primary and secondary fluxes results in time and space variations of neutron flux. The factor among others for primaries is variation of geomagnetic cutoff during Forbush effect after power Sun flare. For secondary components the factors are ordinary variations of atmospheric pressure and temperature, for example - daily and seasonal variations, depth in atmosphere and also abrupt atmosphere perturbations such as thunderstorm, tornado, and atmospheric fronts. So, study of neutron flux variations gives us knowledge on above mentioned phenomena and processes. A global net of neutron monitors have been successfully operated during decades to study neutron variations, with energy threshold for neutron being $\sim$ 20 MeV [9]. Flux of atmospheric neutron with lower energy (up to thermal) is not up to now studied so carefully both during long period observations and during short abrupt atmospheric processes.

In the beginning of the 2000s years in the INR there was designed and constructed a large unshielded scintillation detector of thermal neutrons (en-detector) [1] to study of e- and n-components of EAS events and for long-term and continuous recording of variations of the surface and underground neutron flux. Later we developed a global net of en-detectors. Earlier we have reported an observed dependence of neutron flux as a function of altitude [2] and also the results of registration of Forbush decrease 08, March, 2012 [3]. Both results were obtained with a global net of en-detectors. Obtained altitude dependence is in a good agreement with mean free path for hadrons in atmosphere. Forbush results showed an adequate response of detectors both to time profile of the neutron flux decrease and to geomagnetic cutoff. In this report we discuss a possibility to make an energy spectroscopy of primary particles involved in the Forbush decrease, using the absorbers of different thicknesses above the detectors. Another topic of the report is the behavior of neutron flux during thunderstorms which naturally are accompanied by strong electric field disturbances, lightnings and rains. There are results on thunderstorm neutrons from four groups - Tien-Shan[4], Aragats[5,6], Tibet[8] and Yakutsk[7]. Concerning results of Tien-Shan, Aragats and Tibet, authors of [6] notice that "all 3 groups drastically differ in explanation of the origin of neutron flux". Tien-Shan, Aragats and Yakutsk "quiet" neutron rates are quite similar, but they drastically differ in intensity (from 20% to a factor of hundreds) and duration concerning "thunderstorm neutron" fluxes. The Tibet group [8] reports a much more modest but well argued flux $\sim$ 2%, duration $\sim$ 10 min of "thundercloud neutrons". Some questions are arising . . .

2 Neutron recording methods

Solid and well known specialized granulated alloy scintillator was used to detect neutrons - ^{6}LiF+ZnS (Ag). A distinctive feature of our data acquisition process is that all pulses from PMT are digitized by an FADC, or, in another words, preliminary full pulse shape analysis is used to count real neutron pulses and to reject (but to count them as well!) the noise background. The latter is undoubtedly the major precaution keeping in mind a huge electromagnetic noise producing by nearby lightnings. We have to note that in no one of cited above work the thermal neutron pulse shape digitizing was used. A calibration procedure of the pulse shape analysis with neutron source had been naturally done beforehand. 1 min and 5 min time runs were used in data acquisition process. Statistical accuracy of 1-min run is 12%, and 5.4% for 5-min run.

3 Results concerning the neutrons energy spectroscopy of Forbush decreases

In Fig.1 we show variation of atmospheric neutron flux during Forbush decrease 08, March, 2012, as it was recorded by two neutron detectors: NM (Moscow Neutron Monitor) and Nd1(dots) - one of four thermal Neutron detectors installed at Moscow Engineering Physics Institute (MEPhI). Detector d1 is placed in 2.5 meter wide passing gallery with glass walls and with floor and ceiling = 25g/cm^2 each.

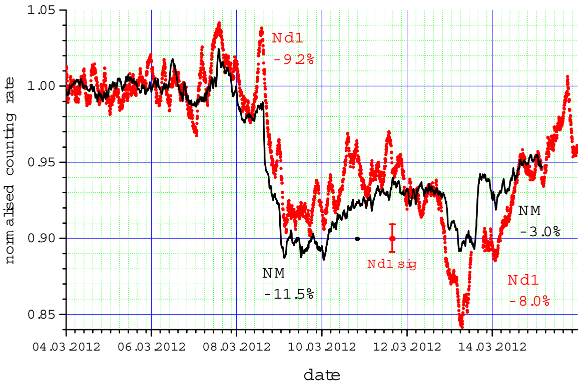

Fig. 1: Comparative behavior of 3-hour smoothed curves for NM and Nd1 pressure corrected data.

A specific (but not rare in common) feature of the Forbush is a dip during 13 March (second Forbush). We would like to note here that amplitude of March 8 decrease at NM is a little bit larger than at Nd1 (11.5% > 9.2%, 2 sigma(Nd1) effect), but the "dip" decrease on March 13 is significantly larger at Nd1(8.0% > 3.0%, 5 sigma(Nd1) effect). We are not sure for a moment - is this peculiarity due to difference in response between thermal and tens or hundreds MeV neutrons, but probably it is so. Another interesting feature of this Forbush is a sharp enhancement seen just before the first decrease. The enhancement is well known for a long time and is real. Probably it was produced by very low energy primary particles and that is why our detector is more sensitive to it in comparison with NM. We need more similar comparative observations with Nd1 detector. Three other detectors Nd2, Nd3, Nd4 are placed inside experimental MEPhI building under different effective thicknesses of roof. Next Fig.2 shows dependence of the March 8 amplitude decrease on absorber thickness. We dont know what does obtained exponential parameter 500 g/cm^2 mean, but sure it must be connected with energy spectrum of primaries involved in the Forbush decrease.

It comes back to our mind an old idea and great efforts (the sixties-seventies of XX century) of L.I. Dorman to construct a neutron spectrograph in Kabardino-Balkarian mountain district of Russia (North Caucasus; Baksan Neutrino Observatory is there) placing three Neutron Monitors at three altitudes from 500 to 3100 m a. s. l. And now we propose some modification of this idea on basis of the thermal neutron detectors (TND) with different thickness of absorber above. Even four TNDs cost not so much as one NM, but they are able to realize some sort of neutrons energy spectroscopy in a 3-hour time step scale. Such sets of TNDs could be placed at different altitudes to get additional information on energy-in-time evolution of Forbush decreases.

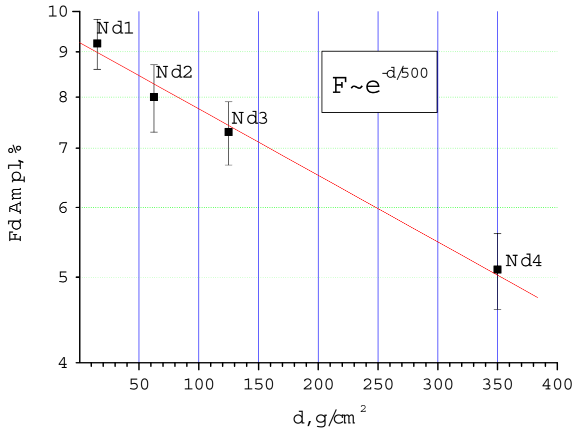

Fig. 2: Amplitude of 08/03/12 thermal neutron flux decrease as a function of absorber thickness. Remark: mean absorber thickness for all detectors was obtained as an averaged value after 4π integration procedure.

4 Results on the thunderstorms neutron behavior

In contrary to standard NM having neutron energy threshold of some tens or even hundred MeV [10] the unshielded neutron detectors (scintillation en-detector or proportional counters) are sensitive to low energy, up to thermal, neutrons. It was at the beginning of "neutron cosmic ray era" that preference was given to shielded proportional tubes to make them less sensitive to variations of H_2O concentration (humidity, snow, rains) in ambient environment. Observed variations of unshielded counters in periods of snow smelting or inches precipitations reached to $10-20\%$ [11], whereas NM counting rate changed 10 times less. Hence neutrons with sub MeV energy (up to thermal) are responsible for observed variations. In our global net of en-detector we have three sites with surface situated detectors which operate starting from the beginning of 2010 year: Moscow (56N, 38E, and 200 m a. s. l.), Obninsk (55N, 37E, 175 m a. s. l.) and LNGS, Italy (42N, 13E, 1000 m a. s. l.) Some geophysical phenomena and Forbush effects were under investigation. Having been interested in reports on "thunderstorm neutron effect", we thoroughly checked up our data bases to find any response (enhancement out of statistics) in neutron flux variations for three above mentioned surface detectors during summer periods 2011-2012 years. (In fact, we had never noticed any enhancements in neutrons counting rate during thunderstorms when information have been checked in routine, by eyes, looking through). Usually about three powerful thunderstorms at a site happened to be during summer months. But no one en-

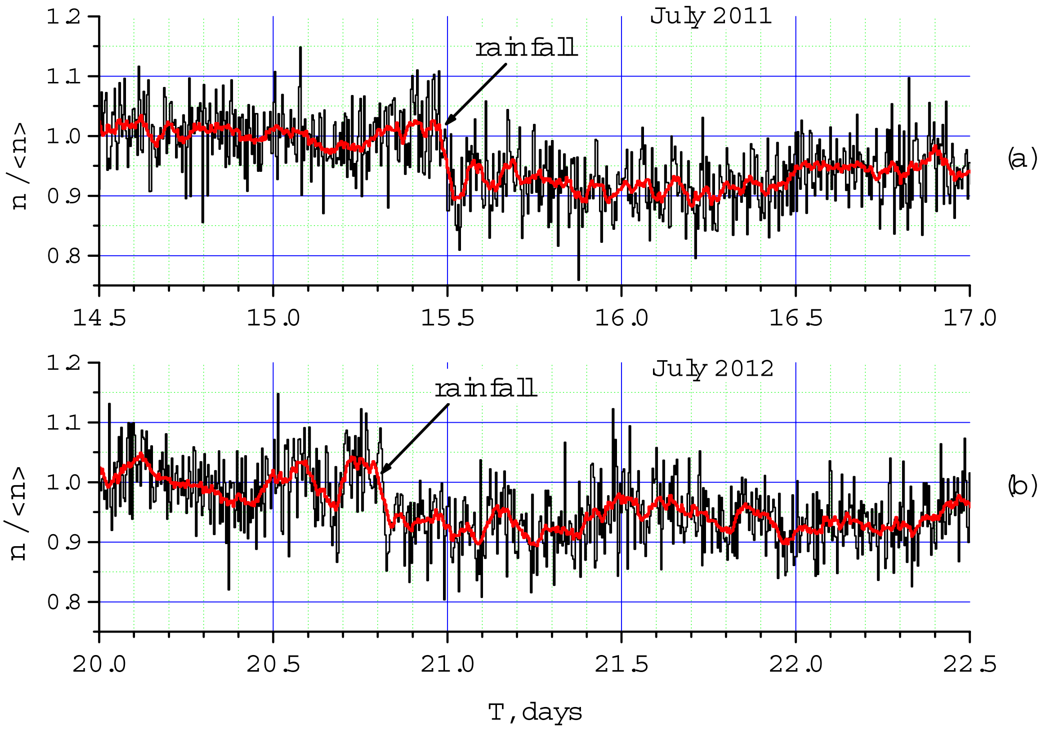

Fig. 3: ~ 10% counting rate decrease for least shadowed detector Nd1 after a rainfalls in thunderstorms on July 15, 2011 and July 20, 2012. Pressure corrected data.

hancement out of statistics was found both in 1-min run, nor in 5-min run. From statistical point of view it means that we may set 95% confidence level for thunderstorm thermal neutron flux enhancement being less than 23% at 1 min interval, and less than 11% at 5 min interval. It is worthwhile to stress here that our detector has no lead, as it is in NM, and as a result we cannot see the photonuclear neutrons elaborated in [8]. At the same time our homemade thunderbolt recorder successfully registered a bunch of pulses during lightnings. Similar observation has been noticed in report [12]: "Proportional counter is made from 2 m long and 15 cm diameter iron tube that is excellent antenna. In spite of grounding when lightning hits nearby all channels of neutron monitor register inference signals due to extremely powerful radio pulses from lightning bolt". Just these noise pulses we call as "electric-kettle effect", - it is easy to see with oscilloscope a bunch of noise pulses in electronic circuit when someone switch "on" or "off" electric kettle. In spite of our failure to present for the moment some bright result on thunderstorm neutron burst we can now demonstrate one classical example of thermal neutron flux behavior (in excellent agreement with [11]) after a rainfall during thunderstorms happened to be on 15/07/2011 and 20/07/2012 after a long dry weather periods. In Fig.3 we show counting rate behavior of MEPhI thermal neutron detector Nd1 during these thunderstorms. Rainfall began near the 15/07/2011 afternoon (panel a) and in the evening 20/07/2012 (panel b). In both cases only the least shadowed detector Nd1 (see Fig.2) showed prominent decrease of counting rate which came back to quiet mean level after a period of ~1 day. Red line is one hour smoothed curve. A remarkable feature of 20/07/2012 event is that one of the lightning hit the experimental MEPhI building resulting in some electronic circuits and devices happened to be damaged. Fortunately Nds data acquisition system was lucky. And even in that "hit the mark" case we have and see nothing, except may be some slight distortion of neutron counting rate before the decrease. The distortion is possibly produced by photonuclear neutrons (in a concrete) elaborated by Tibet group but more probably this is just statistical fluctuations. Similar decreases ~ 5% of counting rate during thunderstorms, with duration ~ some days, from lead-free NMs were reported in [9]. Authors conclusion supported by Monte-Carlo simulation is: "The neutron component behavior depends on moisture content in soil surface".

5 Discussion and conclusions

Our results obtained with unshielded scintillation neutron detectors showed prominent flux decreasing anti correlated with the absorber thickness during a Forbush-decrease or with powerful rainfalls after a long dry period (similar to that we see also after a snowfalls). No evidences for the "thunderstorm neutrons" effect were observed during two summer time periods of data recording. Similar result was obtained earlier in a special study made with the 6NM64 neutron monitor located at altitude of 2270 m in Mexico city [13]. We have to stress here that among all experiments, which have reported their results on the neutron flux during thunderstorms, only our methodics include full pulse shape digitizing and selection. That is probably the reason why we and some other experiments [9,13] taking precautions against the electromagnetic noise do not recorded any enhancement of thermal neutrons during thunderstorms. We plan to expand this methodics and to construct a new 4-en-detector variation array at Baksan site and later at LNGS site to study the above-discussed effects as well as other geophysical phenomena.

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References

[1] 1. Yuri V. Stenkin. In: Nuclear Track Detectors: Design, Methods and Applications, Editor: Maksim Sidorov and Oleg Ivanov (2010) Nova Sci. Publ., Chapter 10, pp.253-256.
[2] Alekseenko V., Gromushkin D. and Stenkin Yu. Bulletin of the Russian Academy of Sciences, Physics, Vol.75(6), (2011), pp.857-859.
[3] Alekseenko V. et al, J. Phys.: Conf. Ser. (2013), 409 12190.
[4] Mitko G. et al, J. Phys.: Conf. Ser. 409 (2013) 012235; A.V.Gurevich, et al. Phys. Rev. Lett. 108, (2012), 125001.
[5] Chilingarian A. et al, J. Phys.: Conf. Ser. 409 (2013) 012019.
[6] Chilingarian A. et al, Journal of Physics: Conference Series 409 (2013)012216.
[7] Kozlov V. et al, Journal ofPhysics:ConferenceSeries 409 (2013)012210.
[8] Tsuchiya H. et al, Phys. Rev. D 85 (2006) 092006.
[9] Eroshenko Eugenia, Velinov Peter et al (Russian-Bulgarian collaboration), Advances in Space Research 46 (2010), pp.637-641
[10] C. J. Hatton. The neutron monitor. Progress in elementary particle and cosmic ray physics (1971), pp. 3-97.
[11] M. Bercovitch, Proc. Intern. Conf. Cosmic Rays, Calgary 1967 Part A, p. 267.
[12] A. Reymers and S. Chilingarian. Proc. 23th ICRS, Moscow (2012), ID 373.
[13] L. X. González and J. F. Valdés-Galicia. Geofisica Internacional Vol. 45,(2006), No. 4, pp. 255-262.