Temporal and lateral distributions of EAS neutron component measured with PRISMA-32

D M Gromushkin[1], F A Bogdanov[1], A A Petrukhin[1], O B Shchegolev[2], Yu V Stenkin[1,2], V I Stepanov[2], I I Yashin[1] and K O Yurin[1]

[1] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, Moscow 115409, Russia
[2] Institute for Nuclear Research of RAS, Moscow 117312, Russia

E-mail: DMGromushkin@MEPhI.ru

Abstract. Some results on the EAS neutron component measurements by means of the PRISMA-32 array are presented. The array consists of 32 electron-neutron detectors (en-detectors) capable to detect two main EAS components: electromagnetic one consisting of charged particles, and hadronic one by measuring delayed thermal neutrons accompanying the showers. For thermal neutrons detection, a compound of a well-known inorganic scintillator ZnS(Ag) and LiF, enriched to 90 % with ^{6}Li isotope is used. The setup allows us to record neutron component over the whole array area.

1. Introduction

PRISMA-32 being a novel type of Extensive Air Shower (EAS) array is working in the Scientific and Educational Center NEVOD (MEPhI) since 2012 [1]. The array layout is shown in figure 1. It was created in cooperation between MEPhI and INR to study neutron component of EAS [2], which is produced in interactions of high-energy hadrons of the shower with the nuclei of atoms of atmosphere and Earth's surface and provides important information about EAS development. The array allows us to study the thermal and epithermal neutron component using the whole area of array. In addition, electromagnetic component is measured (only for passage of multiple charged particles through the scintillator [3]).

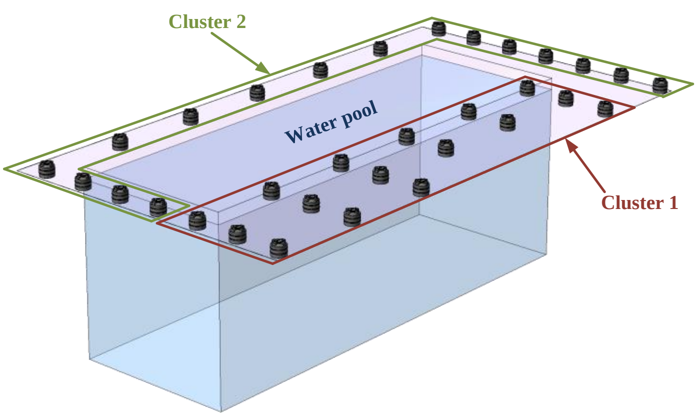


Figure 1. The layout of the PRISMA-32 array.

An advantage of the thermal neutron component study is that the time profile of EAS in thermal neutrons is of the order of 10 ms, that is about 10^6 times longer than the time profile of charged particles close to the shower core. This allows us to record neutrons in a wide dynamic range up to 1000 neutrons per a detector per event.

2. PRISMA-32 array

The array consists of two independently operating clusters of 16 en-detectors each and covers an area of about 500 m^2. En-detectors are installed inside the experimental building at the 4th floor with a distance of 2.5 or 5 m. The non-uniform location of the detectors is explained by the existence of a free space in the experimental complex, which contains some other arrays, including water Cherenkov detector (in the center) [4].

Design and photo of the en-detector are shown in figure 2 and 3. The effective area of each detector is 0.36 m^2. Thin layer of inorganic scintillator ZnS (Ag) and LiF (Li enriched to 90% ^{6}Li) is used for detecting EAS neutrons. Two outputs from the 12th and 7th dynodes of FEU-200 photomultiplier are used to expand the dynamic range of electromagnetic component measurements.

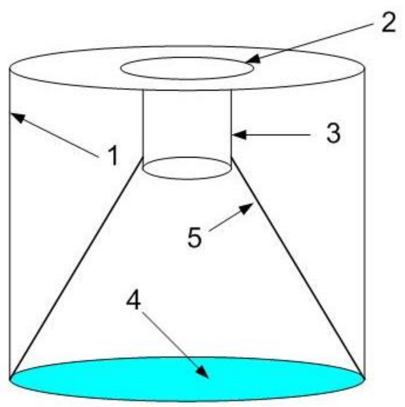


Figure 2. The en-detector design: 1 is PE water tank; 2 is PE lid; 3 is FEU-200 PMT 4 is ZnS(Ag)+^{6}LiF scintillator; 5 is light reflecting cone.

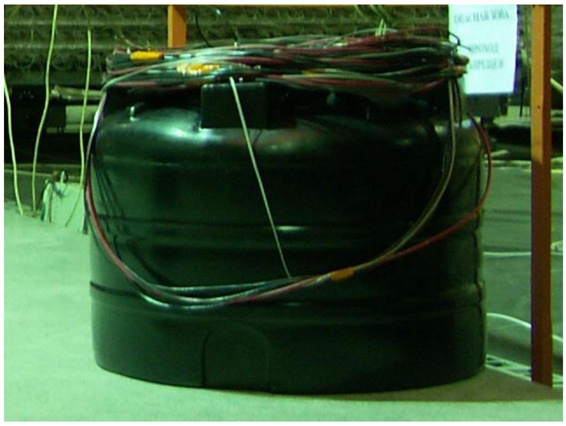


Figure 3. The photo of en-detector.

A multichannel fast FADCs (PCI slots) with a frequency of 1 MHz are used to digitize signals from the detectors. Time gate for neutron counting is 20 ms. The pulses are integrated with the time constant of 1 μs using a special discriminator-integrator-unit (DIU) of front-end electronics.

The first-level trigger is the coincidence of any two of the 16 detectors of the cluster with a threshold of five particles in a time gate of 1 μs [1]. On-line program analyzes the data and generates a second-level trigger depending on the event type (physical trigger, or marker): T1, in a case of coincidence of at least two cluster detectors with threshold of about 5 particles (mip) in the first time bin; T2, in a case when total energy deposit is more than 50 mip in one cluster; and T3, if the number of neutrons detected in a cluster exceeds 4. The program also records the energy deposit in each detector, the number of detected neutrons and temporal distribution of these neutrons with step of 100 μs, and saves this information on a hard disk if there is at least one second-level trigger (counting rate is about 1100 events per day, or 0.013 s^{-1}). Examples of oscillograms of recorded EAS events are shown in figure 4.

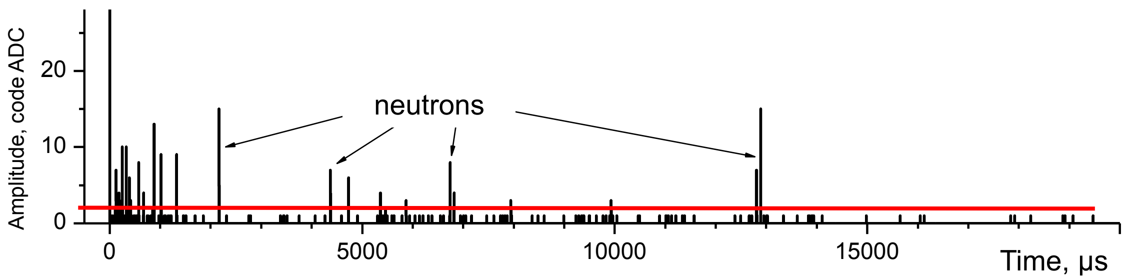
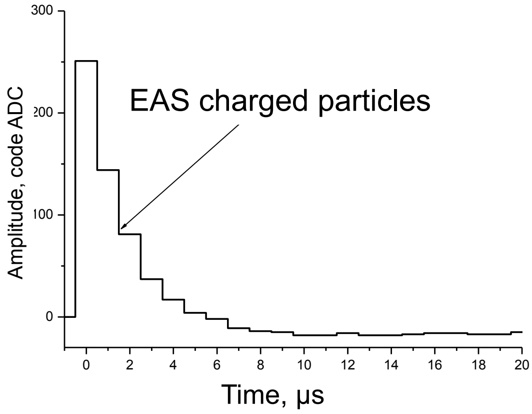


Figure 4. Example of a full oscillogram (20000 μs).



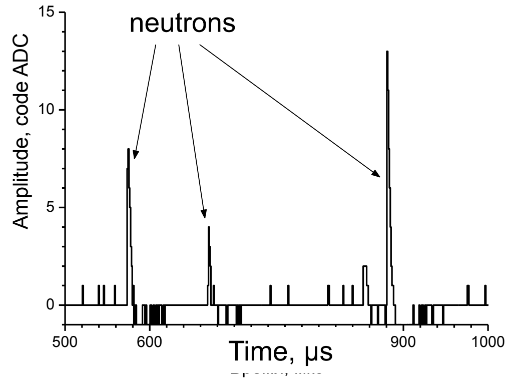


Figure 5. Example of the oscillogram of the EAS charged particles pulse.

Figure 6. Example of the oscillogram of the neutron delayed pulses.

3. Results

PRISMA-32 array is operated in the continuous mode of data taking. In the present paper, the data on temporal and lateral distributions of thermal neutrons in EAS obtained for 3.5 years are used.

Temporal distribution of recorded thermal neutrons (i.e. distribution of time delays relative to the EAS front) is shown in figure 7. Data were selected with T3 trigger and are presented for two clusters separately and for the whole array as well.

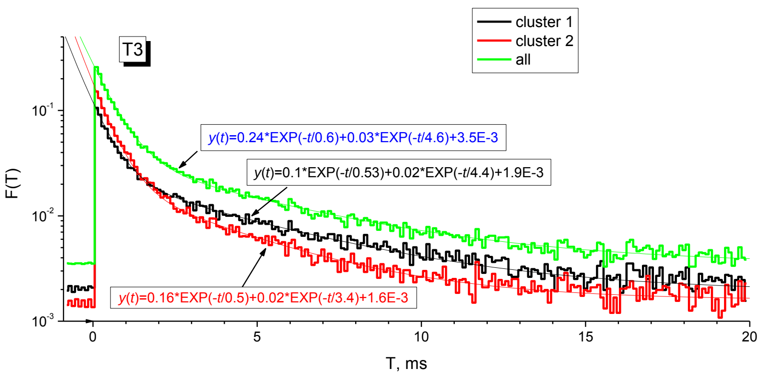


Figure 7. Temporal distribution of delayed thermal neutrons recorded by two clusters of PRISMA-32-array.

Obtained distributions can be fitted with double exponential function $y(t) = A_1\exp(-t/t_1) + A_2\exp(-t/t_2) + y_0$. Parameters of each curve are somewhat different. It is due to different layout of the clusters. The first cluster is a rectangle with distance between detectors 2.5 and 5 m, the second one is installed around the water pool along the walls of the experimental hall. Due to this layout, the first exponential parameter is a little bit less because of the influence of the water and the second parameter is little bit less because of smaller distance between detectors and walls (distance to the walls is less than distance to the ceiling). First parameter (t_1) is connected with the mean lifetime of neutrons in concrete, i.e. neutrons produced under detector (locally-produced). The second parameter (t_2) can be connected with neutrons produced in ceiling and walls. Obtained fitting parameters t_1 and t_2 are close to those measured by us earlier [1,6].

The analysis of recorded EAS was made using the maximum likelihood method with NKG-function for electromagnetic component [5]. Position of the shower core, the shower age and its size N_e were found for each EAS. Only events with core located inside the array were selected. The distance from the located core to each detector was found, and lateral distributions of electrons and neutrons were obtained using detectors (figure 8).

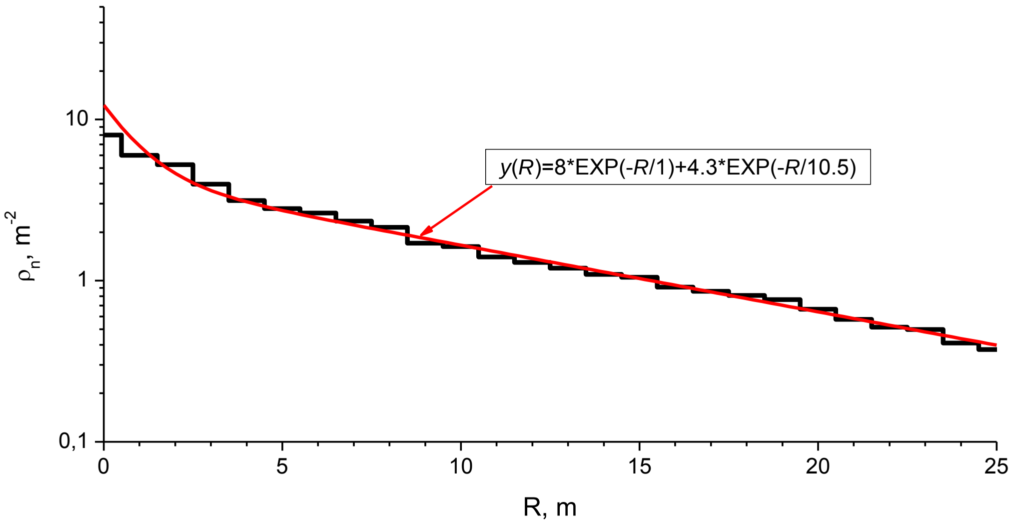


Figure 8. Lateral distribution function of EAS thermal neutrons.

From the figure one can see that data can be fitted with double exponential function $y(R) = A_1\exp(-R/r_1) + A_2\exp(-R/r_2) + y_0$ with parameters r_1=1 m and r_2=10.5 m. The first parameter can be connected with the mean distance of secondary neutrons from parent hadron [7]. The second one (r_2) is a typical distance of parent hadrons from the shower core.

4. Conclusion

Results of the PRISMA-32 array data analysis for 3.5 years of data taking are presented. Temporal distributions of EAS thermal neutrons for clusters with different layouts are obtained. EAS thermal neutron lateral distribution function inside the experimental hall was measured. The influence of the surrounding matter configuration and its chemical composition is demonstrated. Therefore, to compare different experimental data, measurements in the open air are needed. Obtained results are consistent with our preceding data on the temporal and lateral distribution of EAS thermal neutrons.

Acknowledgments

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