Status of the URAN array for detection of EAS neutron component

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Abstract. First prototypes of PRISMA-32 neutron detectors based on the ZnS (Ag) scintillator demonstrated the perspectives of their application for detection of neutrons in extensive air showers. Detected thermal neutrons are generated due to interactions of the hadronic component with the nuclei of the atmosphere or the matter surrounding the detector and carry important information about the energy of primary particles. A mixture of zinc sulfide with natural boron (ZnS + B₂O₃) is used in the URAN setup. Detectors of the URAN array are located on the roofs of NEVOD and neighboring laboratory buildings; the area of each detector is 0.36 m². The array consists of independent clusters of 12 detectors in each and is united by a central station of collection and processing of information. Two new clusters of the array were put into operation in 2017, synchronization with other NEVOD setups (NEVOD-EAS array and NEVOD-DECOR-SCT) was provided, and collection of experimental data was started with the area of about 10³ m². The first events of the EAS with neutrons have been registered and data on the temporal distribution of EAS neutrons have been obtained.

1. Introduction
In recent years, a new method for the study of EAS, based on the detection of thermal neutrons, which are generated due to interactions of the hadron component of EAS with the nuclei of the atmosphere and the matter near the facility, has been widely used [1]. This method allows detect the hadronic component throughout the facility area. The first results on EAS neutrons obtained at the PRISMA-32 facility [2] demonstrated the feasibility of this research method [3-5]. The next step in this direction was the creation of the URAN installation (an installation for registration of atmospheric neutrons), whose detectors are located on the roofs of the buildings on the territory of the MEPhI campus [6]. The location outside the building allows to minimize the influence of various structural elements on the registration of neutrons in the EAS, and to reach a much larger area in comparison with the PRISMA-32 installation. For the URAN setup, new en-detector with new scintillator and cluster type electronics that allows digitizing the signals with different frequencies was created.
2. Design of en-detector and registration system of the URAN installation

Design of the novel type en-detector is based on that developed for the PRISMA-32 array [4]. The construction of the en-detector is presented in figure 1. We use a black cylindrical (Ø740 x 570) standard commercial plastic water tank of 200 l volume as a light protecting housing. To improve light collection, a reflecting cone is used. On the top of the cone, the 6” photomultiplier tube (FEU200) looking to the scintillator at the cone bottom is located. The scintillator area is equal to 0.36 m\(^2\). Zinc coated 0.9 mm iron cylinder (Ø880 x 1100) with a conic roof is used for environmental protection.

A special inorganic compound scintillator (ZnS(Ag)+B\(_2\)O\(_3\)) with natural boron is used for the URAN array construction. It is made of grains of the compound alloy LRB-1 (Russian production) in a transparent silicon disk of 70 cm diameter and 5 mm thickness. Mass content of boron in the compound is equal to ~ 13%, while content of \(^{10}\)B is 2.6%. Total compound thickness is 50 mg/cm\(^2\).

![Diagram of en-detector design](image)

**Figure 1.** The en-detector design.

The signal is produced by heavy charged particles (\(^4\)He and \(^7\)Li) which lose their energy inside one grain. Scintillator ZnS is effective enough for heavy particles and has a record α/e separation ratio.

The recording system of the URAN array clusters consists of twelve boards of amplitude analysis with two integrated controllers BAAC12. Structural scheme of the URAN array electronics is shown in figure 2. The use of two boards per cluster is necessary to increase the dynamic range of the registration of the electromagnetic component.

BAAC12 board has six dual-channel 12-bit ADC with 200 MHz sampling, it receives signals from the detectors (D\#1-12) and implements the processing at a given logic. Boards are installed in the Local Post (LP) of the primary data processing, which, like the detectors, is located on a building roof. A controllable unit of the high-voltage power supply and a data transmission system are also located in the LP. Each local post is equipped with a thermostabilization system consisting of a temperature sensor, a fan and a heater to ensure stable operation temperature of the electronics. Transferring of analog signals from the detectors to the amplitude analysis boards is carried out by means of coaxial cables of the same length (25 m).
Figure 2. Structural scheme of the URAN array registration system.

BAAC12 boards are combined in the local post. Data transmission from the LP to the central post of data acquisition and processing (CDP) is carried out by means of fiber optic lines. CDP consists of the PC on which a client program, allowing to carry out a set-up and start-up of the boards is installed. The synchronization module and data storage and data transfer systems are also located in the CDP. In addition, the CDP is receiving and storing data coming from the boards.

All 12 cards work synchronously of the same frequency, due to the synchronization module. The input signal from the PMT of the detector passes through the integrator-amplifier (IA) for the 12th dynode and through the integrating pre-amplifier (PA) for the 7th dynode, in both cases the time-integration constant is 1 μs, comes to BAAC12-200. It passes through a matching transformer used for galvanic isolation, and then is fed to the ADC. Then the signal is digitized with a step of 5 ns and enters the digital comparator, wherein the data are also written to the buffer. If incoming signal exceeds the threshold of the digital comparator, the “REQUEST” signal is generated, and the value of the internal timer is stored. If the number of “REQUEST” signals for a certain period is greater than or equal to the number specified by trigger conditions, than the “TRIGGER” signal is generated. The “TRIGGER” signal stops recording of the data in the buffer and forms a data packet. In the data packet recorded digitized signals from 12 channels and time of the internal timer are stored: for BAAC12-200N card 1024 samples with steps of 5 ns and 20,000 samples with steps of 1 ms, and from BAAC12-200 card 1024 samples in steps of 5 ns are recorded. The boards implement the internal buffer of 50 packets for security of information in the case of heavy traffic when transmitting to the CDP. To send data, the TCP / IP protocol is used.

Time synchronization of clusters with an accuracy of 10 ns is performed using global positioning systems (GPS/GLONASS). Each BAAC12 board has an internal timer whose value is saved and passed along with the event. Also synchronization module ensures simultaneous starting of this timer in order to set the initial value. The synchronization module performs periodic polling of internal time of boards (once per second), and in case of difference aligns their values.
3. Registration of EAS
Registration of the EAS takes place on the leading edge of the shower and then the oscilloscope is open for writing in the time window of 20,000 microseconds, where the neutrons accompanying the shower are detected. Clusters work independently and have the same criteria for triggering and recording of events. During the series of measurements, it was required that the signals from two or more detectors have amplitudes at least 16 mV. Figure 3 shows the oscillogram obtained by recording the electromagnetic component of the EAS in four detectors of the cluster, the step of digitization is 5 ns, and the oscillogram of the detected delayed neutron with a sampling step of 1 μs. The signals from neutrons of the EAS whose amplitude is ≥ 10 mV are registered after the electromagnetic component. Also, the signal duration from neutron should be at least 4 μs. Figure 3 shows pulses of electron component and five neutrons detected during 20 ms time window (right panel).

![Figure 3. Waveforms from the charged component (left) of the EAS and neutrons accompanying the shower (right).](image)

4. Results
The current configuration of the URAN setup consists of 5 clusters. The temporal distribution obtained with the 5 clusters (Cl1-Cl5) of the URAN array and their total amount (AllCl) of the EAS detection is shown in the figure 4. The time step is 100 μs. The distribution obtained for events with a trigger condition ≥ 6 detectors was fitted by an exponential function:

\[ F(t) = A_1 \times \exp(-t/t_1) + y_0 \]

with the parameter of the function \( t_1 = 646.8 \pm 19.8 \) μs.

The obtained value can be compared with the data on the temporal distribution of neutrons in the EAS measured with the PRISMA-32 array. This distribution can be described with a double exponential function:

\[ F(t) = A_1 \times \exp(-t/t_1) + A_2 \times \exp(-t/t_2) + y_0 \]

with the parameters \( t_1 = 0.49 \pm 0.01 \) ms. and \( t_2 = 3.44 \pm 0.2 \) ms.

As it is seen, the function parameter in the URAN array is consistent with the parameter of the first exponent in the PRISMA-32 array. The obtained result confirms the previously made assumption that in the PRISMA-32 array the second exponent \( (t_2 = 3.44 \pm 0.2 \) ms) has a connection with the neutrons generated due to interactions of the hadronic component with the roof or walls of the building (the
PRISMA-32 detectors are located inside the building under concrete overlap). And the first exponent is related to the average lifetime of locally born neutrons in the matter under the detector.

\[ F(t) = 0.00578 \exp\left(-t/646.8\right) + 0.00078 \]

**Figure 4.** Temporal distribution of neutrons measured with the URAN array.

5. Conclusion
The first stage of the URAN installation for registration of the neutron component of the EAS was created. The installation consists of five clusters of 12 en-detectors capable to detect electrons and thermal neutrons of extensive air showers. The first series with five clusters of the URAN installation were carried out. The first results of data processing showed the possibility of the URAN setup for reliable registration of the neutron component of the EAS. The temporal distribution of the EAS neutrons in the URAN facility is described by a one exponential function whose behavior is comparable to that of one of the exponents obtained by measuring the time distribution of neutrons in the PRISMA-32 facility. The presence of the first exponent in PRISMA-32 data indicates the influence of the roof over the detector. This indicates that when measuring the neutron component of the EAS, it is necessary to take into account the location of the detectors and the distribution of matter around them, in which the neutrons are thermalized.

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