Electronic configurable neutron monitor for studying of atmospheric shower

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Electronic configurable neutron monitor for studying of atmospheric shower

Yu.V. Balabin
Polar Geophysical Institute, Apatity, Russia

balabin@pgia.ru

Abstract. A high speed recording system operated on a neutron monitor (NM) is developed at the Laboratory of Cosmic Rays, Polar Geophysical Institute (PGI). The system records the time a neutron arrives to the NM, in a file, the precision of recording being of 1 µs. The number of the tube is also recorded. The data thus contain the exact time and the place of each of billions of pulses arrived. The recording system is placed on a number of stations, such as Apatity, Barentsburg, Moscow, Neitrino (the Northern Caucasus). The system is used to study the phenomenon of multiplicity on NM, as well as other effects of short-time occurrence. In data handling by pulse selection from a given set of tubes, there is a possibility to modernize a conventional NM to get a device of a different design, due to the actual task. That is, it is possible to get a modernized neutron monitor of a specified design without its stop, disassembling and transformation. A number of electronic neutron monitors have been developed to study the multiplicity events. These monitors differed in different distance between the tubes (with 1-15 tubes omissible). The spacing function for multiplicity events has been obtained. The spacing function has been analyzed to show that great values multiplicities are the result of atmospheric hadron showers, while moderate values multiplicities are of a conventional origin. All the pulses entering the events, are checked if there are any disturbances in order to filter the false multiplicity events off the periodic interference.

1. Introduction
A unique high speed recording system installed on a number of neutron monitors (NM) allows carrying out experimental measurements to determine the size of hadron showers arriving to NM. The time of each pulse arrival from NM is recorded by the above system with precision of 1 µs. Remind that one pulse means one neutron, and being registered with the tube, the neutron disappears. Also recorded is the channel (tube) number of NM. The exact and detailed data obtained allow carrying out experiments with the data recorded on NM, the actual construction being preserved unchanged. A conventional 18-NM-64 may be modified into a "virtual" or an electronic device of any design. To do this, it is necessary only to have a special program to select, from the total number of data, the pulses of the given channels and the time of their arrival. For example, to construct an NM based on one tube, of K in number, or based on a pair of neighboring tubes K and (K+1). Any of the given configurations is capable of selecting multiplicity events by the algorithm accepted.

2. Multiplicity study on a conventional NM
A scheme of multiplicity formation on NM is shown in Fig. 1 (left) [1, 2]. An energetic nucleon (of hundreds MeV and GeV) interact with the lead nucleus in the NM shield. As a result of inelastic interaction, either the excited lead nucleus emits some neutrons, or nucleon breaks the nucleus into fragments which also emit neutrons. These are of a much smaller energy if compared with that of a primary particle. They move in lead and polyethylene more slowly, up to thermal energies, and are absorbed by the active volume of the detector (tube). As a result, in the electric section of NM there is a pulse series, with small intervals $\Delta t$ between them. Each pulse corresponds to one neutron recorded. The notion of infinitesimal here means that $\Delta t \ll \tau$, i.e., the average interval between NM pulses.

Presented on the right is a GEANT-4 modeled interaction between a 10 GeV neutron and NM [3]. The model shows the same result and proves our suggestion. A single particle can't produce multiplicity a event in different (except neighboring) tubes.

It is known from earlier experiments and from the time intervals distribution deriving that the average time interval between pulses on NM $\tau = 17 \mu s$. In addition, clearly seen within this distribution are the Poisson processes with the characteristic time of $\tau_1 = 110 \mu s \ 	au_2 = 430 \mu s$ [4]. We suppose that these are the characteristic times of fast processes similar to multiplicity [5]. Based on the characteristic times determined in the previous experiments, the following criteria have been worked out to select the multiplicity events in a common data body. The algorithm of multiplicity events search (i.e., of an isolated cluster of M pulses) is as follows: 1) a rather great interval $T_p$ before the beginning of multiplicity is present; 2) each subsequent pulse in a multiplicity event occurs not later than $T_0$; 3) the multiplicity event terminates when the next pulse arrives in a period of time greater than $T_0$. $T_p = 3000 \mu s$, $T_0 = 500 \mu s$. According to the algorithm, millions of multiplicity events with $M = 5-100$ have been detected and selected [6].

Figure 1. On the left. Here is the principle of multiplicity formation in NM. In interaction between the primary energetic particle and the lead nucleus there appear some neutrons. On the right, one can see a GEANT-4 modeled interaction between the energetic primary particle (10 GeV) and the lead nucleus. In dark blue, green and red lines are the trajectories of fast, moderate and thermal neutrons, correspondingly. In spite of high energy of the primary particle, the secondary neutrons are not able to pass through more than one tube.

We have obtained complete and detailed information on all the multiplicity events from $M = 5$ to $M = 100$. The next step in our study is to determine the average time profile of multiplicity events. Multiplicity events of the given $M$ were chosen. Selected among these were the first intervals (the time interval between the first and the second pulses in a multiplicity), followed by the calculation of its average value. This procedure was carried out for the second, the third, etc. intervals. As a result, we obtain the average time profile of multiplicity $M$. This was the way the time profiles for multiplicities from $M = 5$ to $M = 100$ were determined. Figure 2 shows the time profiles of multiplicities $M = 15$, $25$, $40$, $60$ and $80$. The profiles have a common singularity. There is a flat section in the multiplicity.
For example, the flat section contains 15 first pulses for $M = 25$. Then gradual increase to the end of the event is observed. This is characteristic for all $M$. It would be noted that any multiplicity $M$ has flat initial section on $(M-10)$ pulses. It is quite important because similar gradual increase of intervals to the end of the event indicates that the process terminating multiplicity is similar in all the events. NM relaxation is supposed to be the result of the effect of a dense of neutron flux [7].

3. Neutron monitors of various design

With all the detailed information concerning each pulse (the time of its arrival, with an accuracy of 1 $\mu$s and the tube number)) being presented in the data, there is a possibility, in data processing, to additionally stipulate that pulses should be selected only from certain tubes, for example, only from tubes numbered as 2 and 4, as shown in Figure 3 (top, right). In other words, having the NM construction physically unchanged, in data processing it is possible to construct an "electronic" neutron monitor of any design, for example, that consisting of tubes 2 and 17, as shown in Fig.3, (bottom panel). In doing so, the number of tubes may be as great as possible, so it is possible to set any NM-configuration.

While studying typical multiplicity events with the help of a number of electronic devices consisting of tube $K$ and tube $(K+n)$ where $n$ changes from 1 to the greatest possible one, it has been...
shown that there are two types of multiplicity events. The first type is multiplicity consisting of pulses that have been generated in two neighboring tubes. The second type is multiplicity into which many tubes are involved, including K and (K+n), where n>> 1. Multiplicities of the first type (not above of the neighboring tube) are generated by a nuclear cascade in lead, which is induced by a single energetic particle. Multiplicities of the second type seem to originate from hadron showers in the atmosphere above NM because tens of pulses (neutrons) are generated only during hundreds of μs in tubes designed on the edges of NM. Remember that the average time between pulses is 8-10 μs. Also carried out here were the experiments when tubes were designed in a more complicated way, which resulted in the spacing function. All the combination of the experiments allows making a conclusion concerning the fact that events formed by only one nuclear cascade in lead are recorded only up to the number of multiplicity ~7. If the number of multiplicities is greater, there occurs the effect of a hadron shower in the atmosphere. The size of these showers is determined by the spacing function. GEANT-4 modelled has carried out the same result.

**Figure 4.** On the left. The sketch of local hadron shower falling on NM. Energetic nucleons (neutrons, mainly) are in green circles. All tubes in NM record neutrons during a short period of time (about hundreds of μs). It would be useful to obtain the spacing function for multiplicity, i.e. to study a number of NM with non-operating tubes. A non-operating tube means that pulses from it are not recorded, microseconds counting is going on until a pulse arrives from the tube marked as an operating one. The spacing function can really show the presence of atmospheric hadron showers. On the right. Multiplicities on electronic neutron monitors of various designs. Shown here is the relative amount of events of the specified multiplicity depending on the distance between tubes (the distance is given in tubes omitted). Multiplicities of M = 8, 15, 20 are actually available only for the electronic NM composed of the neighbouring tubes (tubes 2 and 3). Even one non-operating tube reduces the number of events by a factor of 2-3. The multiplicities of the specified values are practically absent on the electronic NMs with a great number of non-operating tubes. It is when M > 30 that the amount of events becomes considerable, growing and becoming practically uniform with M = 60.

Fig. 4 (right) shows that most multiplicity events of M <20 occur only in the neighboring tubes. The distance equal only to one tube (one omitted tube; the NM-construction corresponds to that shown in Fig. 3, top right) reduces the number of events by a factor of 2-3, and the distance of more than two tubes reduces the multiplicity number to the background one. When M = 30, one can observe that a part of multiplicity events is constant and significant, showing no dependence on the distance between active tubes. When M = 60, all the events are uniformly distributed. In other words, the spacing function for M <20 has obviously sharp peak at 0 (two neighboring tubes are used), and at the distance equal to two tubes the spacing function is close to 0. On the contrary, the spacing function for M = 60 is uniformly distributed from 0 to 14 omitted tubes.
Narrow form at the moderate multiplicity means that such multiplicities are produced by a single particle which comes to given tubes. It generates some neutrons only in neighboring tubes. Large multiplicity events are produced by a lot of particles i.e. a particle shower (like it is on Fig.4 left). We can estimate a distance of absolute neutron cumber along NM: it is 2-3 tube distance. There were studied electronic NM of “pair-pair” design. For example, there were used tubes 2,3 (first pair) and 16,17 (second pair) and so on. There is no significant difference from it.

4. Conclusions
The high recording system for a neutron monitor is developed at Polar Geophysical Institute. Due to it short-time phenomena are possible to be studied as multiplicity. It is possible to develop a number of electronic neutron monitors based on the conventional one. The spacing function of electronic neutron monitors is obtained. This function confirms the presence of two types of the multiplicity origin. Moderate multiplicity is produced by a single energetic primary particle. Great multiplicity is produced by the local atmospheric hadron shower. It is worth noting here that the high speedy registration system developed in PGI allows different studies of fast processes occurring on NM and lasting units and tens of μs.

References
[1] Dorman L I 1972 Meteorological effects of cosmic rays (Moscow: Izdatel'stvo Nauka) p 212 (in Russian)
[2] Dorman L I 1975 Experimental and theoretical foundations of cosmic ray astrophysics (Moscow: Izdatel'stvo Nauka) p 402 (in Russian)
[3] Maurchev E.A., Balabin Yu.V. 2016 Solar-Terrestrial Physics 23
[4] Goldansky V I, Kutsenko A V and Podgoretsky M I 1959 Counting statistics for the registration of nuclear particles (Moscow: Fizmatgiz) p 412 (in Russian)
[5] Balabin Yu.V., Gvozdevsk B.B., Maurchev E.A., Vashenyuk E.V., Dzhappuev D.D. 2011 Astrophysics and Space Science Transactions 7 283
[6] Germanenko A.V., Balabin Yu.V., Vashenyuk E.V., Gvozdevsky 2011 Astrophysics and Space Science 7 471
[7] Yu. V. Balabin, B. B. Gvozdevsky, and A. V. Germanenko 2015 Bulletin of the Russian Academy of Sciences. Physics 79 654