Anomalous Barometric Coefficient of Microsecond Intervals in Neutron Monitor

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Abstract: The paper presents the results of an unusual study aimed at determination of the barometric coefficient for various temporal intervals. It has become possible due to a new high-speed neutron monitor data acquisition system, which records both the count rate and the pulse-to-pulse interval duration to an accuracy of 1 μs. The barometric coefficient values have been found to deviate from the calculated ones at small values of the intervals. The aim of the study is to further investigate the nature of multiplicity on the neutron monitor.

Keywords: neutron monitor, multiplicity, barometric coefficient.

1 Introduction

The earlier studies [1-3] reported the results obtained by the high-speed neutron monitor data acquisition system used in neutron monitors (NM) operated in Barentsburg (Spitzbergen), Moscow and Baksan (North Caucasus). The system allows recording the pulse-to-pulse interval to an accuracy of 1 μs, which originates in neutrons recording by NM-detectors. The great database ($>10^{10}$ pulses) allowed obtaining the highly-accurate distribution of time intervals (Fig.1). In terms of statistics, the time intervals distribution is the main indicator of the processes occurring in the neutron monitor. Being normalized per 1, it shows the probability of an interval of t μs in duration in a data stream, being normalized per day, it shows an average number of the intervals t per day.

The exact consistency of the interval values with the exponential function within a wide range indicates that the process of neutrons origination inside the NM is of a random nature, being consistent with the Poisson law [4]. The amount of short intervals (t<2500 μs), however, has an excess, the shorter the interval, the greater the excess. Within the shortest intervals (t<200 μs), the excess over the Poisson distribution is more than order. This excess is also caused by the Poisson process superimposed on the basic process (more details are in the paper with ID 28 at the conference). As a whole, the experimental distribution is very well presented by the total of three exponential curves with characteristic times τ_3=24 ms, τ_2=460 μs and τ_1=130 μs. According to [4], it means the presence of three independent Poisson processes here, producing neutrons in the NM. By virtue of the values compared, τ_1 and τ_2 are effective values, and the value is τ_1'=180 μs proper. There is no doubt that the process with τ_3 is the flow of neutrons originating in the interaction of primary cosmic rays with the atmosphere. Let it be referred to as a simple process. The two others may be referred to as certain fast processes related to nuclear reactions inside the NM lead producer [5, 6]. The contribution of these fast processes makes ~18% of the total number of the neutrons recorded, with the 7-8% accounting for the fastest process with τ_1'=180 μs. It is impossible however to determine the nature of these fast processes only by the distribution of the intervals. This study has been carried out to clear out the nature of the fast processes inside the NM. The study is based on the assumption that the fast processes producing excess short intervals can be related to other components of secondary cosmic rays penetrating into the NM. The barometric coefficient (BC) of these components differs from the neutron one. The distribution of the time intervals at Baksan or Moscow is similar to that in Fig.1.

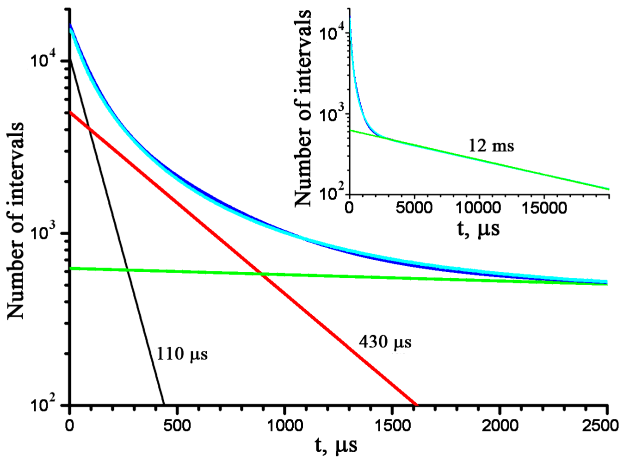

Figure 1: Time intervals distribution at Barentsburg station. Data for ~1400 days were used.

Reminded that, being recorded, the neutron disappears (is absorbed by a nucleus) during registration, so the rule effective in the NM is as follows: one electrical pulse from the detector means just one neutron detected.

2 Calculations and procedures

The Poisson distribution for a random process looks like that in [4]:

$$p_k(t) = \frac{(N_c \cdot t)^k}{k!} exp\left(\frac{-t}{\tau_c}\right) \tag{1}$$

where $p_k(t)$ is the probability to find k events (pulses, in our case) in time t; N_c is the amount of pulses per unit of time; τ_c is the characteristic time. It is remarkable that the relation below is correct for the Poisson process:

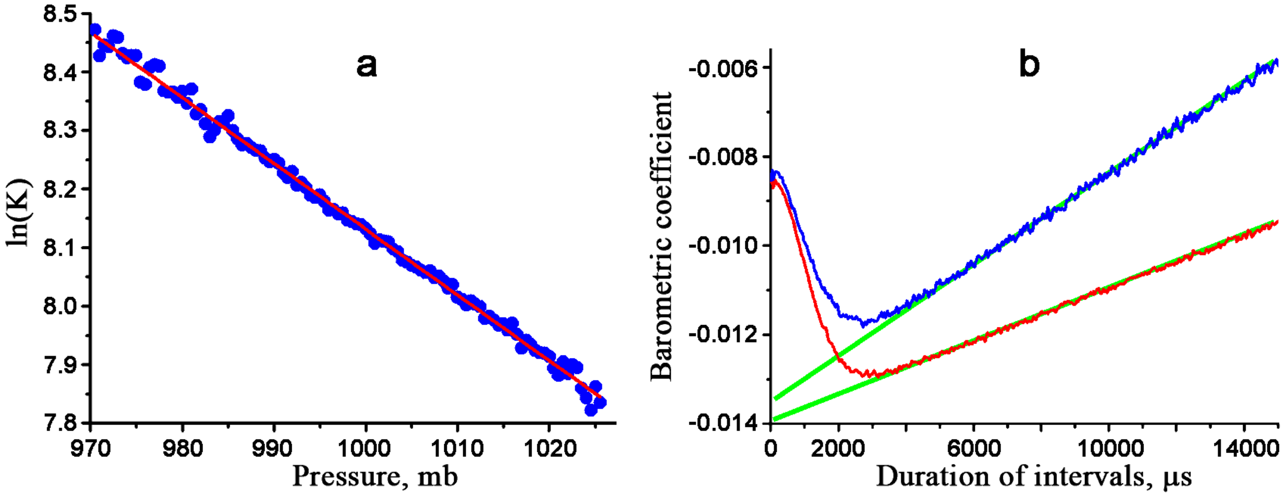

Figure 2: **a)** The dependence of the amount of the intervals in cell dt_{50} (1225-1250 μs) on the atmospheric pressure (Barentsburg st.). Circles are experimental data, line is approximation function. OY is the logarithmic scale and BC β_{dt_i} is just the slope of the line. **b)** BC β_{dt} depends on time intervals. Curves in red and blue are the experimental data from Barentsburg and Baksan stations, respectively, green lines are expression (7) for these stations.

$$N_c = 1/\tau_c \tag{2}$$

i.e. the characteristic time is the average interval between the pulses [4]. If expression (1) is correct for the number of pulses, the probability of occurrence of the interval t between pulses (the distribution of the intervals), with (2) taken into account, is the following:

$$w(t) = N_c \cdot exp(-t \cdot N_c) \tag{3}$$

and the total number of the intervals of t μs in duration makes for the period T is

$$Q(t) = w(t) \cdot N_c \cdot T \tag{4}$$

The value T may be omitted if to agree that (4) is related to unit time. In Fig.1 the intervals are distributed within the wide range of values t just exponentially. For the NM, N_c means an average rate of counting. The NM counting rate depends on both the intensity of the primary cosmic rays coming to the boundary of the Earth's atmosphere and the atmospheric pressure P. The dependence on the latter is determined by the value of the barometric coefficient NM [7] for neutrons. The NM count rate N_c is determined, depending on the pressure, as follows:

$$N_c = N_0 \cdot exp(\beta_{NM} \cdot \Delta P) \tag{5}$$

where N_0 is the NM uncorrected count; $P = P - P_0$ is the difference between the current pressure P at the station and the reference value P_0. The typical $\beta_{NM} \approx 0.007 mb^{-1}$. Substituting expressions (3) and (5) into (4) and making some simple transformations, we finally get the following:

$$Q(t) = N_0^2 \cdot exp(-t \cdot N_0) \cdot exp[-\beta_{NM} \cdot (2 - t \cdot N_0) \cdot \Delta P] \tag{6}$$

By analogy with expression (5), the factor at ΔP in the second exponential function may be taken as that matching BC β_{dt}, which relates the change of the number of the intervals of duration t to the change in the atmospheric pressure

$$\beta_{dt} = \beta_{NM} \cdot (2 - t/\tau_0) \tag{7}$$

Here account is taken of the connection between N_0 and τ_0, according to (2). It is interesting that the BC value is not constant, depending on the duration of the interval t. Note the basic peculiarities: when $t \ll \tau_0$, the value β_{dt} is equal to a doubled β_{NM}, when $t = 2\tau_0$, $\beta_{dt} = 0$, changing sign further. Using expression (7) it is possible to obtain the effective value of β_{NM}:

$$\bar{\beta} = \frac{\beta_{dt}}{2 - t/\tau_0} \tag{8}$$

Some explanation of the calculation results should be given here. In the course of the NM operation the atmospheric pressure changes, so do the average counting rate of neutrons (pulses) and, accordingly, the amount of the intervals of a certain duration between the pulses. Thus if the NM counting is determined only by the neutrons with BC β_{NM}, BC for different intervals t are expressed by (7).

3 Results and discussion

The BC calculation method is presented in [7]. It is necessary to have a rather extensive series of data covering as many days with different values of pressure as possible. It is necessary that the essential variations of the NM countings of the non-atmospheric nature (Forbush decrease, the GLE events) during the tested period be absent.

We have used the NM data from Barentsburg and Baksan obtained in the period of 2009-2012, accounting for ~1400 days. During these years there were some periods with several Forbush decrease, so these periods have been excluded. The temporal scale was divided into cells of an equal size dt (the size was set to be equal to 10, 25 and 100 μs for different variants of processing). The pressure scale was divided into cells of 0.5 mb in size. It has been done to increase the accuracy. The amount of intervals recorded in each cell per day has been counted. For example, in a 10 μs-sized cell, the amount of intervals of 0-10 μs in duration was recorded (cell dt_1), those of 10-20 μs (cell dt_2), those of 20-30 μs (cell dt_3), etc. Simultaneously, based on the NM one minute data, the daily average pressure was

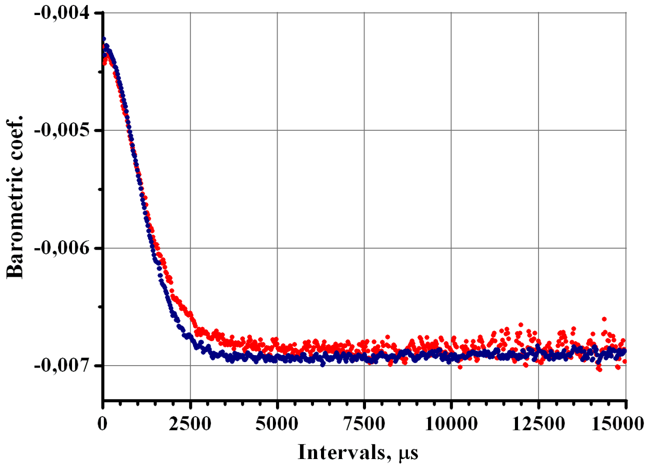

Figure 3: The dependence of the actual BC of the NMs on time intervals, derived from measurements, according to (8). Blue dots are Barentsburg station, red dots are Baksan station.

determined. As a result, an array of 1400 points has been obtained for any cell dt_i, containing the amount of the intervals per every day recorded in the cell, as well as the average pressure during the same day. The value of β_{dt_i} was calculated by the method of least squares for each array. As an example, the dependence of the amount of the intervals in cell dt_{50} (1225-1250 μs) on pressure is shown in Fig.2a. Fig.2b shows the dependence of β_{dt} on the interval duration t at Barentsburg and Baksan stations. When t>3000 μs, this dependence corresponds perfectly to (7), which confirms the correctness of the calculations made. According to (7), the curve slope for each station is determined by an average counting rate of the detector. The green lines are the analytical dependence β_{dt} according to (7). They do not converge in one point at t=0. It is due to the fact that there is the value NM peculiar to each station, which is a little bit different from the reference one [7].

When t<3000 μs, however, the experimental values β_{dt} deviate from the calculated dependence (7). It may happen only due to the change of the factor β_{NM}. Comparing Fig.2b and Fig.1, it is clear that the experimental values β_{dt} and the values of a simple Poisson distribution deviate at similar interval values. It has been shown [2, 3], that the excess of the intervals in Fig.1 is due to the contribution of two additional Poisson processes. The deviation β_{dt} from dependence (7) occurs just at the values of the intervals when the effect of additional processes (APs) is displayed, allowing assumption of the highly probable connection between these two effects. So the deviation β_{dt} means that AP have the value of BC different from β_{NM}, being produced by other particles. Note that within the intervals (t<200 μs) APs are over a simple process more than an order, it is AP that determine the properties of distributions for these t. As t grows, the AD contribution into the amount of the intervals decreases, with a greater role played by a simple process, with the value BC β_{NM}.

Fig.3 shows BC calculated by (8) in the NM for different durations of the intervals. In this case it is clearly seen that as the interval t decreases, the coefficient value changes from the reference value ∼0.007 for t>3000 μs to ∼0.0042 for t<200 μs. The other value BC means that the other component of cosmic rays different from the neutron one is being recorded.

It has been found in [5] (and references within) that ∼7% of the NM counting is due to the contribution of muons. Muons are not registered on the NM directly, though some of these come into nuclear interactions (through lead mesoatom formation), being captured further by the nucleus, then the excited nucleus of lead emits some neutrons with the characteristic time ∼170 μs. It has been mentioned above that a share of AP with τ_1'=180 μs makes 7% of the total NM counting. The close values of BC and of the share contributed indicate that AP with τ_1'=180 μs in the NM are caused by the muon component.

4 Conclusions

The study aimed at the distribution of the intervals between the NM pulses has revealed that within small intervals the barometric coefficient values deviate from the reference NM values. This deviation occurs within the periods corresponding to those of muons recording on the NM (by the mesoatom formation and its being further captured by the nucleus). Due to our high-speed recording system we have found that the significant part of fast processes in NM (with characteristic times of about hundreds μs) is caused by the muon interaction in the lead producer.

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References

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