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MULTIPLIED NEUTRONS AS RESPONSE ON EFFECTS IN COSMIC RAYS

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ABSTRACT

The method to determine parameters of cosmic ray proton spectra variations by using data of the neutron monitor, which can measure neutron multiplicities, is discussed in this work. An accuracy of obtained results is estimated and possible applications of the proposed method are discussed. Using examples of Forbush decreases and solar ground level enhancements it is shown how multiplied neutrons reflect changes cosmic ray energy spectrum.

1 Introduction:

For studies of cosmic ray energy spectra variations it is necessary to have several detectors with different energy sensitivity to primary cosmic rays, i.e. with different response functions of primary and registered variations. Neutron monitors situated at different altitude above the sea level (Dvornikov et al 1972) are used in the spectrographic method for separation and investigation of cosmic ray variations of magnetospheric and interplanetary origin (Dorman et al 1968). Other approaches are possible as well, for instance, neutron monitors situated in geographical points with different geomagnetic cut-off rigidities have, apparently, different energy sensitivity. However, all these methods need data from several cosmic ray stations, so it is reasonable to elaborate a variant of the spectrographic method for which data of only one detector and from one point of observation are necessary. A registration of neutron multiplcities by the neutron monitor provide such possibility. The neutron multiplicity is determined by a number of neutrons generated in one act of cosmic ray interaction with a Pb nuclei in the neutron monitor and registered by neutron counters. A multiplicity value is increased with energy of incident particle, so, different neutron multiplicities have a different energy sensitivity to incident particles and, therefore, to the primary cosmic radiation. This allows to use neutron monitor data obtained for different multiplicities in the spectrographic method.

2 Methods and Results:

If a spectrum of primary variations is assumed as a power law $\delta D(R)/D(R) = BR^{-\gamma}$, then spectrographic equations for neutron multiplicities are similar to analogous equations for the cosmic ray intensity variation (Dorman et al., 1968):

$$\frac{\delta I_k}{I_k} = -\delta R_C W_k(R_C) + B\int_{R_C}^{\infty} R^{-\gamma} W_k(R)dR\,, \tag{1}$$

where I_k - a number of events with neutron multiplicity k, $\delta I_k / I_k$ - a relative variation for a k-multiplicity, $W_k(R)$- response functions for a k -multiplicity, δR_C - variations of geomagnetic cut-off in a point of observation with geomagnetic cut-off R_C; R - a magnetic rigidity of particle. Data for different multiplicities $I_1, I_2, I_{3=5}$ were used for solving of the spectrographic equations (1) and determination of three unknown parameters $\delta R_C, B, \gamma$. The response functions are assumed in a form $W_k = \alpha(\beta-1)R^{-\beta}\exp(-\alpha R^{1-\beta})/(1-\exp(-\alpha R^{1-\beta}))$ (see Dorman & Shkhalakhov (1972)). Parameters α,β were adopted from results of measurements aboard the «Akademik Kurchatov» ship in the year of 1982 and presented in Table with rigidity values for the maximum of response functions and maximum values of the response functions. The main reason, why data of neutron multiplucities are not used widely, is that they can be easly changed by the effect of random coincidences, i.e. when multiplied neutrons from several different acts of nuclear reaction are registered. As a result, multiplicities are redistributed and some miss-interpretation of relation between multiplicity and energy spectrum variations are possible. The registration of neutron multiplicities with automated compensation of the effect of random coincidences is used at the Magadan cosmic ray station for removing this obstacle. The method was proposed by Korotkov (1986) and it can be expressed by formulae

k	α	β	R_{max},GV	W_{max},%/GV
1	7.155	1.808	4.21	4.58
2	10.255	1.951	5.43	5.99
3-5	14.401	1.979	7.43	3.53

$$I_k = \sum_{n=1}^{N} \sum_{m=1}^{n} \frac{(-1)^{m-1} N}{m \binom{N-m+m}{m}} \sum_{\binom{n}{m}} R^{(n)}_{k_1+k_2+\ldots+k_m=k} \,, \qquad (2)$$

where I_k is a number of events with multiplicity k with compensation of random events up to an order of N; $R^{(n)}_{k_1+k_2+\ldots+k_m=k}$ - is a number of events with multiplicity k in m sections under the condition that neutrons are registered in n sections; N is a total number of neutron monitor sections. The neutron monitor at the Magadan station has three identical sections, so in the expression (2) N=3.

For a qualitative analysis of changes in the energy spectrum of cosmic rays we may use an average neutron multiplicity, which is determined by a ratio of a number of registered neutrons to a number of nuclear reactions in the monitor: $\bar{k}_I = \sum_{k=1}^{\infty} kI_k \Big/ \sum_{k=1}^{\infty} I_k$. A value of average multiplicity increases for harder spectrum, so there is a possibility to estimate qualitatively energy spectrum variations. A number of nuclear reactions can be determined by another manner, if the registration is performed with "dead" time t, because multiplied neutrons, corresponding to the same nuclear reaction except the first, are not registered for a rather large value of the 'dead" time (here we use $\tau = 3600 \mu s$). The obtained data of I_t values should be corrected by losses of nuclear reactions coincided within limits of the "dead" time $I_0 = I_\tau / (1 - (\tau / T) I_\tau)$, where T - is a time interval of the registration. In this case the average multiplicity would be determined as

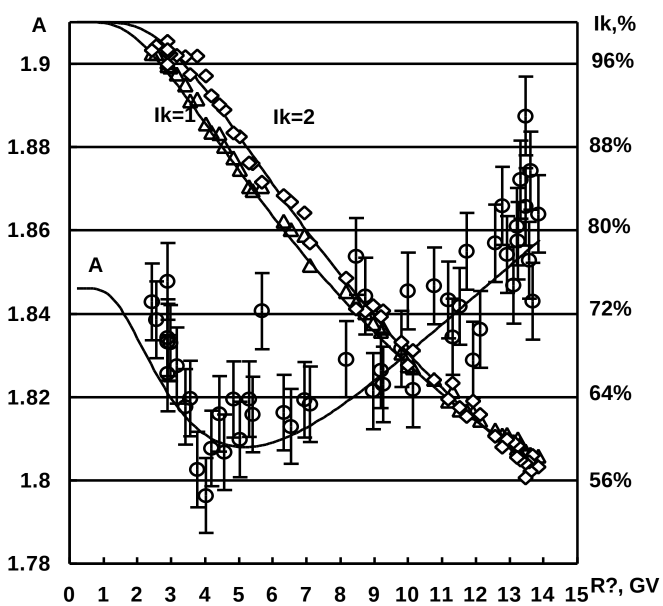

Figure 1: Intensities with different multiplicity k - I_k and an exponent A of the exponential distribution of multiplicities as a function of cutoff rigidity R_c (1982 latitude survey).

$$k_0 = I / I_0 \qquad (3)$$

Results of the calculations for several Forbush-decreases and solar ground level enhancements were presented by Korotkov (1998). In this work parameters of the power law energy spectrum of variations

γ, B and variations of geomagnetic cut-off rigidity δR_C were obtained. A solution of the spectrographic equations (1) is complicated by fact that a statistical error for neutron multiplicities quickly increases with increasing of multiplicity value (for the first multiplicity a standard deviation is about 0.3%, for the second – 0.7%, for the third – 1.4%). Also, an assumption of energy spectrum variation in a form of the power law is not correct and a more complex spectrum should be assumed. Besides, corrections for the response functions are possibly necessary. By these reasons reliable results for variations $\delta R_C, B, \gamma$ were not obtained in this case. However, variations of neutron multiplicities contain information on variations of the energy spectrum of cosmic rays, this information is reflected in changes of the multiplicity distribution. The multiplicity distribution can be approximately expressed as an exponent function: $I_k \propto \exp(A_k)$.

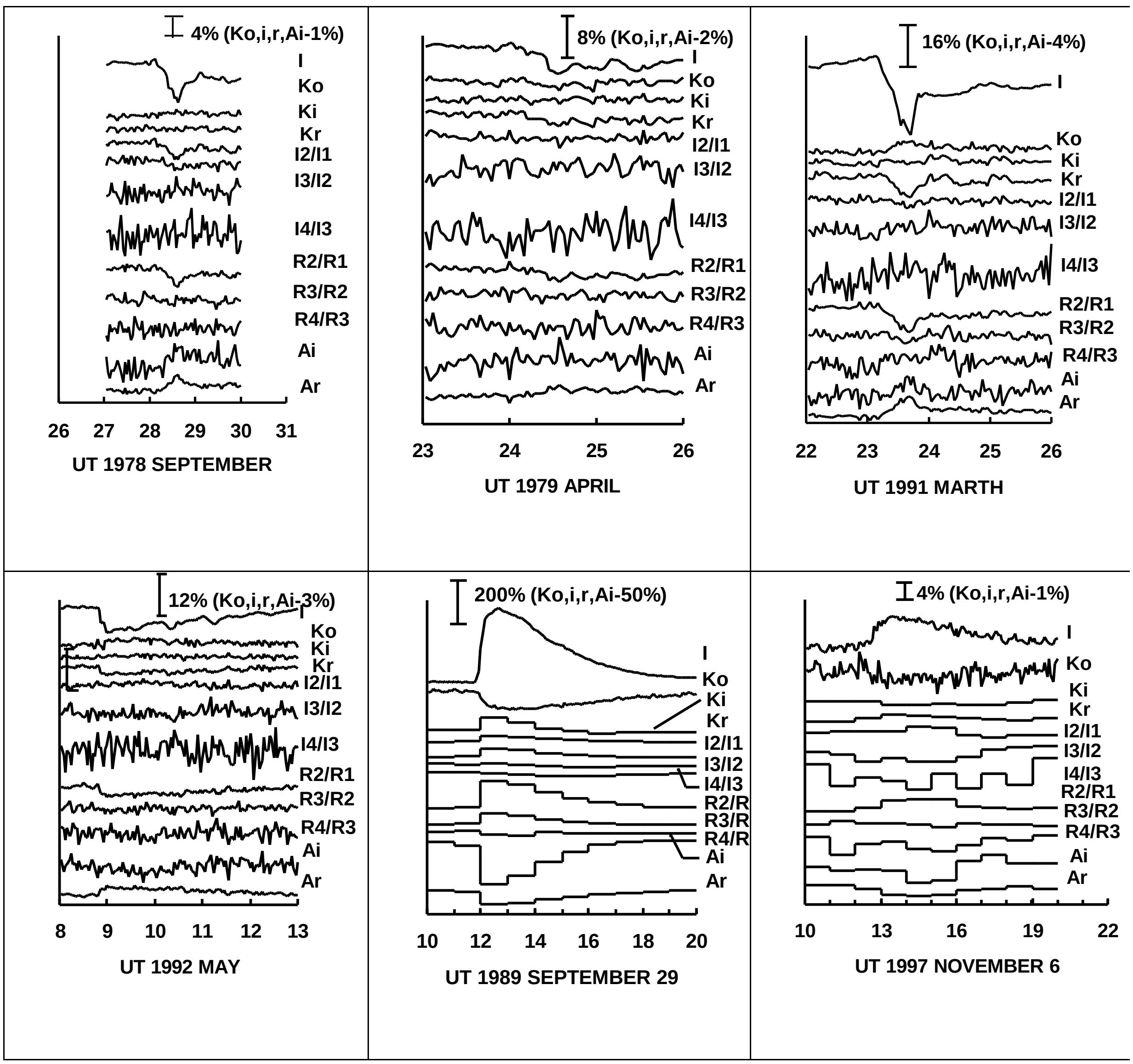

Figure 2: Some cosmic ray effects for neutron intensity I: the mean multiplicity K_o calculated as a ratio of the intensity I to the intensity recorded with dead time (5-min data I and K_o for solar ground level enhancements); the mean multiplicity K_i and K_r; the exponent of exponential multiplicity distribution A_i and A_r. The subscript i and r marks data, which account and not overlapping corrections respectively. Ratios of intensities with different multiplicity k I_k/I_{k-1} and R_k/R_{k-1} with and without overlapping corrections.

Figure 1 shows a dependence of count rate for the first and second multiplicities on geomagnetic cut-off rigidity, as measured during the expedition in 1982, and curves $I_k = I_0(1 - \exp(-\alpha R^{-\beta}))$

approximating these dependencies. Parameters I_0, α, β are presented in the table. Then, we have $A = \log(I_1 / I_2)$. Figure 1 shows as experimental points well as an approximating curve for the exponent . Figure 2 presents a time history of the exponential distribution of multiplicities during Forbush-decreases and ground level enhancements. Figure 2 presents ratios of multiplicities, which show a different response of multiplicities on changes of the energy spectrum of cosmic rays. Let us mention an importance of removing of the random coincidence effect. It is clearly seen on a time history of registered average multiplicity, which just follows the intensity time-history. Decreasing of average multiplicity with corrections of random coincidences k_i and k_0 during solar proton events corresponds to arrival of solar protons with low energies and, therefore, softening of energy spectrum of incoming cosmic rays. Similarly, during Forbush-decreases the energy spectrum of cosmic rays becomes harder and an average multiplicity increases. If the energy spectrum of cosmic rays does not changed, then changes of average multiplicity, multiplicity ratios and exponent of the multiplicity distribution would not be observed.

3 Conclusion:

Neutron multiplicities registered by the neutron monitor and corrected for the effect of random coincidences in accordance with (2) provide information on variations of cosmic ray energy spectrum.

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