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The method of determination of solar neutron spectra with two neutron monitors.

V.Kh. Babayan, H.S. Martirosian
Cosmic Ray Departament, Yerevan Physics Institute, Yerevan, 375036, Armenia

Abstract
According to the method proposed the registration of statistically significant signal of solar flare neutrons by two monitors located on the different altitudes but at the same geographical point is supposed. By comparative analysis based on the data of two monitors the parameters of the solar neutron energy spectra will be determined. The method is supposed to use at neutron monitors data processing, situated on the Aragats Mt., (Armenia) 2000 m and 3200 m above sea level.

1 Introduction:

An excessive neutron flux was first recorded with the help of neutron monitor (NM) during the solar flare of November 19, 1949. At the interpretation of these data it was assumed that the neutrons reaching the Earth are produced at interactions of charged particles accelerated in the field of the Sun with nuclei of solar atmosphere . After interactions the neutrons propagate straight-forwardly and reach the Earth in 10-20 minutes [1]. In the years that followed, quite a number of solar flares concomitant with generation of neutrons was registered with the help of ground based devices.

The energy and direction of propagation of solar neutrons is practically unchanged in the interplanetary space and provide important information on the location of a flare, the nature of nuclear interactions on the Sun, the acceleration mechanisms of high-energy particles etc. Highly important from this point of view is a correct and thorough determination of the energy spectra of solar neutrons by means of the methods of ground based measurements, in particular, the neutron monitor.

The determination of differential energy spectra of solar flare neutrons by means of a single neutron monitor measuring the time lag with respect to the maximum of intensity of hard X-rays is not quite correct since here it is assumed that the flare neutrons are generated simultaneously. In reality, the time span at the production of solar neutrons on the Sun is commensurate with the length of the binning range of the detectable neutrons.

2 Detection of the Excess of Solar Flare Neutrons with the Help of NM:

The neutron monitor detects mainly the neutrons produced in the atmosphere as a result of interactions of nuclear-active particles of the primary cosmic radiation. During high-power solar flares followed by generation of neutrons, one can observe a statistically confident excess of solar flare neutrons by means of NM against the background of weakly fluctuating neutrons of atmospheric origin at about the local noon time. A measure of statistical confidence of the observed excess of solar neutrons is

$$m = (N_{on} - N_{off}) / \sqrt{N_{on} + N_{off}}$$

where N_{on} **-** N_{off} is the number of solar flare neutrons detected by NM during the time lapse Δt , N_{off} is the number of background atmospheric neutrons. The more is **m**, the less is the probability that the observed excess is due to the fluctuation of background.

The onset of production of solar flare neutrons is determined by the maximum intensity of hard X-rays of the Sun. If the instant of detection of maximum intensity of X-rays is t_o , t_1 and t_2 are the start and end of the time interval of solar neutron detection ($t_2 - t_1 = \Delta t$), and their production time on the Sun is $\Delta T << \Delta t$, then

$$T_s = t_1 - t_o + R/c$$

$$T_E = t_2 - t_o + R/c$$

are respectively the times of arrival of the highest and lowest energy neutrons at the Earth. **R** is the distance from Sun to the Earth. The lower and upper boundaries of the energy range of detected neutrons are respectively $E(T_E)$ and $E(T_s)$.

Hence, after each solar flare one can determine with the help of NM the total number of neutrons arriving at the observation point within the energy range [$E(T_E)$; $E(T_s)$]. Here, if **I(E)** is the differential energy spectrum of solar neutrons at the boundary of the Earth's atmosphere, then the excess of neutrons to be detected at the depth **X** g/cm^2 may be written as

$$N_n = N_{on} - N_{off} = S \cdot \Omega \cdot e \cdot \Delta t \cdot \int_{E(T_E)}^{E(T_s)} I(E) \cdot Y(E, X) dE \qquad (1)$$

where **S** and **Ω** are respectively the effective area and solid angle of the arrangement, **ε** is the neutron detection efficiency, **Y(E,X)** is the neutron yield function. By approximating the results of Monte-Carlo simulation of the neutron traversal of the Earth's atmosphere with the help of KASKAD code, the following expression for the yield function has been obtained

$$Y(E, X) = a + b \cdot \ln E$$

where **a** and **b** are dimensionless parameters depending on the depth **X**.

3 The Method of Two Neutron Monitors:

Consider a system of two NM that are set at the same geographical coordinates but different atmospheric depths X_1 and X_2. If a statistically significant excess of solar flare neutrons is registered simultaneously by two NM, then the relation (1) could be written for each neutron monitor independently as

$$N_{n1} = A \cdot \int_{E_1(T_E)}^{E_1(T_S)} I(E) \cdot Y(E, X_1) dE$$

$$N_{n2} = A \cdot \int_{E_2(T_E)}^{E_2(T_S)} I(E) \cdot Y(E, X_2) dE \qquad (2)$$

where $\mathbf{N_{n1}}$ and $\mathbf{N_{n2}}$ are the numbers of flare neutrons as detected by means of neutron monitor at depths $\mathbf{X_1}$ and $\mathbf{X_2}$, $\mathbf{A=S \cdot \Omega \cdot \varepsilon \cdot \Delta t}$. If there are two unknown parameters in the differential energy spectrum of flare neutrons (e.g., **k** and **γ** in the power law spectrum of flare neutrons $\mathbf{I(E)dE=k \cdot E^{-\gamma} \cdot dE}$), then one can uniquely determine these parameters and, hence, also the spectrum from the solution of the system of equations (2).

From the NM-s that are in operation in the worldwide network of stations, one can use the neutron monitors in Tokyo and on the Norikura Mountain.

Station	Altitude (m)	Rigidity of geomagnetic cutoff (GV)	Depth of atmosphere (g/cm^2)	Lattitude (^{o})	Longitude (^{o})
Tokyo	20	11.5	1059	35.8 N	139.8 E
The Norikura Mountain	2770	11.4	753	36.1 N	137.6 E

At the Cosmic Ray Station “Nor-Amberd” of the Yerevan Physics Institute (the Aragats Mountain, Armenia) there is 18-NM-64 neutron monitor that is presently effective. It is envisaged to put into operation in 1999 a similar NM at the Cosmic Ray Station “Aragats”.

Station	Altitude (m)	Rigidity of geomagnetic cut (GV)	Depth of atmosphere (g/cm^2)	Lattitude (^{o})	Longitude (^{o})
Aragats	3200	7.6	715	40.2 N	44.5 E
Nor-Amberd	2000	7.6	810	40.2 N	44.5 E

The data to be obtained with these two NM will enable the parameters of the differential energy spectra of solar flare neutrons to be determined according to the proposed scheme.

As is easily seen from the comparison of above two tables, the measurements at stations “Aragats” and “Nor-Amberd” are more advantageous since the detection of flare neutrons at the atmospheric depth of 1059 g/cm^2 (Tokyo) seems problematic.

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4 References:

1.Adams N., Braddick H.J., Z.naturforschung, 6a, 592, 1951.