SUGGESTIONS FOR IMPROVING THE EFFICIENCY OF GROUND-BASED NEUTRON MONITORS FOR DETECTING SOLAR NEUTRONS

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1. Introduction. On the occasion of the June 3, 1982 intense gamma-ray solar flare a significant increase in counting rate due to solar neutrons was observed by the neutron monitors of Jungfraujoch/1/ and Lomnicky Stit/2/ located at middle latitudes and high altitudes. In spite of a larger detector employed (12-NM64) and of the smaller solar zenith angle, the amplitude of the same event observed at Rome (see Figure 1) was much smaller and the statistical fluctuations of the galactic cosmic ray background higher than the ones registered at the two mountain stations, because of the greater atmospheric depth at which the Rome monitor is located.

We will study here the efficiency for detecting a solar neutron event by a NM-64 monitor as a function of the Sun zenith angle, atmospheric depth and threshold rigidity of the station; some suggestions for improving remarkably the detection efficiency will be given.

2. The efficiency of a standard neutron monitor for the detection of solar neutron events. The increase $\Delta I(X_\Theta)$ produced by a solar neutron event in the neutron monitor counting rate will depend on the amount of atmospheric matter in the Sun's direction, $X_\Theta = X/\cos\Theta$, where X is the actual atmospheric depth in g/cm^2 and Θ the solar zenith angle (see Figure 2). The observed relative amplitude is $\Delta I(X,\Theta)/I(X,P_T,t)$, where the nucleonic intensity background $I(X,P_T,t)$ is a function of atmospheric depth, threshold rigidity P_T and modulation level at the observation time t.

The standard error σ of the relative amplitude is produced by the fluctuations in the cosmic ray background $[\sigma(X,P,t) = \bar{m}(X,P_T,t)/\sqrt{I(X,P_T,t)}$ where $\bar{m}$ is in first approximation the mean detected multiplicity $]$, therefore will depend also on the size and type (IGY or IQSY) of monitor employed. In Figure 3 we show the expected change of the relative amplitude $\Delta I/I$ for a solar neutron event registered at the rigidity threshold of Rome (P_T = 6.3 GV), as a function of X and Θ.

For this computation we used the attenuation lengths $\lambda(X)$ of the nucleonic component estimated by BACHELET et al./3/ for a modulation level I(1033,0,t)=0.9 I(1033,0,May 1965). For the secondary neutrons of the solar neutron event a tentative attenuation length λ_n = 110 g/cm^2 was used. This value of λ_n was derived from the June 3, 1982 solar neutron event (see Figure 3). The expected change of the relative amplitude for a change $\Delta X = (X''-X')$ in atmospheric depth as a function of Θ is computed by

$$\frac{\Delta I(X',\theta)}{I(X')} \Big/ \frac{\Delta I(X'',\theta)}{I(X'')} = \frac{\exp[\Delta X/(\lambda_n \cdot \cos\theta)]}{\exp[\int_{X'}^{X''} dX/\lambda(X)]}$$

In Figure 3 the variation of the inverse of the standard error of the relative amplitude is also plotted. From this plot we may estimate that the value of the signal to noise ratio $[\Delta I/I] \cdot \sigma^{-1} \simeq 3$ obtained for the June 3, 1982 event registered at Rome ($\theta \simeq 20°$) becomes ~14 for the same NM-64 placed at an intermediate altitude of 750 g/cm^2. In Figure 3 the computations relative to $\theta = 0°$ are also reported because the results obtained here for $P_T = 6.3$ GV can be applied to any rigidity threshold by simply taking into account the latitude effect of the nucleonic component.

3. <u>Modifications of the standard neutron monitor for improving the efficiency of detecting solar neutron events.</u> The relative amplitude of the event $\Delta I/I$ for a given X, θ, t and P_T can be increased by decreasing the background cosmic ray intensity I. This could be done in two different ways: (a)- by changing the energy response of the standard neutron monitor towards lower energies and (b)- by modifying the omnidirectional property of the standard neutron monitor in order to have the maximum response for particles approaching the monitor from the Sun direction. A simple way to increase the low energy response and decrease the cosmic ray background is suggested by the energy dependence of the number of neutrons emitted by the nuclear disintegration in lead /4/ ; the number of detected correlated neutrons (multiplicity) will be also function of the energy of the colliding neutron /5/. It is expected that the secondaries produced by solar neutrons of energy $\lesssim$ 1GeV /6/ should influence mainly the intensity I_1 of the channel of detected multiplicity 1; for this channel the relative amplitude of a solar neutron event can be estimated as:

$$\frac{\Delta I_1(X,\theta)}{I_1(X)} \simeq \frac{\Delta I(X,\theta)}{I(X)} \cdot K(X) \quad \text{where } K(X) = I(X)/I_1(X) \;;$$

$$\sigma_1(X) = 1/\sqrt{I_1(X)} = \sigma(X)[\sqrt{K(X)}\,/\,\bar{m}(X)]$$

The signal to noise ratio increases by a factor $\bar{m}(X) \cdot \sqrt{K(X)}$, which is $\simeq 2$ for a NM-64 at sea level. In Figure 3 we show the expected change of the relative amplitude $\Delta I_1/I_1$ and of its $1/\sigma_1$ for a solar neutron event registered by a NM-64 at 6.3 GV, as a function of X and θ. The attenuation length $\lambda_1(X)$ of the detected multiplicity 1 was taken from /7/; K(X) is found to increase with altitude because $\lambda_1(X) > \lambda(X)$. When only the events with detected multiplicity 1 are registered, it is convenient to increase the probability of detecting the locally produced neutrons; this could be obtained by adding some BF_3-counters to the standard geometry without increasing the amount of lead; for instance, if the detection probability is increased by a factor 2, the signal to noise ratio $[\Delta I_1/I_1].\sigma_1^{-1}$ will increase by a factor 1.5-2.0. Moreover the background cosmic ray intensity can be largely decreased, at least at middle latitudes, by shielding the monitor with an appropriate structure able to reduce the flux of cosmic ray particles which approach the monitor from the portion of the sky never scanned by the Sun. For instance at 42N geographic latitude we might shield the monitor from ~20S to 90N. If the background intensity is reduced by a factor ~2 the signal to noise ratio increases by a factor~1.4. This effect can be improved remarkably if the monitor is mounted on a platform which rotates with the Sun; in this case the shielding structure may also cover the lateral sides of the monitor; a possible geometry of this solar neutron telescope is given in Figure 5. With this telescope the cosmic ray background can be reduced by a factor 10. In Figure 6 we show, for a proper network of 9 near-equatorial solar neutron telescopes, located at mountain altitude, measuring the intensity of the detected multiplicity 1 and with increased (by a factor 2) probability of detecting the locally produced neutrons, the contour-lines of $(\Delta I_1/I_1).\sigma_1^{-1}$ = A, 2A and 4A respectively, as a function of time (day and hour); the value of A given in Figure 6 was computed for an event with observed relative amplitude $\Delta I/I$ = 0.5 % for P_T = 6.3GV, X = 1010 g/cm², $\theta = 20^\circ$.

References.

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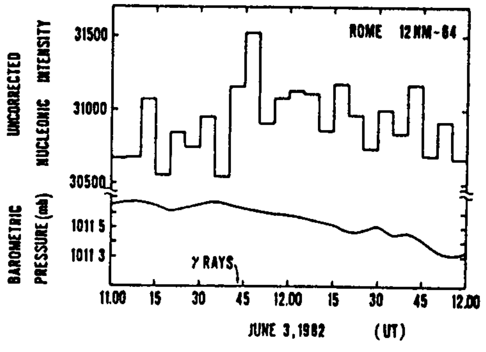

Figure 1

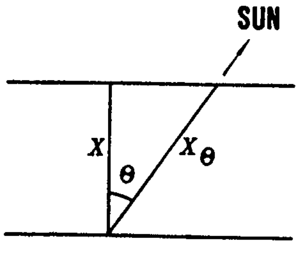

Figure 2

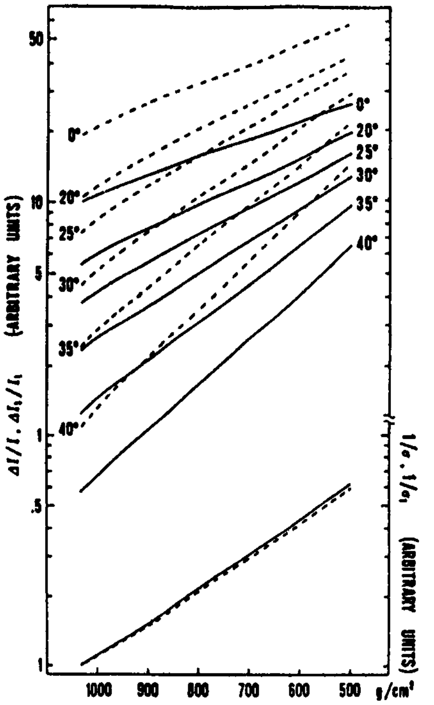

Figure 3: Changes of the observed relative amplitude and of the inverse of its standard error, for a solar neutron event registered by a neuton monitor located at R_T = 6.3 GV vs. atmospheric depth for different Sun zenith angles (total counts registered: full lines; multiplicity 1 counts registered: broken lines).

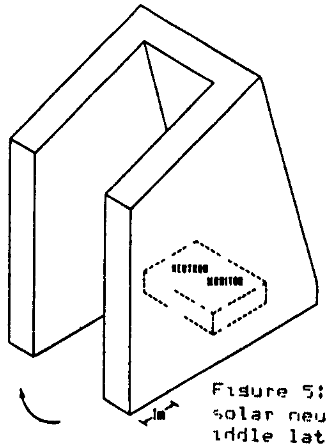

Figure 5: Sketch of a possible solar neutron telescope for middle latitudes (~40°).

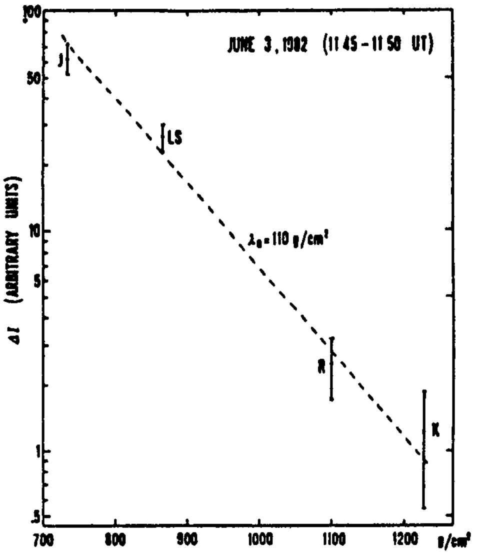

Figure 4: The absolute amplitude ΔI of the June 3, 1982 event for the JungfrauJoch(J), Lomnicky Stit(LS), Rome(R) and Kiel (K) stations vs. atmospheric depth to Sun X☉. The I are computed from the ΔI/I by applying the latitude and altitude changes of I.

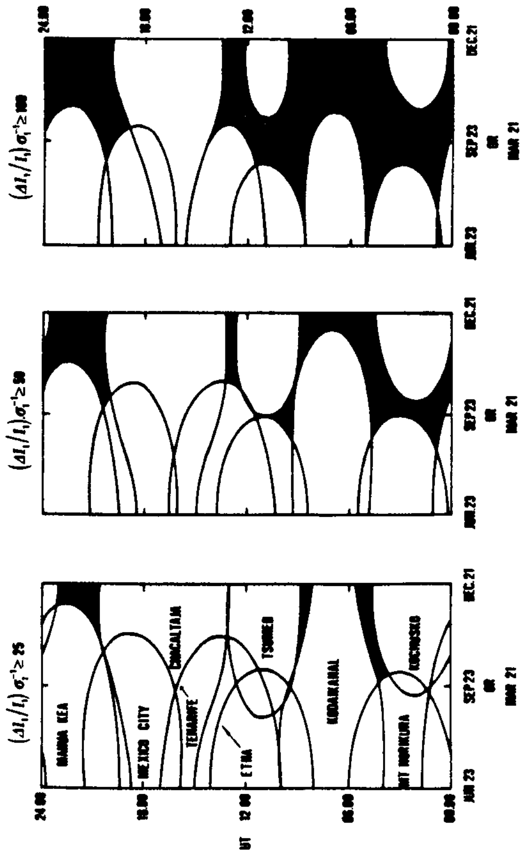

Figure 6