THE NEUTRON MODERATED DETECTOR AND GROUNDBASED COSMIC RAY MODULATION STUDIES

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ABSTRACT

Over the past years several reports have appeared on modulation studies with the neutron monitor without lead. Some of these studies cast doubt on the reliability of this detector. We report here on the stability of the neutron moderated detector (NMD) at Sanae, Antarctic. The barometric coefficient of the 4NMD for epoch 1976 appears not to differ statistically from the 0.73%/mb of the 3NM64. The monthly averaged hourly counting rate of our 4NMD and 3NM64 correlates very well (correlation coefficient: 98%) over the years from 1974-1984, with the 4NMD showing a 8% larger longterm modulation effect than the 3NM64, indicating a difference in sensitivities of the two detectors. From this difference in sensitivities spectra of ground level solar proton events and modulation functions of Forbush decreases were deduced.

1. Introduction. A neutron counter surrounded by a low Z moderator records at ground level secondaries produced by primary cosmic rays with primary energies down to ~ 1 GeV. The counting rate may be increased significantly when high Z materials are also part of the neutron monitor geometry because of the much larger rate of neutron production by cosmic rays in the heavier materials (Simpson and Uretz, 1953).

It was shown by Mischke et al. (1973) that the neutron moderated detector (NMD), consisting of BP28 Chalk River neutron counters surrounded by paraffin wax but without lead, is more sensitive to low rigidity (~ 1 GV) primary cosmic rays than the NM64 super neutron monitor. They reported on differential response functions deduced from aircraft latitude surveys at 30 000 feet pressure altitude for both the NMD and NM64 and on the altitude dependence of the counting rates of these two detectors at different cutoff rigidities. They have also shown that the fractional variations in counting rates of these two detectors are different during ground level solar proton events and that the hardness of the relativistic solar protons as described by the spectral rigidity function may be deduced from the relative increases in counting rates above the cosmic ray background.

In this paper we report on the performance of the 4NMD in comparison with the 3NM64 at Sanae, Antarctica (72°S 02°W). Zhu and Kawasaki (1983) occasionally observed fluctuations in the counting rate of a neutron monitor without lead in comparison with the counting rate of the Tokyo super neutron monitor. When raining the counting rate of the neutron monitor without lead was decreased, while the cause of many other fluctuations in counting rate could not be traced. Similar problems were experienced by other investigators. We found on the contrary that changes in counting rates of the 4NMD and 3NM64 correlate well with each other and that the relative changes in counting rates of the two detectors may be related to temporal variations in the low rigidity portion (~ 1 GV) of the primary cosmic ray spectrum (Stoker et al., 1979). Simpson (1951) reported that local production in materials of high atomic weight and slowing down of neutrons in hydrogenous materials were the principle sources of erroneous results with the neutron moderate detector. At Sanae the local environment is hydrogenous throughout the year and the snow fall amounting to 2 meters annually does not effect the counting rate. The station is situated on a ice shelf.

2. Experimental details. In Figure 1 curves a, b and c are representing the sensitivity of neutron counters surrounded by paraffin wax of thicknesses 1.25 cm, 7.5 cm and 12.5 cm respectively as a function of neutron energy (Hess et al., 1959). Also shown is the sensitivity as a function of neutron energy (curve d) for a NM64 neutron monitor (Hatton, 1971). It appears that the contribution to the counting rate by environmentally produced low energy neutrons may be reduced by surrounding a neutron counter with a relatively thick layer of paraffin wax.

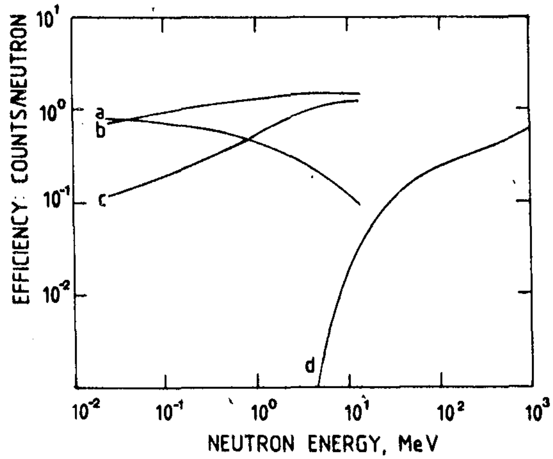

Figure 1

The 4NMD at Sanae consists of 4 BP28 Chalk River neutron counters, each of which is, together with its polyethylene cylinder, inside a paraffin wax cylinder with a wall thickness of 7.5 cm. These 4 paraffin wax cylinders with their neutron counters are enclosed in a rectangular aluminium container, having cavity walls filled up with paraffin wax of 5 cm thickness. This container is temperature controlled. The 3NM64 neutron monitor is enclosed in a similar temperature controlled container. Each container is inside a small wooden hut with heat insulated walls, about 3 meters above snow level and some 100 meters away from the station and its invironment.

3. Intercomparison of changes in counting rates. Since the fractional changes in pressure corrected counting rates of the two detectors differ during temporal variations of cosmic rays, 1976 was selected for intercomparing barometric pressure dependent changes in counting rates. During this period of minimum solar activity, temporal variations in counting rates due to cosmic rays may be neglected comparing to barometric pressure effects. Daily averaged hourly counting rates and barometric pressures were considered.

A linear regression fitting between the pressure uncorrected counting rates of the 4NMD and the 3NM64 yielded a gradient m = $(9.68 \pm 0.035) \times 10^{-2}$ with a correlation coefficient of 0.999. With the average ratio of the counting rates = 0.09670 it follows that the ratio of the barometric coefficients of the 4NMD to the 3NM64 is

$$\frac{\beta(4NMD)}{\beta(3NM64} = 1.0008 \pm 0.0035$$

This implies an identical pressure dependence for both detectors. In order to confirm this result, a linear regression analysis was also carried out on the ratio of the counting rates of the 4NMD and the 3NM64 as a function of the barometric pressure.

With

$$\ell n \frac{N(4NMD)}{N(3NM64)} = \ell n \left(\frac{N(4NMD)}{N(3NM64)}\right)_o + \Delta\beta(p-p_o)$$

we found $\Delta\beta = -(3 \pm 2).10^{-5}$/mb. with a correlation coefficient of r = -0.33. Since $\Delta\beta = \beta(4NMD) - \beta(3NM64)$, it means that the ratio of the barometric coefficients

$$\frac{\beta(4NMD)}{\beta(3NM64)} = 0.997 \pm 0.003$$

if one accepts that $\beta(3NM64) = 0.0073$/mb.

When the linear regression method for successive differences of Lapointe and Rose (1962) was used, the same value for the ratio of the barometric coefficients was obtained, but the correlation coefficient, r, was as small as - 0.05. The small correlation coefficients obtained by both linear regression methods confirm that the barometric coefficients of both detectors are the same.

In Figure 2 are shown the monthly averaged pressure corrected counting rates of the 4NMD and of the 3NM64 for the period from March 1974 through to December 1984. Different symbols have been used in the plot for different years. A linear regression analysis gives for the longterm variation of the 4NMD relative to the 3NM64 a ratio of 0.108 ± 0.002, with a correlation coefficient of 0.985.

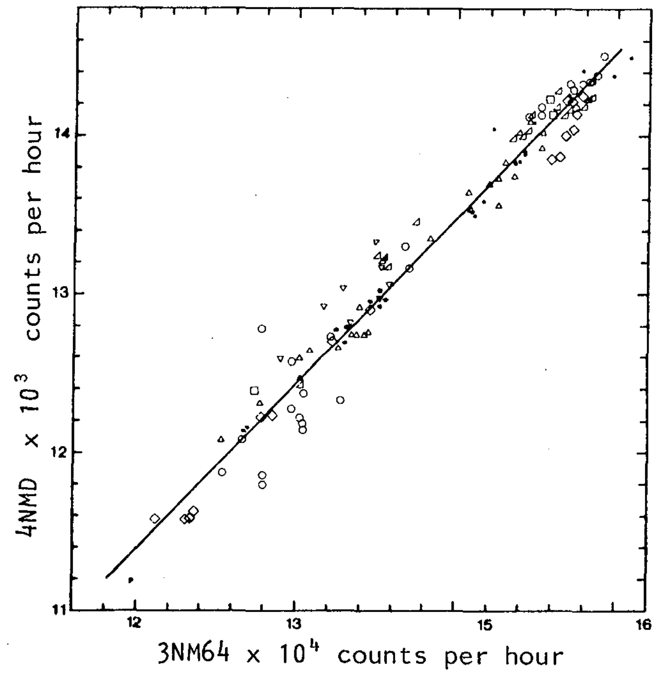

Figure 2

4. Discussion and conclusions. The results show a highly correlated variation of the counting rates of the 4NMD and the 3NM64, both due to pressure variations and to temporal variations in the primary cosmic ray intensity. No statistically significant difference in the pressure dependence of the two detectors could be established.

The 4NMD shows an 8% larger variation in counting rate than the 3NM64 on long term modulation. This relative larger variation in fractional counting rate of the 4NMD was expected from the larger latitude dependence of the 1NMD compared to the 1NM64 (Mischke et al., 1973). Also the larger variations of the counting rate of the 4NMD relative to the 3NM64 for Forbush decreases and ground level solar proton events (Stoker et al., 1979) show a larger sensitivity of the 4NMD relative to the 3NM64 for primary cosmic rays of rigidity $\gtrsim$ 1 GV.

Mischke et al. (1973) reported a barometric coefficient of (0.76 ± 0.02)%/mb for the 1NMD, which was then in operation at Sanae, with the same nominal shielding by paraffin wax than the present 4NMD. This coefficient may be compared with the barometric coefficient of the 3NM64, which is 0.73%/mb. The pressure dependence of the 4NMD may be different from the 1NMD, because the inner tubes of the 4NMD are shielded from the environment by the outer tubes, since environmentally produced neutrons do contribute significantly to the counting rate of a neutron moderated detector (Simpson, 1951).

Zhu and Kawasaki (1983) reported a barometric coefficient of (0.593 ± 0.013)%/mb for their 6 BP28 neutron counters with only the 2 cm polyethylene cylinder, compared with 0.667%/mb for the Tokyo super neutron monitor. This difference in pressure dependence reported by Zhu and Kawasaki may also be due to environmental effects.

The scattering of the points in Figure 2 should be due to variations in the rigidity spectrum of primary cosmic rays. Variation in the rigidity dependence of the modulation function for galactic cosmic rays may be deduced from the relative variation in the counting rates of the two detectors, provided that the specific yield function of each detector at ground level is known.

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