The Use of the Neutron Moderated Detector for Analysing Cosmic Ray Events

P H Stoker
and
C F W Mischke

Department of Physics, Potchefstroom
University for C.H.E., Potchefstroom

A neutron counter surrounded by a 7,5 cm paraffin wax moderator has recorded cosmic rays at Sanae since May 1971. It follows from the variation in counting rate of this neutron moderated detector (NMD) relative to the variation recorded by the neutron monitor (NM64) during cosmic ray events, that the NMD has a higher sensitivity for low-energy cosmic rays than the NM 64. A differential response function for sea level was derived from aircraft latitude surveys, and used to calculate regression coefficients for the relative variation in counting rates of the NMD and NM64.

'n Neutrontelbuis met 7,5 cm paraffienwas daaromheen is sedert Mei 1971 gebruik om kosmiese strale te Sanae te registreer. Deur die variasie in teltempo van hierdie neutrongemodereerde detektor (NMD) met die variasie in teltempo van die neutronmonitor (NM64) tydens kosmiese straal-gebeurtenisse te vergelyk, is bevind dat die NMD gevoeliger vir kosmiese strale van lae energie as die NM64 is. 'n Differensiële intensiteitsverloop vir seevlak uit breedtegraadopnames op vliegtuighoogtes afgelei en gebruik om regressiekoëffisiënte vir die relatiewe variasie in teltempo's van die NMD en die NM64 te bereken.

Introduction

Neutron counters, surrounded by moderators of various thicknesses and atomic masses, played an important part in the development of the neutron monitor as we know it today. Neutron counters were used on latitude surveys (*Simpson,* 1951) to record the latitudinal variation of secondary cosmic ray neutrons, and to measure the cosmic ray energy spectrum (*Hess et al.,* 1959), but not to record secondary cosmic rays continuously over long periods.

The neutron moderated detector (NMD) has a much larger latitude dependence than the neutron monitor (NM64) at aircraft altitudes, and the energy response of the NMD is lower than that of the NM64 (*Hess et al.,* 1959). These facts suggest that the differential response function of the NMD is not the same as that of the NM64. This should also be apparent at sea-level. Consequently the NMD may be used to follow the time history in the functional dependence of a cosmic ray event, when an NMD is operated together with an NM64.

A neutron moderated detector was installed at the South African Antarctic base, Sanae, for long enough to compare the variation in counting rate of the NMD with the 3NM64 neutron monitor at Sanae during cosmic ray events. Sanae, with its cutoff rigidity at 1,02 GV and with snow the only changing material in its vicinity, provides an acceptable location to operate an NMD. In this paper experimental details of the NMD are given together with preliminary results obtained during the period from 1 May 1971 to 1 September 1972.

Experimental Details

A neutron counter without any moderator around it records neutrons that are thermalized in the atmosphere and that are products of star reactions in matter of high atomic mass in the vicinity of the detector. Such a detector will be susceptible to changes in humidity, temperature and the presence of clouds. By surrounding the counter with a moderator, the atmospheric thermal neutrons and environmentally produced neutrons are absorbed, while higher energy atmospheric neutrons are thermalized by the moderator and recorded by the counter.

From the experimental work of *Hatton & Carmichael* (1964) it appears that a moderator with a thickness of 7,5 cm is sufficient to reduce the environmentally produced neutrons to a negligible level relative to atmospheric cosmic ray neutrons. The results of *Hess et al.* (1959) on the response of neutron moderated detectors to external neutrons of known energies show that an NMD with a moderator thickness of 7,5 cm has a much lower neutron energy response than a neutron monitor.

The NMD at Sanae consists of a BP28 Chalk River neutron counter surrounded by 7,5 cm of paraffin wax, cast between cylindrical double walls of fibreglass, as shown in Fig. 1. It is housed in a temperature-controlled wooden box, and was about 3 m above the snow level early in 1971. Snow accumulates at a rate of about 1,5 m per annum, without any observable effect (within statistical limits) on the counting rate of the NMD. The hourly counting rate, which is of the order of 4 × 10^3,

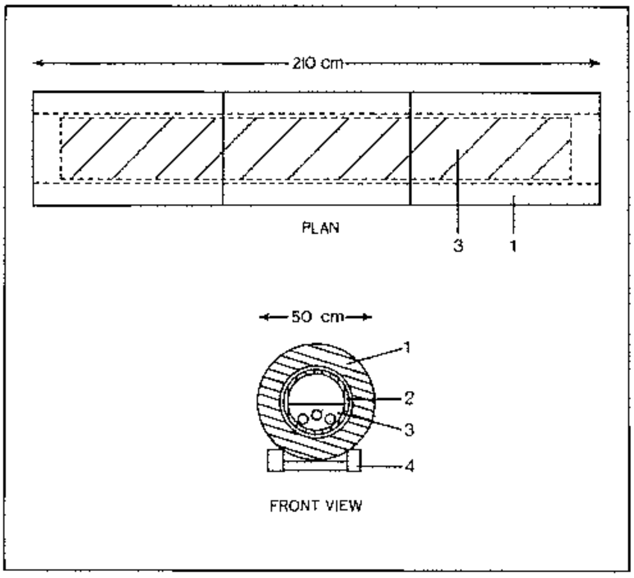

Fig. 1. The construction of the NMD at Sanae, showing: 1 - 7,5 cm parraffin wax moderator, 2 - polyethylene reflector, 3 - BP28 neutron counter, and 4 - supporting timber.

as well as that of the NM64, has been recorded continuously since May 1961 by the same automatic readout system.

The Differential Response Functions

In Fig. 2 differential response functions of the NMD and of the NM64 neutron monitor are shown, both for sea-level and for the time of maximum cosmic ray intensity (May 1965). The curve for the NM64 was obtained from the latitude survey of *Carmichael & Bercovitch* (1969) and was adjusted towards lower rigidities to take account of solar proton flare data recorded by the neutron monitors at Calgary and Sulphur Mountain (*Mathews et al.*, 1971). The curve for the NMD was obtained from the latitude variation in counting rates of NMD's at 9 150 m pressure altitude, transformed to sea-level by a suitable attenuation coefficient function. This latter function was derived from height-intensity readings taken at different pressure levels in steps of about 50 mm Hg from 9 150 m pressure altitude to near sea-level. These height-intensity readings were taken at six locations with cutoff rigidities ranging from 3 to 14 GV during survey flights in 1971.

The differential response curve derived for the NMD at sea-level from aircraft surveys was re-adjusted towards lower rigidities to account consistently for the results of the solar proton flare event of 1-2 September 1971 (*Mischke et al.*, 1973).

Eleven-year Variation and Forbush Decreases

Fractional decreases for eleven-year modulation and Forbush decreases are derived from the equation

$$\frac{\Delta N}{N_0} = \frac{1}{N_0} \int_{P_c}^{\infty} \frac{dN_0}{dP} \left(1 - e^{-M(P)}\right) dP \quad (1)$$

where N_0 is the counting rate of the detector, estimated for the reference time t_0, and dN_0/dP is the differential response function of the detector at time t_0 for primary cosmic ray particles of rigidity P. The differential responses dN_0/dP are derived from the May 1965 function shown in Fig. 2 by a suitable modulation function. Above 15 GV the differential response functions for May 1965 are approximated by $AP^{-\gamma}$. For the NMD it was found that $\gamma = 1{,}61$ at sea-level, using the method of *Webber & Quenby* (1959), while for the NM64, $\gamma = 1{,}57$.

The modulation function used to describe the cosmic ray variation with respect to the reference time t_0 may be written as

$$M(P) = \frac{\Delta\eta}{P^{\alpha}} \quad (2)$$

where $\Delta\eta$ is determined by the degree of modulation after the time t_0.

As the reference time for the eleven-year variation, the time of minimum cosmic ray modulation, in May 1965, is used. The results of a regression analysis on daily average counting rates of the NMD relative to the neutron monitor at Deep River (which has a high counting rate) for the period 1 May 1971 to 31 December 1971 are given in Table 1, together with the coefficients for relative fractional decreases of these two detectors calculated using equation (1).

On account of the low counting rate of the NMD, only the larger Forbush decreases are considered in a regression analysis with respect to the neutron monitor at Sanae. The results are also given in Table 1, together with the calculated coeffi-

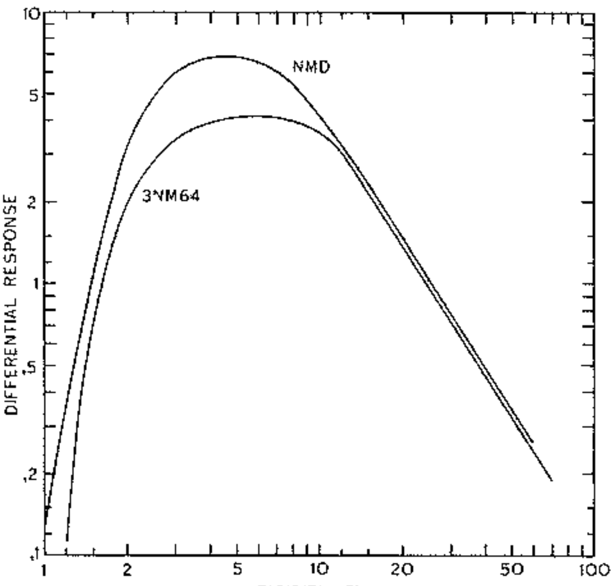

Fig. 2. Differential responses of the neutron moderated detector (NMD) and of the NM64 neutron monitor, for sea level at the time of minimum cosmic ray modulation in May 1965.

Table 1

Comparison of calculated and experimental regression coefficients for the fractional decrease in counting rates of the NMD relative to the fractional decrease in counting rates of the NM64 for different intensity variations

Variation		Regression coefficient: NMD/NM64		
Type	Fractional	Calculated	Experimental	Correlation Coefficient
1 May–31 December 1971 (11 year) Daily mean	9%	$\alpha = 1\ :1{,}20$ $\alpha = 0{,}7:1{,}15$	1,18 ± 0,03	0,98
18–26 December 1971 (FD) Hourly	9%	$\alpha = 1\ :1{,}20$ $\alpha = 0{,}7:1{,}15$	1,15 ± 0,03	0,93
3–10 August 1972 (FD) Hourly	26%	$\alpha = 1\ :1{,}17$ $\alpha = 0{,}7:1{,}13$	1,13 ± 0,03	0,98

cients for $\alpha = 1{,}0$ and $\alpha = 0{,}7$. The effective pre-event differential responses were used in equation (1) for the NMD and the 3NM64 at Sanae. From Table 1 it is apparent that the calculated coefficient depends on the magnitude of the event, given by the fractional variation of the counting rate.

Analysis of the counting rate of the NMD for the period 1 May–31 December 1971 shows an eleven-year variation consistent with the modulation function (2) with $\alpha = 1{,}0$. The large Forbush event of 3-10 August 1972 also appears to be consistent with a modulation for which $\alpha = 1{,}0$ (*Dutt et al.*, 1973; *Stoker*, 1973). When the calculated regression coefficients for $\alpha = 1{,}0$ and $\alpha = 0{,}7$ are compared with the experimental values, the calculated coefficients for $\alpha = 1{,}0$ seem to over-estimate the experimental results. However, the experimental regression values are not accurate enough to distinguish between modulations for which $\alpha = 1{,}0$ and $\alpha = 0{,}7$. Improvement of the results will only be attained if an NMD with a much higher counting rate to ensure better statistical accuracy is installed.

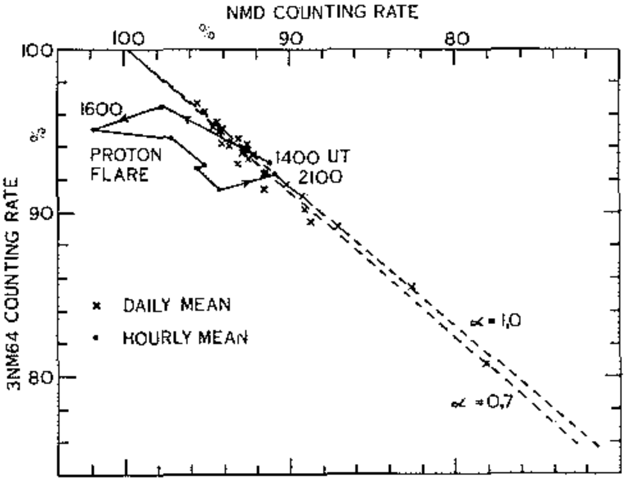

Fig. 3. Plot of daily average counting rates of the NMD relative to the NM64 for August 1972, together with the hourly values during the proton flare event of 4 August 1972. The broken lines were calculated from the differential responses for different modulation functions.

In Fig. 3 the daily mean counting rates, normalized to the effective counting rate for May 1965, are plotted for the NMD relative to the 3NM64, from 1 to 30 August 1972. The broken lines represent the relative counting rates calculated for modulation functions with $\alpha = 1{,}0$ and $\alpha = 0{,}7$. A regression analysis of the daily mean counting rates for August 1972 yields the same value for the regression coefficient as that given in Table 1 for the analysis of hourly counting rates.

The hourly counting rates for the solar proton event on 4 August 1972 are also plotted in Fig. 3 for the hours 13h00-14h00 and 20h00-21h00 UT. The peak intensity of the solar protons was recorded earlier by the NM64 than by the NMD. This observation suggests that the spectrum of protons arriving initially at earth from the solar flare was harder than the spectrum of protons arriving later on, since the NMD is more sensitive to low-energy primaries than the NM64. The time history of the solar proton spectrum from these recordings will be investigated in more detail for publication in a later paper.

Conclusions

The neutron moderated detector may be used together with a neutron monitor to investigate the modulation function for eleven-year variation and Forbush decreases, particularly if an NMD with a much higher counting rate than the one now in use at Sanae is used. This detector is particularly useful for investigating solar flares, since directional asymmetry is of minor importance if an NMD is used together with an NM64 at the same site.

Acknowledgements

The financial and logistic support of the Department of Transport is gratefully acknowledged.

The Editor thanks M A Pomerantz of Bartol Research Foundation, Franklin Institute, USA, for his assistance in evaluating this paper.

References

Carmichael, H & Bercovitch, M Analysis of IQSY cosmic ray survey measurements. *Can. J. Phys.*, **47**, 2073, 1969.

Dutt, JC, Humble, JE & Thambyapillai, T The unprecedented cosmic ray disturbances of early August 1972. Preprint circulated by the Physics Department, Imperial College, London S.W.7, 1973.

Hatton, CJ & Carmichael, H Experimental investigation of the NM-64 neutron monitor. *Can. J. Phys.*, **42**, 2443, 1964.

Hess, WN, Patterson, HW, Wallace, R & Chupp, EL Cosmic-ray neutron energy spectrum. *Phys. Rev.*, **116**, 445, 1959.

Mathews, T, Stoker, PH & Wilson, BG A comparative study of the rigidity dependence of Forbush decreases and 11-year variation in cosmic ray intensity. *Planet. Space Sci.*, **19**, 981, 1971.

Mischke, CFW, Stoker, PH & Duvenage, J The neutron moderated detector and the determination of rigidity dependence of protons from the 1/2 September 1971 solar flare. 13th International IUPAP Conference on Cosmic Rays. Conference Papers, **2**, 1570-1575. University of Denver, 1973.

Simpson, JA Neutrons produced in the atmosphere by the cosmic radiations. *Phys. Rev.*, **83**, 1175, 1951.

Stoker, PH The rigidity dependence of cosmic-ray variations during the August 1972 solar events. Collected data reports on August 1972 solar terrestrial events, UAG Report 28, part II, 441-444. Boulder, Colorado, World Data Center A for Solar Terrestrial Physics, 1973.

Webber, WR & Quenby, JJ On the derivation of cosmic-ray specific yield functions. *Phil. Mag.* (*Series 8*), **4**, 654, 1959.

(Received 11 June 1973)