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# II-4-37. Some Experiments with a Mobile Neutron Monitor

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A series of measurements at Hobart at different altitudes using a cosmic ray neutron monitor in a mobile laboratory has yielded a value of 135 gm $cm^{-2}$ for the attenuation length in air of the nucleonic component during September 1960–February 1961. The measurements also reveal significant effects of sky obscuration by nearby hills on the monitor counting rate and such screening effects are used in an experimental determination of the zenith angle dependence of the fast nucleon intensity.

A brief discussion is given of changes observed in the attenuation length during the solar flare events of November 1960.

## §1. Introduction

During the past year at Hobart (43°S, 147°E), a series of measurements has been made using a 4-counter neutron monitor installed in a truck and this paper reports very briefly on some of the results obtained. Over the same period operation of the fixed neutron monitor on Mt. Wellington (725 m) has been continued. Both monitors conformed in essential features with the standard IGY pattern. Hourly and short-term chart recorder data were obtained from the Mt. Wellington monitor but only hourly data were obtained from the mobile monitor.

## §2. Determination of the Attenuation Length of the Nucleonic Radiation

Using records from the fixed Mt. Wellington monitor at 725 m as a reference control on primary intensity variations, a series of intensity measurements was made with the mobile monitor at different altitudes from sea level to 1270 m. Atmospheric pressure at the locations of the two monitors was continuously recorded and the measurements were checked by repeating the series.

One set of results is shown in Fig. 1. Other results obtained during the periods September-October 1960 and January-February 1961 are quite consistent with these and indicate no significant changes in attenuation length. Disregarding point $D$ for reasons to be discussed below, the remaining points are well fitted by a straight regression line the slope of which corresponds to an attenuation length of 135.0±1.0 gm $cm^{-2}$.

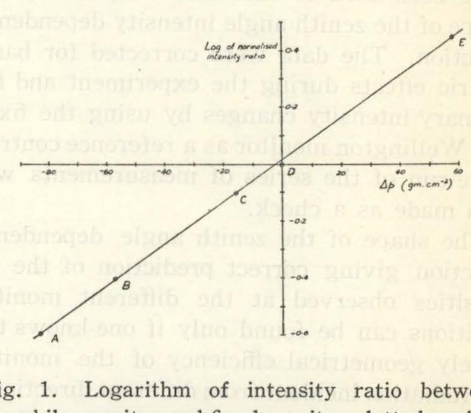


Fig. 1. Logarithm of intensity ratio between mobile monitor and fixed monitor plotted against difference in pressure level between the two for five locations. The straight line is fitted to points A, B, C and E (see text) and corresponds to an attenuation length of 135.0 gm $cm^{-2}$.

This value is significantly lower than values of approximately 138 gm $cm^{-2}$ determined by a rather similar method and also by multivariate correlation methods for the period near sunspot maximum[1]. It indicates a significant lowering of the mean energy of star-producing nucleonic radiation in the lower atmosphere since that time.

## § 3. The Zenith Angle Dependence of Fast Nucleon Intensity

In Fig. 1 the point $D$ was obtained from measurements with the mobile monitor at an altitude of 725 m. In repeated check runs the measured intensity at this location was consistently 2 percent lower than predicted by the straight regression line fitting the other points. A simple interpretation of this is that at this location the higher neighbouring slopes of Mt. Wellington in one azimuth quadrant have a screening effect on radiation incident from relatively low elevation angles.

This screening effect suggested a method of making quantitative measurements on the intensity variation of the nucleonic component with zenith angle. To make these measurements the mobile monitor was operated at a series of different distances from the high rock face of a stone quarry. At each position the elevation of the skyline round the full azimuth circles was plotted. Assuming complete screening of all radiation from elevations below the sky-line, the different measured intensities and the sky obscuration plots have been used to determine empirically the shape of the zenith angle intensity dependence function. The data were corrected for barometric effects during the experiment and for primary intensity changes by using the fixed Mt. Wellington monitor as a reference control. A re-run of the series of measurements was also made as a check.

The shape of the zenith angle dependence function giving correct prediction of the intensities observed at the different monitor positions can be found only if one knows the purely geometrical efficiency of the monitor for radiation incident from different directions. This depends not only on the cross-sectional area presented in different directions by the lead of the monitor but also on the relative thickness of the lead in the direction of the incident radiation, and its disposal in relation to the counters. The monitor used in this experiment was a 4-couter instrument, and from a consideration of the various factors involved we find that the purely geometrical efficiency of the monitor varies with zenith angle approximately as $\cos\theta+\frac{1}{3}\sin\theta$. This means that for a parallel beam of radiation in the horizontal direction the counting rate of the monitor would be one third of its value if the same beam were incident vertically.

Using this geometrical function together with the observed total counting rates and sky obscuration patterns at the different monitor positions we find that the intensity of fast nucleons at sea level varies with zenith angle as shown by curve A in Fig. 2. This is the curve which accurately predicts the observed relative counting rates. Curve $B$ is a theoretical zenith angle dependence function based on the usual assumptions for the Gross transformation[2] and is of the form

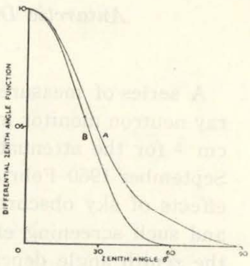


Fig. 2. Curve A: Empirical zenith angle intensity variation of the fast nucleonic component.
Curve B: Theoretical variation in the absence of scattering effects.

$$F(\theta)=K\left(1+\frac{x}{L\cos\theta}\right)\exp\left(\frac{-x}{L\cos\theta}\right)$$

where $x$ is the atmospheric depth and $L$ the attenuation length in gm $cm^{-2}$.

It neglects scattering in the atmosphere, the effect of which is to increase the relative intensity of radiation arriving at greater zenith angles. Curve A which correctly predicts the experimental results therefore indicates the manner in which scattering in the atmosphere modifies this zenith angle intensity variation.

If the geometrical efficiency function discussed earlier is $S(\theta)$ and the zenith angle intensity-dependence function (curve A) is $I(\theta)$, then the relative contribution to the total counting rate of a monitor, unscreened over the whole hemisphere above it, arising from radiation incident from the zenith angle interval $d\theta$ at $\theta$ will be given by

$$R_\theta d\theta=I(\theta)\,S(\theta)\sin\theta d\theta.$$

For the particular monitor used in these experiments for which $S(\theta)\simeq\cos\theta+\frac{1}{3}\sin\theta$, the variation of this function with $\theta$ has been calculated and plotted as curve $C$ in Fig.

3. It is clear from this curve that although the greatest contribution to the total counting rate arises from radiation incident at zenith angles around 20°-25°, radiation from zenith angles near 70° still contributes substantially to the total counting rate. The integral of this curve is plotted as curve *D* in Fig. 3 with the ordinate scale in percent.

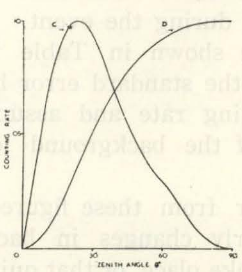

Fig. 3. Curve C: Relative contribution to the total counting rate of the neutron monitor from different zenith angles.

Curve D: Integral of curve C, giving percentage of total counting rate due to radiation arriving from zenith angles 0° to $\theta$.

From this may be read the percentage of the total counting rate which is due to radiation incident from zenith angles less than $\theta$.

These results indicate the importance, when the highest possible counting rate is desired, of setting up a neutron monitor at a position where sky obscuration even at low elevation angles due to hills or nearby massive obstructions is a minimum. It is clear also that the screening effects giving rise to the anomalous position of point *D* in Fig. 1 must not be overlooked in any similar direct experimental determination of the atmospheric attenuation length of the nucleonic radiation.

## § 4. The Attenuation Length during the Solar Flare Effects of November 12 and 15, 1960

During these events the mobile neutron monitor was operating at sea level and the Mt. Wellington monitor at 725 m. Comparison of records from the two monitors allowed calculation of the attenuation length of the total recorded radiation at different times during the course of the events. Without a knowledge of the changing intensity level of the background galactic radiation it is not possible to calculate directly the attenuation length of the flare particles alone at different times, and it is well known that this background level was substantially affected by a Forbush decrease on November 12.

However all evidence suggests that whereas the flare particles arrived on November 12 from ~1400 UT onwards, the Forbush decrease did not occur until after 1700 UT. Consequently we are fairly safe in extrapolating the pre-event level up to 1700 and measuring the intensity of the flare particles from this level. By this method we obtain for the attenuation length $L_{excess}$, values of $111\pm2$, $112\pm2$, $113\pm2$ gm cm$^{-2}$ for the three hours 1400-1700. These are consistent with a constant value of 112 gm cm$^{-2}$ and thus with a constant flare particle spectrum and geomagnetic cut-off during these three hours.

If the value of 112 gm cm$^{-2}$ had remained applicable to the excess particles throughout the remainder of the event it would be a simple matter to determine the course of the galactic background intensity through the Forbush decrease. If this constancy of $L_{excess}$ is assumed, we find that the background intensity variations from 1400 November 12 through 0400 November 13 would have to be as shown by curve *D* in Fig. 4. The level 22% below normal during the hour 1800-1900 and the return to the normal level during 2200-2400 both seem quite unreasonable, particularly in view of the relatively small and

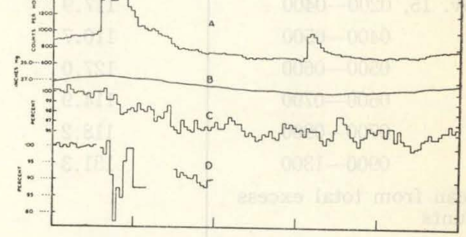

Fig. 4. A: Uncorrected hourly values of the nucleonic component intensity at Mt. Wellington during November 12-16, 1960.

B: Barometric pressure variations.

C: Pressure corrected hourly meson intensity at Hobart (sea level).

D: Showing calculated variations in pressure-corrected background nucleonic component intensity on November 12-13, 1960 based on the assumption that the attenuation length of the excess radiation remained constant at 112 gm cm$^{-2}$.

not unusual variations exhibited by the meson intensity (curve C). Hence the assumption of constant $L_{excess}$ throughout the event seems untenable, and it follows that $L_{excess}$ was almost certainly significantly $<112$ gm cm$^{-2}$ during 1800–1900 reflecting a marked lowering of the geomagnetic cut-off with the onset of severe magnetic disturbance and that $L_{excess}$ increased above 112 gm cm$^{-2}$ during 2200–2400 due either to a significant increase in mean energy of the flare particles reaching the station or to a change in the cut-off to above the normal value.

Little more can be said along these lines about this particular event because of the uncertainties introduced by the disturbed galactic background. At least the conclusions mentioned above seem justified and it is clear that for solar flare increases uncomplicated by simultaneous Forbush events two monitors operating at different altitudes at the same geographical location can give a useful continuous indication of any changes in cut-off or flare particle spectrum during the events.

The case of the November 15 event is relatively free of the difficulties mentioned, since any fluctuations in galactic background during the influx of low energy particles were certainly quite small. Consequently by interpolating background intensity levels between those immediately before and after the event and measuring the flare particle intensities from such levels it is possible to calculate values of the attenuation length of the excess particles with reasonable accuracy for intervals during the event. The values obtained are shown in Table I. For each value given the standard error based on the excess counting rate and assuming correct estimation of the background level is $\leq 3.5$ gm cm$^{-2}$.

Table I. Values of $L_{excess}$ during the November 15, 1960 event, assuming continuation of the pre-increase background level.

| Interval U. T. | $L_{excess}$ (gm cm$^{-2}$) |
|---|---|
| Nov. 15, 0200—0400 | 117.9 |
| 0400—0500 | 110.7 |
| 0500—0600 | 127.0 |
| 0600—0700 | 114.9 |
| 0700—0900 | 118.2 |
| 0900—1300 | 131.3 |
| Mean from total excess counts | |
| 0200—1300 | 120.0 |

It is clear from these figures that either marked hourly changes in background intensity did take place, or that quite significant changes occurred in mean energy of the excess radiation detected.

That changes in background intensity cannot reasonably account for the large changes in $L_{excess}$ is clear from the fact that to produce the range of values obtained, the range of background fluctuations would have to be of the order of 30%. Consequently we are justified in concluding that the changes in $L_{excess}$ reflect genuine irregular changes in mean energy of the solar flare particles reaching the station.

The potential value of such simultaneous recording by two monitors separated in altitude in detecting short term changes in the properties of low energy particle influxes is obvious. It is hoped that such observations can be continued at Hobart with somewhat higher counting rates to improve statistical accuracy.

## References

1) K. G. McCracken: Thesis, University of Tasmania (1958).

2) L. Janossy: *Cosmic Rays* (Oxford University Press) (1950) 139.

### *Discussion*

**Wada, M.:** What is the exponent of cos $\theta$ to approximate $S(\theta)\,I(\theta)$?

**Parsons, N. R.:** The function $I(\theta)$ giving the empirical differential zenith angle dependence of intensity at the monitor is similar to a $\cos^6\theta$ dependence over the range $\theta=0$ to about 40°. Thereafter $I(\theta)$ falls off more slowly than $\cos^6\theta$ and has appreciable values even at around $\theta=70°$.

**Katz, L.:** The University of New Humpshire group of Dr. J. A. Lockwood operates a two altitude neutron monitor station system, (one on top of Mt. Washington, N. H.

and second at sea level in nearby Durham, N. H.). It is my understanding that this group calculated the change of energy spectrum which could be responsible for the observed effects during the November 1960 events and possibly at other times of cosmic-ray storms. Unfortunately, I do not recall quantitative results of these investigations.