Progress Report on the Intercalibration of the World’s Neutron Monitors

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Abstract: Two calibration neutron monitors were designed for calibrating the ~ 40 stationary neutron monitors around the world in order to obtain rigidity spectra. One calibrator was sent to Kiel ($P_c = 2.36$ GV), Germany, and later to Doi Inthanon ($P_c = 16.8$ GV), Thailand. The other calibrator was transported to Antarctica to calibrate the NM64 and NMD at SANAE ($P_c = 0.73$ GV). Both calibrators were calibrated against each other and the IGY in Potchefstroom ($P_c = 6.94$ GV), South Africa. Initial results on the intercalibration of these four stationary neutron monitors are reported.

Keywords: neutron monitors, modulation

1. Introduction

Each of the approximately 40 neutron monitors (NM) in the worldwide network has its own detection efficiency, being of different design, in a different environment, at different cutoff rigidities and altitudes. The counting rate, $N$, of such a NM at cutoff rigidity, $P_c$, is

$$N(P > P_c) = \int_{P_c}^{P_{\infty}} dN/dP \ dP$$

and the differential response function, $dN/dP$, is related to the primary cosmic ray intensity, $j(P)$, and the neutron monitor yield function, $S$, of the secondary cosmic rays at atmospheric depth $x$, by

$$dN / dP = S(P,x) \ j(P,t).$$

In order to derive such a differential response function from the counting rates of the world’s stationary neutron monitors, they need to be inter-calibrated accurately. Then the differential response function can be calculated from the difference in counting rates divided by the difference in cutoff rigidities:

$$\frac{dN}{dP} = \frac{N(P_2) - N(P_1)}{P_2 - P_1}.$$
properties of the calibrators were investigated. These properties are their instrumental temperature and environmental (surface) sensitivities, as well as their energy response. The results on these parameters were reported in [1], [2] and [3].

In this paper these previous environmental results are compared with new results obtained at the location of the Doi Inthanon NM in Thailand at \( P_c = 16.8 \) GV, altitude 2560 m. The experiments were performed from November 2009 to June 2010. A preliminary calibration or efficiency number of the Doi Inthanon NM relative to the Potchefstroom NM is also given.

This paper also includes earlier, similar calibration results for the Kiel and SANAE NMs.

2. Environmental sensitivities

In [3] we described a series of experiments performed in Potchefstroom with varying heights of water (in a portable swimming pool) beneath the calibrator, to determine the amount of water needed to eliminate surface effects. In these experiments the calibrator was kept just above the water level. It was determined that the counting rate decreases with an increase in the amount of water, and that the counting rate levels off when the water layer below the NM exceeds approximately 30 cm, as shown in Figure 2. The decrease in the counting rate due to this 30 cm of water was \( \approx 4.0\% \).

From March to May 2008 a similar ground-surface experiment was performed in Kiel, Germany. Three data points were taken: (1) with the calibrator on ground level, (2) the calibrator elevated 70 cm above the ground with no water beneath it, and (3) the calibrator at 70 cm above the ground, with the pool filled with water to \( \approx 65 \) cm. This time the counting rate decreased by 4.2%, confirming the Potchefstroom result.

![Figure 2: The ratio of the count rates of the Potchefstroom NM (open circles) and the NM at Doi Inthanon as function of varying heights of water beneath the calibrator.](image)

In 2010 this experiment was repeated a third time at Doi Inthanon, Thailand. The same dependence on the water height was found. In this experiment the calibrator was set at two heights above the surface, at 140 cm and 70 cm, as shown in Figure 2. When the calibrator was at 140 cm, it seems that the counting rate leveled off at a height of water \( \approx 70 \) cm. The decrease in the counting rate was only 1.56%. However, when the calibrator was at 70 cm above the surface, the decrease was also 4.2%, confirming the previous results at Potchefstroom and Kiel.

3. Calibration Process

We use the above results to standardize the calibration procedure, namely that it must be done outside, removed from any buildings and structures, and that it must be done above 30 cm of water (or in 70 g/cm² ice in the Antarctic experiment). If these conditions are met, the cosmic-ray intensity at any two sites can be compared, because then the difference is only due to different cutoff rigidity and atmospheric depth. (The necessary temperature corrections involved in the calibration were calculated in [2]).

In December 2006 the calibrator was taken to SANAE, Antarctica, in a first attempt to calibrate the SANAE standard 6NM64 and 4NMD (neutron moderated detector, i.e. a neutron monitor without lead and reflector). The geographic latitude is 71°40' S, longitude is 2°51' W, altitude is 856 m above sea level, ambient atmospheric pressure is 660 mm Hg, pressure coefficient is 0.97%/mm Hg for the 6 NM64 and 1.01%/mm Hg for the 4NMD and the vertical geomagnetic cutoff rigidity is 0.73 GV.

One of the calibrators was sent to Kiel, Germany, in 2007/8 to calibrate the standard 18NM64 in Kiel. This monitor is housed on top of the old building (with a wooden roof) of the Nuclear Physics department. The geographic latitude is 54.34° N and longitude is 10.12° E. The altitude is 54 m above sea level and the effective vertical cutoff rigidity is 2.36 GV. The reference atmospheric pressure is 1006.7 mb, and the barometric coefficient is 0.721%/mb. The calibration was done in the open air in the Botanic Gardens of this University.

In 2008 in Potchefstroom, South Africa, the two calibrators were calibrated against each other and against the local 15-counter IGY NM. This NM is situated on the roof of the Physics building on the Potchefstroom Campus of the North-West University, latitude 26° 41.9' S, longitude 27° 05.6' E, altitude 1351 m, ambient atmospheric pressure 652.4 mm Hg, barometric coefficient 0.99%/mm Hg, and vertical cutoff rigidity 6.94 GV.

In 2009/2010 the calibrator was stationed in Thailand for almost a year. The purpose was to calibrate the Princess Sirindhorn Neutron Monitor (PSNM), an 18NM64 at Doi Inthanon, latitude 18.59°N, longitude 98.49°E, altitude 2560 m, average atmospheric pressure 563 mm Hg, barometric coefficient 0.83%/mm Hg, and vertical geomagnetic cutoff rigidity 16.8 GV.

To quantify the calibration process, consider two NMs at different cutoff rigidities and altitudes, with different efficiencies (due to difference in type of neutron monitor, number of counters, and different environment). Suppose NMI is calibrated against the calibrator at time \( t_t \), and
similarly NM2 at time $t_2$. Then we have the following five measurements:

1. At time $t_1$ the counting rate (cr.) of NM1 is $N_{1,1}$
2. At time $t_2$ the cr. of NM1 is $N_{1,2}$
3. At time $t_1$ the cr. of NM2 is $N_{2,1}$
4. At $t_1$ the cr. of the calibrator at NM1 is $C_{1,1}$
5. At $t_2$ the cr. of the calibrator at NM2 is $C_{2,2}$

At time $t_2$ the counting rate of the calibrator at NM1 can then be calculated as $C_{1,2} = (N_{1,2}/N_{1,1})C_{1,1}$.

The ratio $R_m = N_{2,2}/N_{1,2}$ is the measured ratio of the two NMs at time $t_2$. This ratio includes the differences in efficiency. The ratio $R_e = C_{2,2}/C_{1,2}$ is the “measured” ratio of the calibrator counts at the two positions. (We note that $C_{1,2}$ is not actually measured, but can be calculated as mentioned above.) The calibrator at the two different positions should have the same efficiency.

Hence the ratio of efficiency of the two NMs is

$$R_{\text{eff}} = \frac{R_m}{R_e} = \frac{N_{2,2}C_{1,1}}{N_{1,2}C_{2,2}} = \frac{N_{2,1}C_{1,1}}{N_{1,2}C_{2,1}} \quad (1)$$

This ratio reflects the difference in the counting rates of the two NMs due to their different design and environmental conditions. Therefore, to compare the counting rate of NM2 relative to NM1, the counting rate of NM2 must be divided by this number.

4. Preliminary Results

The preliminary results for the Doi Inthanon, Kiel, and SANAE NMs relative to Potchefstroom (NM1) are reported.

The Potchefstroom IGY is used as the standard (NM1), and therefore time interval $t_1$ is day 295 to 302 of 2008. Time $t_2$ is day 24 to 28 of 2007 at SANAE, alternatively day 109 to 128 of 2008 at Kiel, or day 98 to 110 of 2010 at Doi Inthanon. Table 1 shows the average counting rate per hour and the ratio of efficiency of the monitors.

Pressure uncorrected counts were used, because the monitors have the same atmosphere above them during each set of measurements. After rejecting spurious counts, the counting rates per second were integrated into hourly rates.

Table 1. Hourly counting rates during the calibrations

<table>
<thead>
<tr>
<th></th>
<th>$t_1$, Potchefstroom</th>
<th>$t_2$, SANAE NM64/NMD</th>
<th>$t_2$, Kiel</th>
<th>$t_2$, Doi Inthanon</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANAE/Kiel/Thailand NM</td>
<td>557152/30795</td>
<td>611133</td>
<td>2195452</td>
<td></td>
</tr>
<tr>
<td>Calibrator</td>
<td>10197</td>
<td>11703</td>
<td>4520</td>
<td>12123</td>
</tr>
<tr>
<td>IGY in Potchefstroom</td>
<td>216767</td>
<td>206104</td>
<td>217211</td>
<td>215230</td>
</tr>
<tr>
<td>Efficiency ratio ($R_{\text{eff}}$)</td>
<td>1.000</td>
<td>2.240/0.124</td>
<td>6.360</td>
<td>8.519</td>
</tr>
</tbody>
</table>

Table 2. Characteristics, barometric coefficient, and efficiency ratio of each NM relative to the Potchefstroom NM.

<table>
<thead>
<tr>
<th></th>
<th>$P_i$ (GV)</th>
<th>Pressure (mm Hg)</th>
<th>$\beta$ at NM (%/mm Hg)</th>
<th>$\beta$ at sea level (%/mm Hg)</th>
<th>Efficiency ratio, $R_{\text{eff}}$</th>
<th>$R_{\text{eff}}$ at sea level</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANAE NM64</td>
<td>0.73</td>
<td>660</td>
<td>0.97</td>
<td>0.96</td>
<td>2.240</td>
<td>2.800</td>
</tr>
<tr>
<td>SANAE NMD</td>
<td>0.73</td>
<td>660</td>
<td>1.01</td>
<td>1.00</td>
<td>0.124</td>
<td>0.155</td>
</tr>
<tr>
<td>Kiel</td>
<td>2.36</td>
<td>755</td>
<td>0.96</td>
<td>0.96</td>
<td>6.360</td>
<td>6.360</td>
</tr>
<tr>
<td>Potchefstroom</td>
<td>6.94</td>
<td>652</td>
<td>0.99</td>
<td>0.972</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Doi Inthanon</td>
<td>16.8</td>
<td>563</td>
<td>0.83</td>
<td>0.815</td>
<td>8.519</td>
<td>10.649</td>
</tr>
</tbody>
</table>

The next step is to reduce these efficiencies to the same atmospheric depth. For this purpose the counting rates must be corrected with the formula $N = N_0 e^{-\beta(P-P_0)}$, where $P$ and $P_0$ are the station pressure and reference level pressure, and $\beta$ the barometric coefficient. The values of $P$ and $\beta$ for each station are shown in Table 2. When correcting the counting rates from a significant altitude to sea level, one must take into account that $\beta$ varies with altitude, as was found by [5]. Therefore, Table 2 also shows our estimate for $\beta$ at sea level of the particular NM. Then the average of the two barometric coefficients was used to transform the efficiency ratio of the five neutron monitors to sea level, as shown in the last column of Table 2.

This procedure describes the essence of the calibration procedure. When about 10 neutron monitors are calibrated in this way, we will be ready to derive differential response functions from them.

5. Future calibrations/projects

The pressure corrections, from which the efficiencies in the last column in Table 2 were calculated, need consi-
Apart from these refinements, the following projects are planned.

Due to electronic development during the past 10 years, the electronics heads of the calibrators are being completely redesigned and rebuilt.

Another two calibrators, with new electronics heads, are presently being built. They should be completed and tested by October 2011.

The first of these new calibrators will conduct annual latitudinal surveys on the research vessel Polarstern of the German Polar Programme, in collaboration with the University of Kiel, between cutoff rigidities 1 to 15 GV. This calibrator will function for at least the next solar cycle together with a muon telescope. The second calibrator will be installed on the Neumayer station, Antarctica, for continuous monitoring of the cosmic-ray intensity.

In the immediate future, the existing two calibrators, with redesigned and modernized electronics heads, will be used to recalibrate the Potchefstroom and SANAE NMs, and then to also calibrate the Hermanus and Tsumeb NMs.

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References