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Environmental effects on neutron monitors

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Two calibration neutron monitors were completed in September 2002. One was used to calibrate the Sanae neutron monitor and to investigate temperature and environmental sensitivity. This paper reports on these effects. An accompanying paper discusses the performance of the other calibrator on its three voyages between the USA and Antarctica.

1. Introduction

At the previous ICRC Moraal *et al.* (2003) reported on the construction of a calibration neutron monitor, and first tests done on it from December 2002 until February 2003 at Sanae, Antarctica. The intention was to calibrate the Sanae neutron monitor, but while doing this, a large instrumental temperature effect of about 0.13%/°C was discovered. At the same time, the Bartol group (K.R. Pyle and J. Clem, private communication) also discovered similar temperature effects on their stationary neutron monitors. We note that this temperature effect is instrumental and not the well-known atmospheric effect of about –0.03%/ °C at the poles (e.g. Iucci *et al,* 2000). Several measurements of this temperature effect, as well as the effects of different surfaces underneath the calibration monitor, are discussed in this paper.

2. Temperature sensitivity of neutron monitors

The temperature experiment at Sanae, described in Moraal *et al*. (2003), was repeated in Potchefstroom. Here the temperature coefficient of the calibrator was determined with simultaneous recordings of the Potchefstroom IGY neutron monitor. The calibrator was placed in a separate room about 18m from the IGY neutron monitor hut on the same level. The temperature of this room was varied gradually with an air

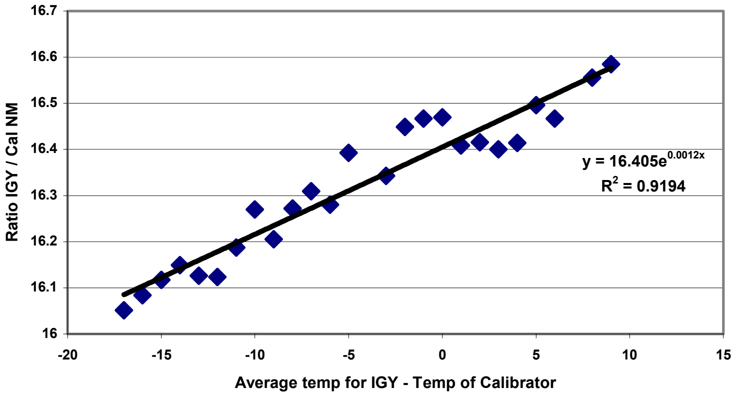

Figure 1. The temperature effect of the calibrator, obtained from day 289-322 in 2003, in Potchefstroom.

conditioner and heaters, letting the calibrator's temperature to change over a range of 25 degrees, while the IGY was kept at a constant temperature in the monitor hut.

Figure 1 shows the ratios of the counting rates of the IGY to the calibrator as function of the difference in temperature between the two monitors. The regression line gives a positive slope of 0.12%/^{o}C, which agrees well with the value of 0.13%/^{o}C determined by Moraal *et al.* (2003) at Sanae.

This experiment was repeated with the calibrator in a smaller room on the same level as the monitor hut, now about 10m from the IGY. The same coefficient of 0.12%/^{o}C was obtained. These two experiments, together with the one at Sanae, demonstrate the reliability of the method.

As a next step, the temperature coefficient of the IGY was determined by keeping both monitors inside the monitor hut at four different fixed temperatures for several days each. Figure 2 shows the ratios of the counts of the IGY and calibrator as function of temperature. The regression line gives a negative slope of –0.06%/^{o}C. Since the temperature coefficient of the calibrator is known, that of the IGY was calculated, as follows:

$$N_{cal} = N_{c0} e^{0.0012 \Delta T}$$

$$\frac{N_{IGY}}{N_{cal}} = \frac{N_{I0}}{N_{c0}} e^{-0.0006 \Delta T}$$

$$\Rightarrow N_{IGY} = N_{I0} e^{0.0006 \Delta T}$$

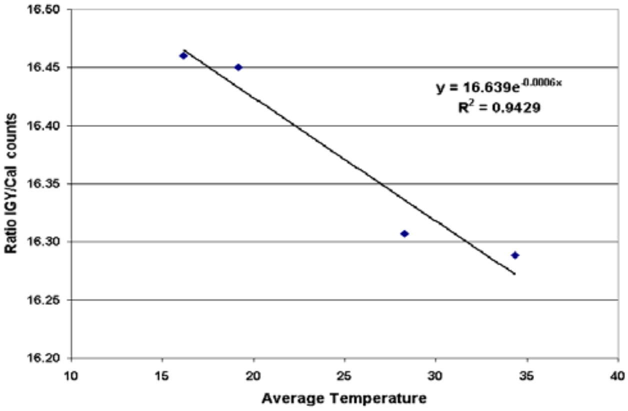

Figure 2. The IGY and calibration neutron monitor in the monitor hut, days 197-247 in 2004.

To determine the temperature coefficient of the other calibrator on the US/Australian 2004/05 sea-voyage to McMurdo, a proposal was made to the Bartol group to switch off the air conditioning for some time while the ship stayed around McMurdo. This would be a repeat of the Potchefstroom IGY-experiment as described above, but for the other calibrator. As stated in the accompanying paper, some failure occurred in this calibrator, and therefore no results were obtained.

J. Clem (private communication, 2004) simulated the temperature sensitivity of a 3NM64 neutron monitor with both ^{3}He and ^{10}BF$_3$ counters using the FLUKA simulation program. A temperature coefficient of (0.0730 ± 0.0071)%/^{o}C was determined for the ^{3}He counters, while the temperature coefficient of the ^{10}BF$_3$ counters was (0.0176 ± 0.0060)%/^{o}C.

K.R. Pyle (private communication, 2004) described how the Bartol group detected this instrumental temperature effect in their neutron monitors due to a runaway thermostat at their Thule station. Due to this, they conducted temperature tests on the Thule and Nain monitors, similar to ours.

At Thule, they used nine ^{3}He counters and nine ^{10}BF$_3$ counters, all in one room at approximately the same temperature. Several years of temperature and counting rate data were used. An average value of 0.04%/^{o}C was obtained for the ^{10}BF$_3$ counters of an NM64.

At Nain, they used 3 independently heated vans, each containing six ^{3}He counters. Each van was kept at a different fixed temperature for several weeks. Combining the measurements at Thule and Nain, an average temperature coefficient of 0.09%/^{o}C was found for the ^{3}He counters.

A summary of the temperature coefficients is shown in Table 2. The calibrator has the largest sensitivity, followed by the ^{3}He NM64, the IGY and the $^{10}BF_3$ NM64. The simulations generally produce lower coefficients. The lowest coefficient, obtained for the $^{10}BF_3$ NM64, is a beneficial design characteristic of that widely used monitor. The Clem simulations explain this low coefficient as due to positive coefficients in the lead and polyethylene that are offset by a negative coefficient of the counter tube.

Table 2. Temperature coefficients by measurements and simulation

^{3}He Calibrator:	0.12%/°C
^{3}He NM64 (Thule/Nain):	0.09%/°C
^{3}He NM64 (Simulation):	0.07%/°C
$^{10}BF_3$ IGY (Potchefstroom):	0.06%/°C
$^{10}BF_3$ NM64 (Thule):	0.04%/°C
$^{10}BF_3$ NM64 (Simulation):	0.02%/°C

This experiment has demonstrated that we are well on our way to understand the temperature effect, and that we will be able to account for it in calibration measurements.

3. Environmental (surface) sensitivity

There are several factors that affect the stability of a monitor, such as changes in the absorbing material around the monitor and variations in the environmental background. Hatton (1971), for instance, described the effect of snow on the counting rate of a monitor. If one wants to achieve calibration accuracies of better than 0.02 %, such environmental factors must be known within this limit. In general, the effects of roofs and walls can be avoided by placing the calibrator in the open. However, the limiting factor seems to be its sensitivity to different ground surfaces. In general, these surfaces will have a different effect due to their different neutron production and moderation characteristics. Therefore, the sensitivity of the calibrator to different ground surfaces was investigated.

To do these experiments, the bottom of the calibrator was positioned about 50 cm above the surface. An area of approximately 3.0 m^2 beneath it was then filled up in steps with wax, water and bricks, respectively. One million counts were recorded for every individual measurement, giving a statistical accuracy of 0.1%. The counting rates of the calibrator were then compared with those of the stationary IGY, which was kept at constant environmental conditions. Figure 3 shows the ratio of the counting rates (IGY/calibrator) as function of column density of material underneath the calibrator. It shows that there was a clear decrease in the counting rate of the calibrator with increase in the amount of water and wax layers beneath the calibrator. However, the opposite was observed for the bricks as surface.

The results confirm in the first place that wax (a C-H polymer) and water (H_2O) have molecular structures so similar that their neutron absorbing properties are almost identical. Secondly, the very large effect (about 3% per 40 g/cm^2) seems to flatten off at about 40 g/cm^2). Thirdly, the increase in counting rate with the addition of bricks indicates that this higher Z material is an effective neutron producer with quite different properties than the absorbers.

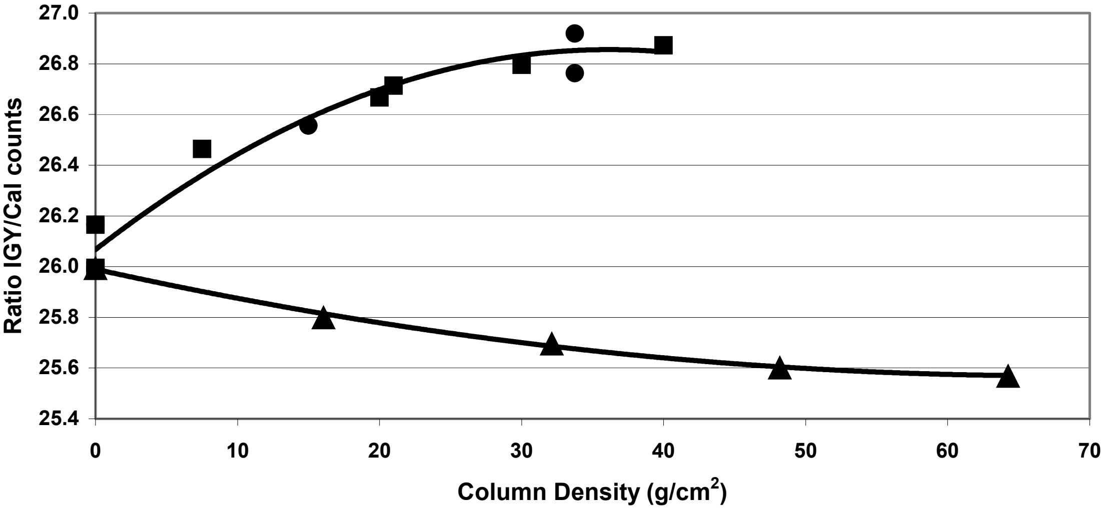

Figure 3. Surface effects. The circles indicate the ratios for the wax layers, the squares for water and the triangles for layers of bricks beneath the calibrator.

4. Conclusions

The surface tests have shown a very large sensitivity, and they are still not complete. In a next series of experiments the different surfaces have to be built up underneath the calibrator while it is lifted by the same amount so that it always remains the same distance from the top of the surface. Due to the low counting statistics of the calibrator, these experiments take rather long, and we foresee that they will last at least another six to nine months before the calibrators are ready for calibration measurements.

5. Acknowledgements

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