Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 741–744

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

Experiments with two calibration neutron monitors

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Abstract: Two identical calibration neutron monitors were completed in September 2002. They are designed to provide an intercalibration between the ≈ 50 neutron monitors around the world, so that rigidity spectra can be calculated from them. This paper discusses the final results of latitudinal surveys by one of them on five voyages from Seattle to McMurdo, Antarctica, and back. The other calibrator was used to investigate temperature and environmental sensitivity, which are also reported.

Introduction

Initial tests and results of two mobile neutron monitors to intercalibrate the worldwide network of neutron monitors were reported by Krüger *et al.* [1] at the previous ICRC. The purpose of this intercalibration is to derive intensity spectra of secondary cosmic rays, so that continuous spectral information about cosmic-ray modulation, to at least one decade higher in energy than is typically available from spacecraft, can be determined. However, to be useful, this intercalibration must be accurate to within ± 0.2%, as described by Moraal *et al.* [2].

Neutron monitors are integral detectors of secondary cosmic rays, each with its unique design and detection efficiency. Thus, to achieve this accuracy, one must know any differences in energy response between the calibrator and the standard NM64 stationary neutron monitors. Final results on this aspect are reported in this paper.

Moraal *et al.* [3] reported on the calibrator's large instrumental temperature sensitivity of 0.13%/°C, discovered at SANAE. At the same time, the Bartol-group also discovered similar temperature effects on their stationary neutron monitors. 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.*, [4]). Several measurements of this temperature effect, as well as those of different surfaces underneath the calibration monitor, are discussed.

Final results of the latitudinal surveys

The Bartol Research Institute, in collaboration with the Australian Government Antarctic Division and the University of Tasmania, has conducted neutron monitor latitudinal surveys annually since 1994, from the United States to Antarctica, and back, over 5-6 months periods. A standard 3NM64 neutron monitor was carried aboard one of two US Coast Guard icebreakers, the vessels *Polar Sea* or *Polar Star*. These surveys cover cutoff rigidities from ≈ 0.1 GV at McMurdo to ≈ 15.5 GV in the mid-Pacific. The details of these annual sea surveys are described by Bieber *et al.* [5, 6]. One of the Potchefstroom calibrators was sent together with this 3NM64 on five of these voyages since 2002 to measure the difference in energy (latitudinal) response.

The first three surveys with the calibrator were discussed at the previous ICRC, by Krüger *et al.* [1]. It was repeated two more times to reduce statistical uncertainties. For the 2005/06 season,

Table 1: Latitudinal surveys with the calibration neutron monitor, since 2002.

Year	Vessel	Departure Seattle	Crossing Equator	Arrival McMurdo	Departure McMurdo	Arrival Seattle
2002/03	*Polar Sea*	4 Nov 02 day 308	day 328	3 Jan 03 day 369	day 428	19 Apr 03 day 475
2003/04	*Polar Sea*	17 Nov 03 day 321	day 340	31 Dec 03 day 365	day 401	30 Mar 04 day 455
2004/05	*Polar Star*	5 Nov 04 day 310	day 327	30 Dec 04 day 365	day 406	17 Mar 05 day 442
2006	*Polar Star*				day 47	29 Mar 06 day 88
2006/07	*Polar Sea*	18 Nov 06 day 322	day 342	9 Jan 07 day 374	day 410	10 Apr 07 day 465
Cutoff rigidity		≈ 1.7 GV	≈ 15.5 GV	≈ 0.095 GV	≈ 0.095 GV	≈ 1.7 GV

only the return leg could be recorded, due to logistical reasons. Table 1 shows a summary of the five surveys. The ratio of the calibrator to 3NM64 counting rate was calculated. The average daily ratios were then binned into rigidity intervals of 1 GV each, ranging from 0 to 16 GV, as shown by the data points in Figure 1. The error bars were obtained from the statistical fluctuations expected from the total number of counts in that interval. The middle solid line in Figure 1 represents a linear regression of $-(8.4 \pm 0.7) \times 10^{-5}$/GV. The error is one standard deviation in the value of the counting rate. This gives a fractional change in the slope of $-(0.235 \pm 0.018)$%/GV. This implies that over the rigidity range of 0 – 15 GV the upper limit on the uncertainties is $\approx \pm 15 \times 0.018 = 0.27$ %, which is larger than the desired accuracy of at most 0.2%. However, it will be a constant error, and will have little effect on spectral studies.

The dashed curve in this figure indicates the calculated ratio for the two monitors by using the FLUKA particle transport code by one of the authors (J. Clem), for both solar maximum (bottom line) and solar minimum periods. There is a free normalization between this simulation and the observations. The slope is less than half of the measured slope, and these simulated values can not yet be used in further quantitative studies.

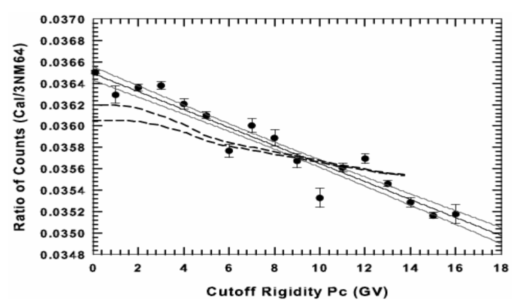

Figure 1: Latitudinal response of the counting ratios as function of cutoff rigidity for 2002-07.

Temperature sensitivity of neutron monitors

The second calibration neutron monitor was taken to SANAE, Antarctica, between 19 December 2002 and 2 February 2003. An unexpected large instrumental temperature sensitivity of 0.126 %/°C was found, as described in Moraal *et al*. [3]. Several experiments were performed in Potchefstroom, where the temperature coefficient of the calibrator was determined with simultaneous recordings of the Potchefstroom IGY neutron monitor. These experiments were reported by Krüger and Moraal [7] at the previous ICRC. By using standard weighting procedures, the composite of the experiments done at Potchefstroom and

SANAE determines the temperature sensitivity of the calibrator as α = (0.118 ± 0.005) %/°C.
The temperature coefficient of the IGY was also determined by keeping both monitors inside the monitor hut at different fixed temperatures. As reported by Krüger and Moraal [7], the coefficient obtained was α = (0.053 ± 0.012) %/°C.
Evenson *et al*. [8] described independent investigation of the instrumental temperature sensitivity of the Thule and Nain standard 3NM64 monitors, due to a runaway thermostat at their Thule-station. Their neutron monitors have combinations of $^{10}BF_3$ and ^3He counters. The coefficients are shown in Table 2.
J. Clem simulated the temperature sensitivity of a 3NM64 neutron monitor with both ^3He and $^{10}BF_3$ counters using the FLUKA simulation program. These calculated temperature coefficients for the ^3He and the $^{10}BF_3$ counters are also shown in Table 2, and it can be seen that a ^3He neutron monitor is about four times more sensitive to temperature changes than a $^{10}BF_3$ monitor.
To determine the temperature coefficient of the other calibrator on voyages to McMurdo, air conditioning was switched off for extensive periods in 2006/07 when the ship was at McMurdo. Using α = (0.044 ± 0.002) %/°C for the $^{10}BF_3$ 3NM64, as shown in line 5 of Table 2, the coefficient for the calibrator was determined as α = (0.131 ± 0.020) %/°C, which agrees well with the value obtained at SANAE, and confirms the validity of the two independent methods.

Table 2: Measured and simulated temperature coefficients.

1	^3He Calibrator:	0.118 ± 0.005 %/°C
2	^3He 3NM64 Thule/Nain	0.091 ± 0.002 %/°C
3	^3He 3NM64 Simulation	0.073 ± 0.007 %/°C
4	$^{10}BF_3$ IGY Potchefstroom	0.053 ± 0.012 %/°C
5	$^{10}BF_3$ 3NM64 Thule	0.044 ± 0.002 %/°C
6	$^{10}BF_3$ 3NM64 Simulation	0.018 ± 0.006 %/°C

A summary of these temperature coefficients is shown in Table 2, where it can be seen that the calibrator has the largest sensitivity, followed by the ^3He NM64, the IGY and the $^{10}BF_3$ NM64. The simulations generally produce lower coefficients. Evenson *et al*. [8] explained the low coefficient for the $^{10}BF_3$ NM64 as due to positive coefficients in the lead and polyethylene that are offset by a negative coefficient of the counter.

Environmental (surface) sensitivity

Environmental factors affect the performance and stability of a monitor, such as changes in the material around it, and variations in the background such as snow, as described by Hatton [9]. These factors must be known to < 0.2% to achieve the desired calibration accuracies. Krüger and Moraal [7] stated that, in general, roof and wall effects can be avoided by placing the calibrator in the open. Thus, the limiting accuracy factor is the sensitivity to different ground surfaces.
Previous results for different ground surfaces, described by Krüger and Moraal [7], were inconclusive. Therefore, the experiments were extended in 2006 by hanging the calibrator from the roof of an enclosed building on a tackle system at different heights above bodies of water and bricks.

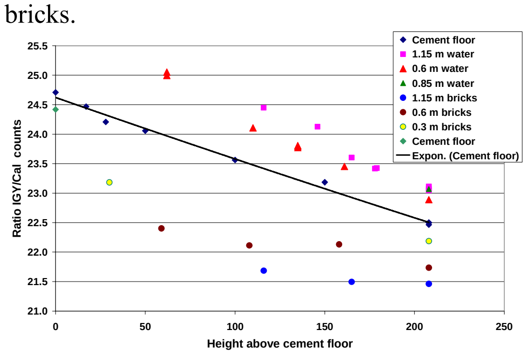

Figure 2: Counting ratios of the IGY and calibration neutron monitor as function of height above the cement floor, with different amounts of water and bricks beneath it. The regression line indicates the ratios for different heights above the cement floor only (without water or bricks).

The calibrator was first elevated at different heights above the floor level, without water or bricks, to determine the effect of the cement floor only. The calibrator counting rate increases with height, as shown by the diamonds and the regression line, which indicates that the surface has a stronger absorption than production effect.
Next, this experiment was repeated above a body of water in a plastic pool of 4 m diameter and 1.15 m high. This depth is ~10 times larger than

the amount estimated by Hatton and Carmichael [10] necessary to absorb virtually all the environmental evaporation neutrons. The upper squares (for 1.15 m water) and triangles (for 0.6 m) confirm this effect – the counting rate increases with ~ 3% with 1.15 m of water, and there is a clear saturation between 0.6 and 1.15 m.

Next, the water was replaced by the same volume of bricks. This caused a significant increase in counting rate of ~5%, confirming the secondary production in this material.

Conclusions

The five latitudinal surveys with the calibration neutron monitor have confirmed the results of Krüger *et al*. [1, 11] that the calibrator has an energy response that is 0.24%/GV larger than that of a standard NM64 neutron monitor.

The temperature sensitivity experiments for the various neutron monitor configurations are such that one will be able to account for this sufficiently accurately in the calibration measurements. These experiments have established that neutron monitor temperatures should be kept stable to within a few degrees.

Finally, the calibrator has a very large sensitivity to the type of surface beneath it. Water has neutron absorbing properties, while brick with its higher-Z material is an effective neutron producer. This sensitivity to different surface types has turned out be the greatest challenge for the intercalibration of the neutron monitor network, and it can only be avoided by calibrating above a body of water of 12 m^2 area by 1 m high.

Acknowledgements

This work is supported in part by U.S. grant ATMOSPHERE-0000315, and by the South African National Antarctic Programme. We thank A. Benadie, D. de Villiers, L. Shulman, J. Roth, K. Bolton, and B. Wilson for technical and logistic support.

References

[1] Krüger, H., Moraal, H., Bieber, J.W., Clem, J.M., Evenson, P.A., Pyle, K.R., Duldig, M.L., and Humble, J.E., Proc. 29th ICRC, 2, 473, 2005.

[2] Moraal, H., Benadie, A., de Villiers, D., Bieber, J.W., Clem, J.M., Evenson, P.A,., Pyle, K.R., Shulman, L., Duldig, M.L., and Humble, J.E., Proc. 27th ICRC, 10, 4083, 2001.

[3] Moraal, H., Krüger, H., Benadie, A. and De Villiers, D., Proc. 28th ICRC, 3453, 2003.

[4] Iucci, N., Villoresi, G., Dorman, L.I. and Parisi, M., J. Geophys. Res., 105, 20135, 2000.

[5] Bieber, J.W., Clem, J., Duldig, M.L., Evenson, P., Humble, J.E. and Pyle, R., Proc. 27th ICRC, 10, 4087, 2001.

[6] Bieber , J.W., Clem, J., Duldig, M.L., Evenson, P., Humble, J.E. and Pyle, R., Proc. 10th Int. Sol. Wind Conf., AIP Conf. Proc, 679, 628, 2003.

[7] Krüger, H., and Moraal, H., Proc. 29th ICRC, 2, 477, 2005.

[8] Evenson, P., Bieber, J.W., Clem, J., and Pyle, R., Proc. 29th ICRC, 2, 485, 2005.

[9] Hatton, C.J., Progr. in elementary particle and cosmic-ray physics, X, Ed J.G. Wilson en S.A. Wouthuysen, N.H. Publ. Co., Amsterdam, 1971.

[10] Hatton, C.J. and Carmichael, H., Canadian Journal of Physics, 42, 2443, 1964.

[11] Krüger, H., Moraal, H., Bieber, J.W., Clem, J.M., Evenson, P.A., Pyle, K.R., Duldig, M.L., and Humble, J.E., Proc. 28th ICRC, 6, 3441, 2003.