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Latitude surveys with a calibration neutron monitor

H. Krüger[a], H. Moraal[a], J.W. Bieber[b], J.M. Clem[b], P.A. Evenson[b], K.R. Pyle[b] M. Duldig[c], J.E. Humble[d],
(a) School of Physics, North-West University, Potchefstroom, South Africa.
(b) Bartol Research Institute, University of Delaware, Newark, De., USA.
(c) Australian Antarctic Division, Kingston, Tasmania, Australia.
(d) School of Mathematical Physics, University of Tasmania, Hobart, Tasmania, Australia.
Presenter: H. Krüger (fskhk@puk.ac.za), saf-kruger-H-abs1-sh36-poster

Two calibration neutron monitors were completed in September 2002. These instruments are designed to provide an intercalibration between the 40-odd neutron monitors around the world, so that rigidity spectra can be calculated from them. This paper describes the performance of such a calibration neutron monitor on three voyages from Seattle to McMurdo, Antarctica, and back. An accompanying paper discusses the instrumental temperature effect of the second calibrator.

1. Introduction

The final design and first results of a mobile neutron monitor to intercalibrate the worldwide network of neutron monitors were described by Krüger *et al.* (2003). The main objective of this intercalibration is to derive intensity spectra of cosmic rays. This will provide continuous spectral information about cosmic ray modulation to at least one decade higher in energy than is presently obtained by spacecraft. The aim is that this intercalibration must be accurate to within ± 0.2%, as described in Moraal *et al.* (2001).

Neutron monitors of different design have different responses to primary intensity variations, as well as different atmospheric responses. Thus, to achieve this accuracy, one must accurately know any differences in energy response between the calibrator and the standard NM64 type stationary neutron monitors. The best way to represent such differences is to calculate and measure the ratio of the counting rate of the calibrator relative to the NM64 as a function of cutoff rigidity.

Preliminary simulations of the energy response of the calibrator against a 6NM64, as function of cutoff rigidity P_c, were described in Moraal *et al*. (2000). The Hatton (1971) NM64 detection efficiency with the Clem (1999) atmospheric Monte Carlo transport code FLUKA, was used, as described by Clem and Dorman (2000). Their simulated counting ratio changes with -2.7% from 1 to 15 GV, i.e. it has an average slope of about -0.18%/GV. This different cutoff rigidity dependence is due to the different designs and geometry, and must be corrected for.

This value of -0.18%/GV should be experimentally confirmed, and this was done by taking one of the two calibrators on a series of three latitude surveys together with an NM64.

2. Results of the latitude surveys of the calibrator together with the 3NM64

The Bartol Research Institute, in collaboration with the Australian Antarctic Division and the University of Tasmania, has conducted neutron monitor latitude surveys annually since 1994, from the United States to Antarctica, and back, over a 5-6 months period. They use a standard 3NM64 neutron monitor that is 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 GV in the mid-Pacific. The details of these annual sea surveys are described by Bieber *et al.* (2001). One of the Potchefstroom calibrators was sent together with this 3NM64 on three of these voyages to measure the difference in energy (latitude) response.

The first survey started at Seattle, with $P_c \approx 1.7$ GV, on day 308 (4 November) 2002, on the 'Polar Sea'. The equator, with maximum $P_c \approx 15.2$ GV, was crossed on day 328. On day 368 the ship arrived at McMurdo, Antarctica, with $P_c = 0.095$ GV. The return journey started on day 427 and the equator was crossed on day 461. The journey ended on day 474 (19 April 2003) in Seattle. The results of this survey were reported in Krüger *et al.* (2003). The amount of data from this survey was insufficient for proper interpretation, and therefore it was repeated two more times.

With the second survey the 'Polar Sea' departed from Seattle on day 321 (17 November) 2003. The location of the 3NM64 and the calibrator was the same as on the previous voyage. The equator was crossed on day 340, with maximum $P_c \approx 15.5$ GV reached the previous day (day 339). McMurdo was reached on day 365, with $P_c = 0.095$ GV. The return journey started on day 401 and the equator was crossed on day 442. It ended in Seattle on day 455 (30 March 2004).

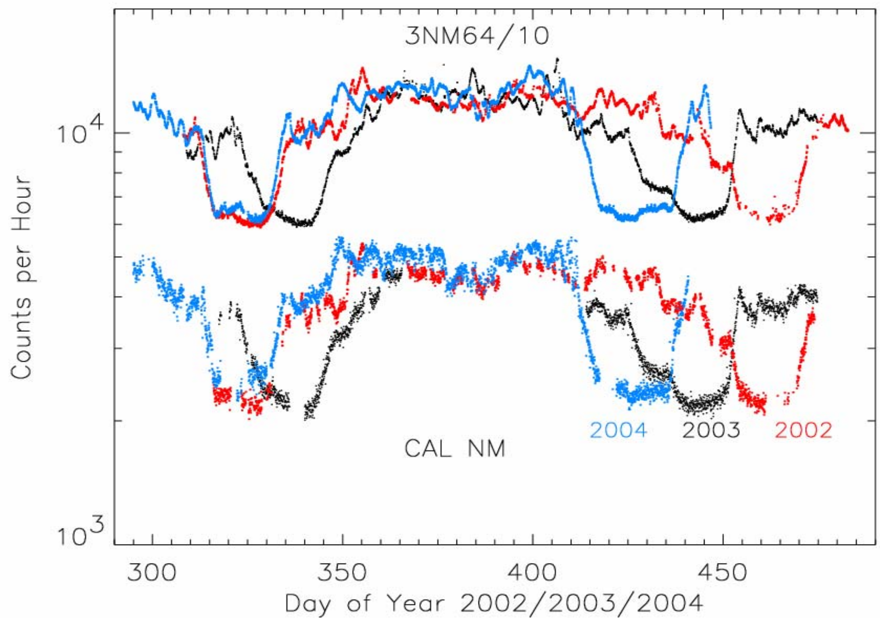

Figure 1. The average hourly counting rates of the calibrator and 3NM64 for three latitude surveys. The horizontal axis starts on day 290 of each year, and continues past day 365 into the first part of the next year.

The third journey started on day 310 (5 November) 2004, when the other vessel, the 'Polar Star', departed from Seattle. The calibrator and 3NM64 were left in exactly the same location inside the monitor van as in the previous voyages on the 'Polar Sea' (L. Shulman, private communication). The ship crossed the equator on day 327, and reached McMurdo on day 365. On day 406 she departed from McMurdo, crossed the equator on day 423, and reached Seattle on day 442 (17 March 2005).

The average hourly counting rates of the two neutron monitors for the three voyages as function of time are shown in Figure 1. The three upper curves show the counts of the 3NM64 (divided by 10), while the bottom curves show the counts of the calibrator. No corrections were made for pressure variations or anything else. All data points with obvious electronic pick-up were eliminated. This explains the gaps in the calibrator data. In addition, no data is available for the calibrator for the extended period from day 366 to day 413 in 2003/04, when the electronics head had to be removed to fix the hard disk. The decrease in the counting rates when passing the equator can clearly be seen. The cutoff rigidity of the position of the ship was obtained at 12:00 every day during the 2002/03 voyage. For the 2003/04 and 2004/05 voyages the cutoff rigidities were estimated from the geographical position at noon, with an accuracy of ≈ 0.5 GV.

The results of the first two journeys will be described in this paper. Although it cannot be seen in Figure 1, there were random fluctuations on the third voyage in the calibrator counts that were at least four times larger than the statistical fluctuations, rendering this voyage useless. This was probably due to a problem with the pre-amplifier.

The results of the 2002/03 and 2003/04 voyages are presented separately in Figure 2. Daily average values of the calibrator to 3NM64 count rate were calculated for all days that had at least 7 hours of data. These average daily ratios were then binned into rigidity intervals of 1 GV each. This means that all the days during which the monitors were within such a range were averaged into one point. Separate crossings of a rigidity interval were, however, kept separate. In this way one can find up to four such points per interval: two for crossing it on both sides of the equator on the outbound leg, and two for the return. The filled circles are the values for 2002/03, while the open circles are the 2003/04 measurements. At cutoff rigidities > 1GV the number of data points collected is more for 2003/04 than during the previous year. The reason is that there are many gaps in the 2002/03 calibrator data because of intermittent failures of the electronics. The small errors on the data points at zero GV are due to the long period that the ship spent at McMurdo.

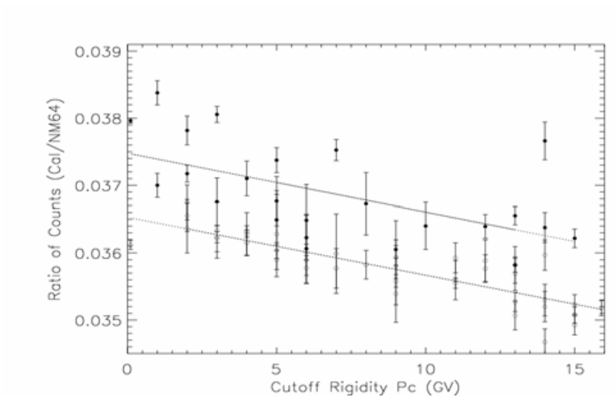

Figure 2. The counting ratios binned into rigidity intervals for 2002/03 (filled circles) and 2003/04 (open circles).

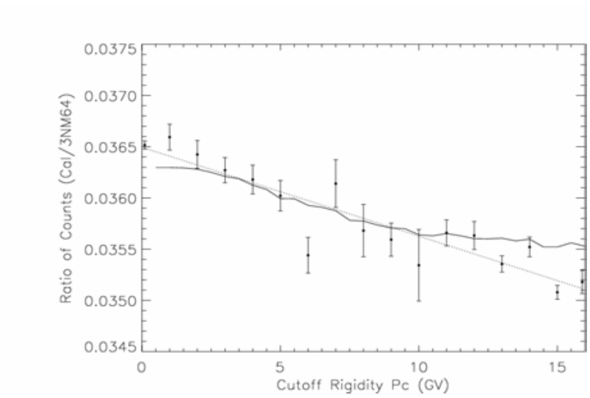

Figure 3. The latitude response for the average daily counting ratios as function of cutoff rigidity for 2002-04.

Regression lines were drawn for each year. The slopes of these lines are -0.25%/GV in 2002/03 and -0.24%/GV in 2003/04. The offset between the two is 1.026. The reason for this difference of 2.6% could not be determined. The position of the calibrator had not changed for these two voyages. It may be that something in the environment had changed. The fact that this difference exits, demonstrates the sensitivity of the experiment.

The 2002/03 ratios were normalized to those of 2003/04 by dividing the former with 1.026. Thereafter, all the ratios in a given rigidity interval were averaged into one single point, as represented in Figure 3. The dotted linear regression line has a slope of –0.24% /GV.

The continuous curve in this figure indicates the calculated ratio for the two monitors by using the Fluka particle transport code by J. Clem, as described before. There is a free normalization between this Clem calculation, which was calculated for a 6NM64, and the observations. The regression line lies encouragingly near the Clem calculation. If a linear regression is done on this calculated curve, the slope is -0.18%/GV.

4. Conclusions

A second latitude survey with the calibration neutron monitor has confirmed the results of Krüger *et al*. (2003) that the calibrator has a different energy response than a standard NM64 neutron monitor, such that its cutoff rigidity response is 0.24%/GV larger. This is encouragingly near to the calculated value of 0.18%/GV. A third survey was unsuccessful due to an electronics failure. Since the errors on the measurements are still fairly large, we intend to repeat this survey one more time. In addition, the simulation of the calibrator is also being repeated at present, because the existing calculation was done for a prototype that had somewhat different specifications than the final version.

5. Acknowledgements

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References

[1] Bieber, J.W., Clem, J., Duldig, M.L., Evenson, P., Humble, J.E. and Pyle, R., *Proc. 27th Int. Cosmic Ray Conf.*, 10, 4087, 2001.
[2] Clem, J.M., *Proc. 26th Int. Cosmic Ray Conf.*, 317, 1999.
[3] Clem, J.M. and Dorman, L.I., *Space Sci. Rev.*, 93, 335, 2000.
[4] Hatton, C.J., *Progress in elementary particle and cosmic-ray physics,* X, Ed J.G. Wilson en S.A. Wouthuysen, North Holland Publishing Co., Amsterdam, 1971.
[5] 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 Int. Cosmic Ray Conf.,* 6, 3441, 2003.
[6] Moraal, H., Belov, A. and Clem, J.M., *Space Sci. Rev.,* 93, 285, 2000.
[7] 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 Int. Cosmic Ray Conf.*, 10, 4083, 2001.