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Determination of Yield Functions of Neutron Counters at the South Pole from Monte-Carlo Simulation

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1. Introduction

Neutron monitors are the premier ground-based instruments for precise measurements of the time variations of GeV primary cosmic rays. It is crucial to know the energy-dependent effective area (yield function: *YF*) of the monitor, depending on the detector types, altitude, and location. The standard design neutron monitor (NM64) was introduced in 1964 by Hatton and Carmichael [1] and was used worldwide to study the time variations of the Galactic Cosmic Rays (GCR). Bare neutron detectors, a type of lead-free neutron monitor, present a more sensitive response to lower energy primary particles than an NM64; however, they are more sensitive to environmental effects [2, 3, 4, 5].

In our previous work [6], we derived the *YF* from the direct measurement from the latitude survey in 2009 – 2010 ("Oden" survey) of a specific configuration of paraffin-moderated bare neutron detectors. After finishing the survey in April 2010, the two detectors were later installed in December 2010 as part of an array of 12 bare detectors at the South Pole, where an NM (with a distinct *YF*) is also operated. In the fact that the yield function of the paraffin that derived from [6] is the one measured at sea level, while the South Pole station is at a high altitude of about 2,835 meters above sea level. Therefore, the *YF* measured at the sea level may differ from that corresponding to the station. In this work, we aim to describe the simulated yield of the neutron counters at the South Pole using FLUKA 4-1.1, an open-source particle physics Monte Carlo simulation package (https://fluka.cern/) [7, 8]. DPMJET (rQMD) interaction models has been used [9, 10].

2. South Pole Neutron Detectors

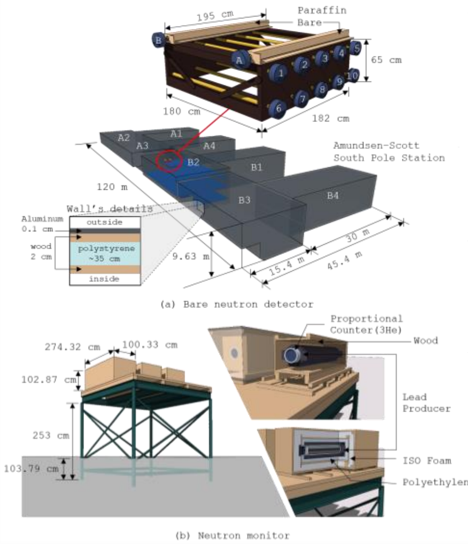

Figure 1: (a) Bare neutron detector array at South Pole. (b) Three single NM64s placed in the same row (3NM64) at the South Pole located outside the station. The renderings are created by Flair 3.1 [11], which is an advanced user–friendly interface for FLUKA 4-1.1

3. Simulated Energy Response of the South Pole Detector to Secondary Particles

3.1 Bare neutron detector tests

The test results are summarized in Table1. In all cases, the counting rates are expressed as counts per second per detector. The high rate at the South Pole is mostly due to the high altitude. The rates presented are not corrected for barometric pressure or modulation level but the dates when the data were taken are recorded for possible interpretation in that context.

Location	Moderator	Rate	Date
	South Pole, Antarctica		
B2	None	13.492(4)	2012
B2	Paraffin	14.862(5)	2012
B2	Donut	13.82(2)	2010-01-23
Snow	Donut	12.88(9)	2010-01-26
	University of Delaware, USA		
Patio	None	1.487(4)	2010-08-26
Patio	Paraffin	1.727(5)	2010-08-27
Patio	Donut	1.448(4)	2010-08-27
Patio	Standard	2.585(5)	2010-08-30
Shop	None	0.844(1)	2010-08-31
Shop	Paraffin	0.889(1)	2010-08-27
Shop	Donut	1.111(1)	2010-08-27
Shop	Standard	1.257(1)	2010-08-31

Table 1: Bare Helium-3 Neutron Detector Tests

3.2 Bare neutron detector simulations

We use simulations to understand why the moderator increased the count rates only slightly. Figure 2 (c) shows the preliminary result from the simulation of vertical neutrons that obviously see consistent with the tests. At energy 100 MeV, the best estimation for comparing with the counting rate [12, 13, 14], the energy response for the Paraffin is slightly higher than None only about a half-order of magnitude in energy ranges 1 keV – 10 MeV and about 1.35 orders of magnitude at higher energy than 100 MeV. Conversely, None has a better response to lower energy neutron than 1 keV.

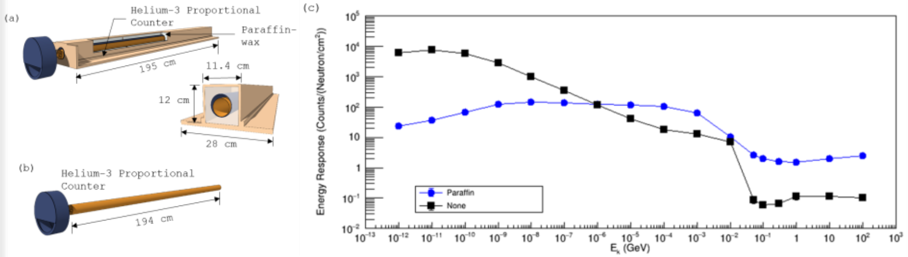

Figure 2: (a) Paraffin-moderated bare detector, (b) None moderated bare neutron detector. And (c) Their energy responses. The deadtime 20 μs has been applied in the analysis.

3.3 Energy Response of the Ratios

The neutron monitor at the South Pole is uniquely suited to observing solar energetic particles due to its high altitude and lowest geomagnetic cutoff. Each type of detector has *YF* function differently and although they are the same type of detector installed at different altitudes, the *YF* function is not the same. This reason leads us to estimate the spectral index from the Bare/3NM64 ratio [5, 15].

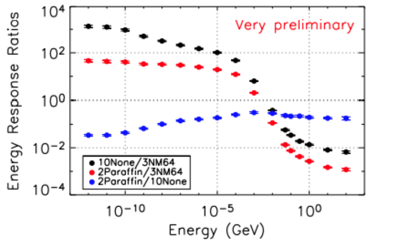

Figure 3: The simulated results for 10None/3NM64, 2Paraffin/3NM64, and 2Paraffin/10None energy response ratios.

4. Yield Function of the South Pole Neutron Detector

The simulations began with generating libraries of SPs (neutrons, protons, muons±) produced by the interaction of primary protons and alpha particles (from 1 GV to 200 GV) in the atmosphere. The atmospheric profile at the South Pole was based on the Global Data Assimilation System (GDAS) and Naval Research Laboratory Mass Spectrometer, Incoherent Scatter Radar Extended model (NRLMSISE-00) following the method described in [15].

4.1 Comparison of Bare Designs

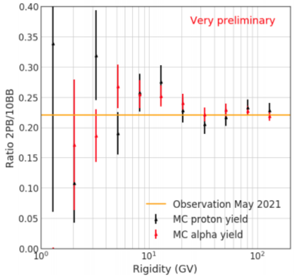

Figure 4: The ratio of the observed count rates at the South Pole for the two types of configuration (orange line) and the ratios of the simulated yield functions (red and black markers).

4.2 Comparison with Previous Results

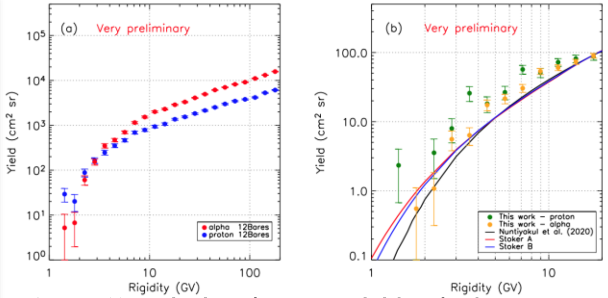

Figure 5: (a) Simulated *YF*s for protons and alphas of 12 bare counters at the South Pole. (b) *YF*s of the two Paraffin bares from simulation work (this work) compared to the determination of [6] and [15].

5. Conclusion

We studied in this work the energy responses of three types of neutron detectors at the South Pole and developed a simulation method to determine the corresponding yield functions. We obtained preliminary results of the yield functions of the 12-bare array. Their current agreement of the ratios of the yield functions for two types of bares with the observation is an encouraging event if more statistics are needed to refine the results and confront them to more observations. The determination of the *YF* of the 3NM64 located outside the station is a work in progress. We will continue our effort to improve the precision and accuracy of the three detectors simulation to improve the determination of the spectral index of the Solar Energetic Particle during Ground Level Enhancement using the South Pole neutron monitor data. The research is supported in part by Thailand Science Research and Innovation via Research Team Promotion Grant RTA6280002.

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