"Physics of Auroral Phenomena", Proc. XXXIII Annual Seminar, Apatity, pp. 83 - 86, 2011

Polar Geophysical Institute

MODELLING OF HADRON INTERACTIONS IN THE NEUTRON MONITOR

E.A. Maurchev, B.B. Gvozdevskij, J.V. Balabin, E.V. Vashenjuk (*Polar Geophysical Institute KSC RAS, 26a, Academgorodok Str., Apatity, 184209, Russia; E-mail: maurchev@pgai.ru*)

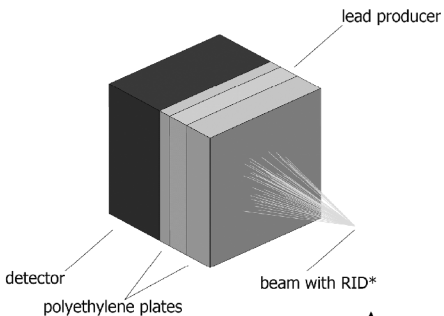
Abstract. We have carried out two modelling experiments with a software package GEANT4, allowing investigating the neutron monitor (NM) response function to various kinds of radiation. In the first experiment the system of layers (the polythene-lead-polythene) simulating the parts of a neutron monitor was irradiated with particle beams with random incident direction. As a result of calculations spectra of secondary neutrons which have reached the detector have been obtained.

In the second experiment the whole neutron monitor was simulated, with geometry as much as possible approached to a reality. The particle flux simulating the basic components of secondary cosmic radiation at the ground surface fell on the top surface of the instrument. For each particle the basic processes of its interaction inside the neutron monitor were traced: 1) interaction with lead resulting to birth of secondary neutrons, 2) moderation of them in polythene and 3) interaction with boron (10) nuclei which are a part of gas BF_3, filling the neutron counter tube CNM-15. Responses and the relative contribution to the neutron monitor count rate of all kinds of secondary cosmic rays are calculated. In this work calculation results of the neutron response function are presented. Also the spectra of secondary neutrons obtained at modeling in the polythene-lead-polythene system, simulating the NM structure are presented.

Introduction

The neutron monitor section (NM, fig. 1, b) consists of six proportional counter tubes filled by the $^{10}BF_3$ gas. These counters are surrounded by a cylindrical polyethylene moderator (thickness of 2.5 cm). This inner moderator is installed inside of a great lead volume, so-called lead generator. Finally, the outer walls of the NM again consist of polyethylene (7.5 cm thick) that forms the so-called reflector, because of which low-energy neutrons are scattered back into the NM from within or into space when they are going outside.

In this work a series of modeling experiments aimed to investigate physics of interactions of cosmic ray particles in the neutron monitor with a software package GEANT4 were carried out. In the first experiment the system of layers polythene-lead-polythene was simulated with the purpose to improve understanding of physics of particle interaction in the matter surrounding the detector. The system was irradiated with beams of monoenergetic particles (n, p, π^-) with energy 100 MeV, 300 MeV, 1 GeV and 10 GeV, as shown in fig. 1, a.



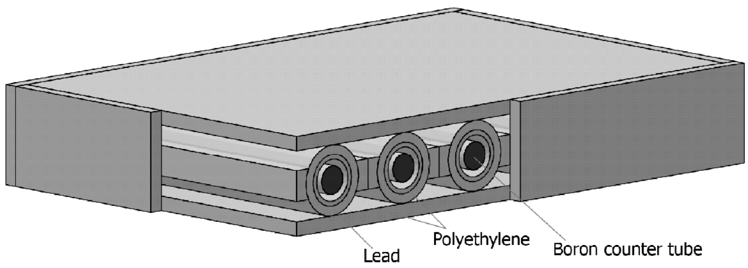


Fig. 1. A. The system used at the first modeling stage and simulating the construction of a neutron monitor. It consists of polyethylene plates, a lead plate (lead producer) and a detector of secondary neutrons. RID* is random incident directions. **B**. Real construction of the neutron monitor section 6-NM-64 used at the second modeling stage. It consists of six cylindrical proportional counter tubes (200 cm in length and 15 cm in diameter) surrounded by a cylindrical polyethylene moderators by thickness 2.5 cm. This construction is placed inside the lead producer (5 cm thick) and surrounded by the polyethylene reflector of 7.5 cm thickness.

As a result multiplicity spectra of secondary neutrons reaching a detector as well as their energy spectra in dependence on species and energies of primary particles were obtained. In the second experiment the whole neutron monitor was simulated for calculating the response function and tracking of secondary neutrons in the lead producer. The neutron monitor was irradiated with a particle flux incident perpendicularly to a surface with a random incident position, Fig. 2. As the results secondary neutrons typical tracings in a NM were obtained. Also the NM response function was calculated.

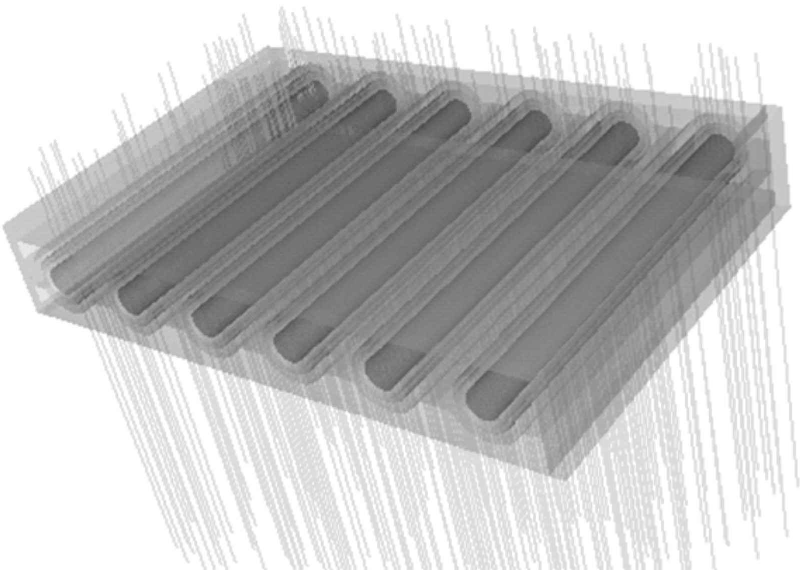


Fig. 2. Visualization of neutron monitor model with a graphic system FreeWRL. In the figure the neutron monitor 6-NM-64 is placed in a particles beam with random incident positions (particles fall on the monitor from above).

Modeling technique

For the calculations presented in given work the software package Geant4 (version 9.2. p.2 [1]) installed on OS SuSe Linux 11.2 was used. Also the library of data G4NDL 3.13 (Neutron Data Library) [2] which is based on calculation of cross sections ENDF/B-VI and which also includes cross sections for thermal scattering was installed. For visualization of modeled system graphic interface DAWN was used. In describing the physics of interactions we used a standard list of physical processes, based on ready-made models (Bertini cascades and model exact calculation of low energy neutron interactions with matter [3]).

Calculation results

In Fig. 3 typical multiplicity spectra of secondary neutrons depending on primary particle (n, p) energy are presented. For calculation of the neutron monitor response function first of all, the information is necessary on neutrons which have reached the detector and have interacted with nuclei ^{10}B. In Fig. 4 the typical energy spectrum of secondary neutrons which have reached the detector, obtained as a result of the first modeling experiment (energy of a primary neutron 100 MeV) is presented. It should be noted, that at increase of primary particle energy a spectrum form remains constant, and the amplitude varies only.

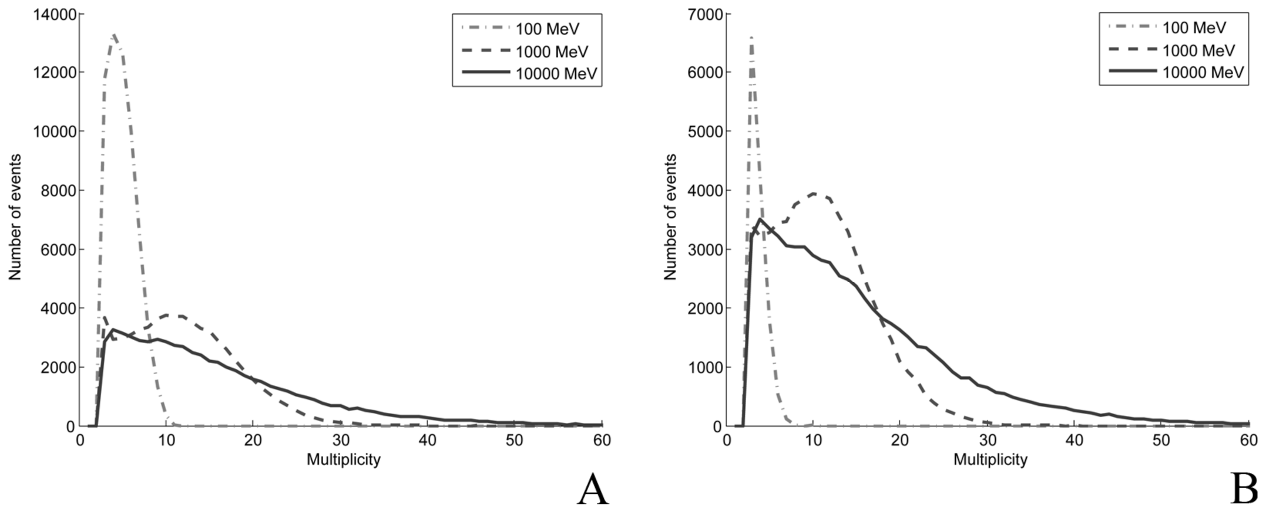


Fig. 3. Multiplicity spectra of secondary neutrons resulting in the irradiation of a system: polythene-lead-polythene by the incident neutrons (A) and protons (B) beam with a random angular distribution.

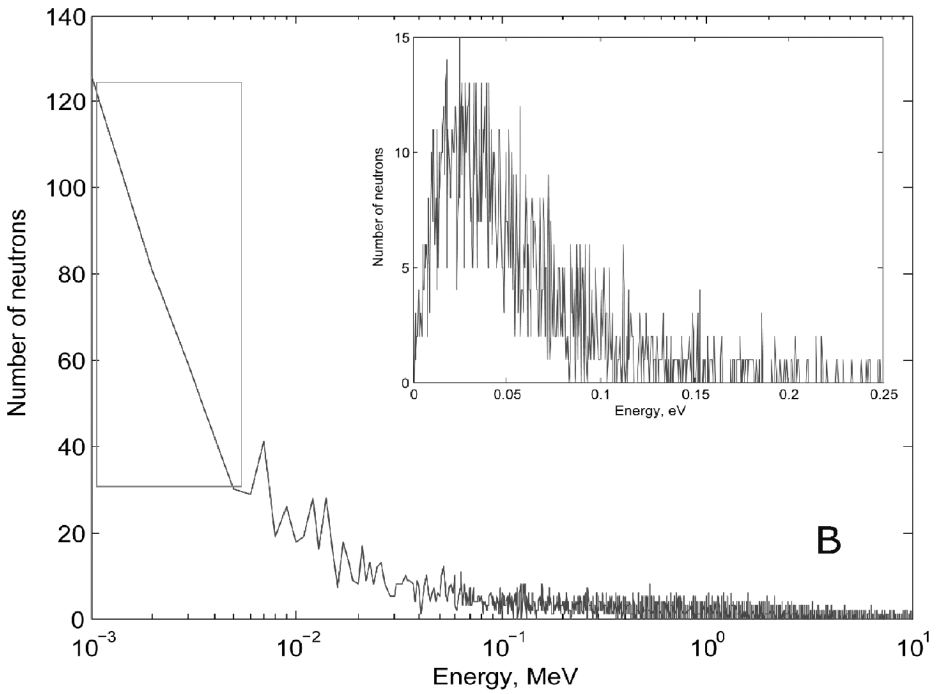


Fig. 4. A typical energy spectrum of secondary neutrons resulting in interaction of a primary neutron (100 MeV) with a lead and reached the detector layer.

In Fig. 5 the calculated response function obtained with a software package GEANT4, for comparison presented together with the response function calculated in [4] with a software package FLUKA is presented. Almost on whole energy range both response functions well agree. Very similar results on the response function calculations (Fig.5) were obtained by C. Pioch et al., 2009 [5]. Though they used in the calculations with the GEANT4 package their own Physics List.

Distinction in low energy range between our calculations and Clem and Dorman, 2000 [4] is connected, most likely, with distinction between cross sections used in [4] and ones in the present work.

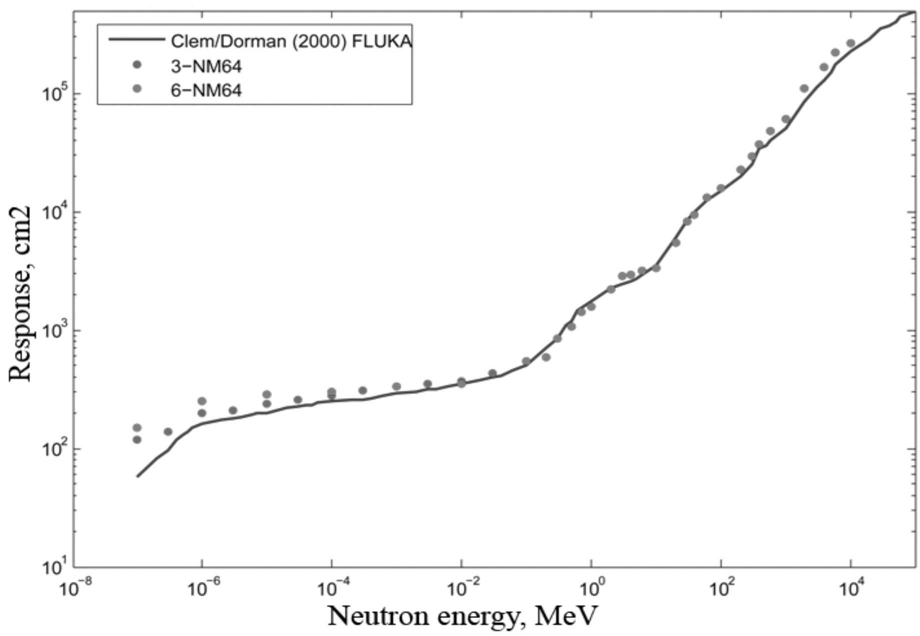


Fig. 5. Calculated response functions for the neutron monitor with 3 and 6 counter tubes (3-NM64 and 6-NM64). For calculation the standard package of physical processes GEANT4 QGSP_BERT_HP including various models for corresponding energy range was used. For comparison, the response function obtained in [4] with a software package FLUKA also is presented.

For incident on NM low-energy neutrons the response is insignificant because of their reflection from an external layer of polythene. The reflection is a result of process of elastic collision on nuclei of hydrogen or inelastic collision through reaction (n, γ).

Above the energy 9 MeV a response function of NM64 monotonously increases with increase in energy of incident neutrons, owing to formation of secondary neutrons at inelastic collision with heavy nuclei of lead surrounding counters. For this energy range the class of physical processes G4BinaryCascade was used.

Conclusions

A modeling and calculation of a response function of the standard neutron monitor NM-64 to various species of secondary cosmic rays with a software package GEANT4 were carried out. The results of a NM response function calculations for the neutron energy range from 10^{-7} MeV up to 10^{5} MeV are presented. The obtained results are in the good agreement with similar calculations of other authors executed the last years and with use of other techniques.

References

1. http://geant4.web.cern.ch/geant4/support/download.shtml
2. http://www.nndc.bnl.gov/csewg/
3. http://www.geant4.org/geant4/support
4. Clem J.M., Dorman L.I. Neutron Monitor Response Function. // Space Sci. Rev. 2000. V. 93 (1). P. 335–359.
5. C. Pioch, V. Mares, W. Rühm, E.A. Maurchev, E. V. Vashenyuk, Yu. V. Balabin Measurement of secondary neutrons from cosmic radiation at 79° N – a combined analysis of data from a Bonner spheres spectrometer and a neutron monitor (2010 to be published elsewhere)
6. Dorman L.I., Experimental and Theoretical Principles of Cosmic Ray Astrophysics. //M. Nauka. 1975. 464 p.