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Integral Neutron Multiplicity Measurements from Cosmic Ray Interactions in Lead

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Abstract. Sixty element ^3He neutron multiplicity detector systems were designed, constructed and tested for use in cosmic ray experiments with a 30-cm cube lead target. A series of measurements were performed for the cosmic ray configuration at ground level (3 meters water equivalent, mwe), in the St. Petersburg metro tunnel (185 mwe), and in the Pyhäsalmi mine in Finland (583 and 1185 mwe). Anomalous coincidence events with charged cosmic ray particles at sea level produced events with 100-120 neutrons due possibly to the total disintegration of the Pb nucleus. These events were also detected at 185 mwe, but the particles causing such disintegration are currently unidentified. We present examples of preliminary data from the various measurements and discuss future plans for underground experiments including possible searches for Weakly Interacting Massive Particles (WIMP, dark matter).

Keywords: cosmic rays, neutron physics, neutron multiplicity, dark matter

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INTRODUCTION

Production of neutrons in high-Z materials by penetrating components of cosmic rays is important for planning of many low background experiments, especially for neutrino detectors and other underground systems. Understanding of this process needs more experimental data for verification and validation of high-energy radiation transport codes. Also, some new unexpected processes and/or reactions may be discovered in such studies, including possibly various high energy neutral particles or even Weakly Interacting Massive Particles (WIMP or dark matter). Some earlier observations at ground level of total lead disintegration by cosmic ray particles indicated neutron “bursts” or “flashes” of about 120 neutrons [1], which produced “peaks” in neutron multiplicity distributions.

Neutron multiplicity detector systems (NMDS) consisting of sixty ^3He detectors were constructed by the V. G. Khlopin Radium Institute (KRI). Experiments were performed at KRI, at the Univ. of Nevada, Las Vegas (UNLV), in the St. Petersburg, Russia, Metro Tunnel, and at the University of Oulu Centre for Underground Physics in Pyhäsalmi (CUPP), the underground laboratory in the Pyhäsalmi Mine, Finland. Each NMDS is modular and can be configured for a variety of neutron multiplicity measurements including measurements of cosmic particles, scientific investigations of proton spallation targets, transmutation of nuclear waste, production of radioisotopes, and non-proliferation materials accountability and control.

EXPERIMENTAL

For neutron multiplicity measurements in cosmic ray experiments the ^3He detectors were arranged around a 30-cm cube lead target. The lead cube was surrounded by polythene moderator 15 cm thick, and the ^3He counters were placed in this moderator layer on all sides of the target. In some measurements a plastic scintillator was added on top of the assembly for coincidence registration of charged particles incident from above. The NMDS were calibrated

with ^{252}Cf neutron sources placed at the center of lead target cubes. Fission neutron registration efficiency with the source in target center was 23.2 %, which is in satisfactory agreement with Monte-Carlo calculations [2]. Pulses from the plastic scintillator were also stored in the record of every multi-neutron event, enabling us to discriminate charged particles events. Usually only events with (apparent) multiplicity of 6 or more neutrons were stored and analyzed in detail. Such events cannot be caused by natural radioactivity (spontaneous fission or α,n reactions). The average lifetime of neutrons created in the NMDS assembly was 65 μs , so we collected neutrons for 256 μs in each event (94% of total neutrons).

RESULTS AND DISCUSSION

An example of a measured neutron multiplicity distribution is presented in Fig. 1. To estimate the neutron multiplicity of an event in the target, we divide counts by efficiency. As can be seen from Fig. 1, the “triggered” events multiplicity has a noticeable peak around $M = 23\text{-}24$ counts or a multiplicity of about $N = 100$ ($23/23\%$). This triggered peak is associated with both muons and other low-Z particles, possibly protons.

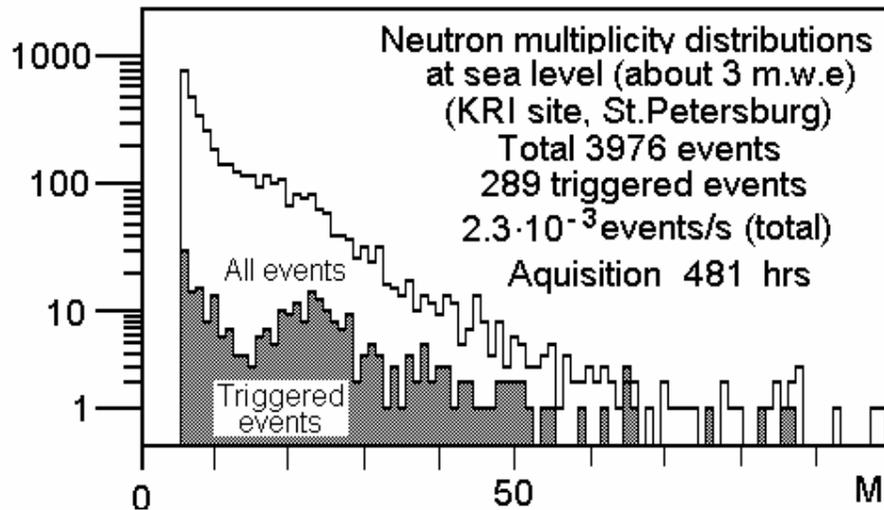


FIGURE 1. Multiplicity distributions (total and triggered) acquired at sea level in the KRI site (building equivalent to 3 mwe) during 481 hours of neutron counting.

In the distribution acquired in the St. Petersburg tunnel at 185 meters water equivalent (mwe), with 126 total events of $M > 24$ ($N > 100$) in 385 hours, the “peak” around $M = 23\text{-}24$ was still visible. Figure 2 illustrates the distribution from the CUPP laboratory [3], which is 220 m (583 mwe) underground. Since the muon flux at this depth is much weaker, data acquisition took 6504 hours. Nevertheless, with the poor statistics nothing can be said about the “peak” features around $M = 31$ and $M = 48$. The origin of these possible peaks are unknown at this time. Three events of $M = 93\text{-}99$ were recorded which implies multiplicities of $N > 400$ neutrons per event!

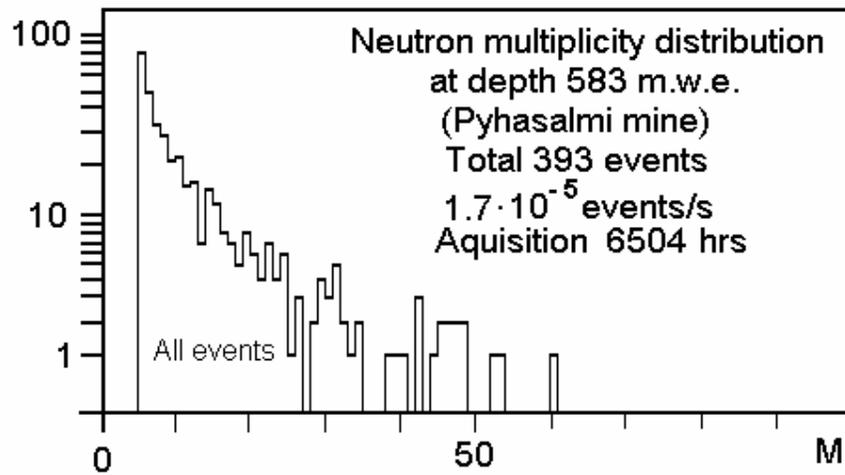


FIGURE 2. Multiplicity distribution (total) acquired in the underground CUPP laboratory (equivalent to 583 mwe) in Pyhäsalmi, Finland, during 6504 hours of counting [M].

The distribution obtained at 1166 mwe taken for 1440 hours produced only 6 total events with $M > 6$. Current plans are to increase the target size to about 12 Mt and to provide for a full plastic scintillator shield for measurements at depths greater than 1000 mwe. At these depths it may be possible to observe weak interactions of dark matter (WIMP) in the Pb target identified by neutron multiplicity peaks [4].

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