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Prototype of Neutron Detector Based on Boron-Containing Plastic Scintillator

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The boron enriched plastic scintillators are designed for the purpose of neutron detection in cosmic ray physics. Enhanced time resolution capability so as high neutron registration efficiency of these scintillators made them a preferable detector for studying of intensive hadron fluxes in the core region of extensive air showers.

1. Introduction

Investigations of extensive air showers (EAS) being carried out with the 18NM-64 neutron supermonitor at the Tien-Shan mountain station (3340 m a.s.l.) resulted in the discovery of the anomalously delayed neutron signals in EAS cores [1, 2]. This effect is illustrated by Figure 1, where the time distribution of neutron intensity registered in the passage of the core of an EAS with primary energy 20 PeV is presented. The expected intensity curve, normalized to the measured counting rate at the tail of experimental distribution, is shown in Figure 1 too. (At the energies below 1-2 PeV this curve with a high accuracy describes intensity distributions being accounted for by the diffusion of thermal neutrons inside the monitor). We see that the measured distribution has an anomalous prolonged shape, the deviations from the expected diffusion curve being two-three orders of magnitude in a time interval of 10 to 500 μs. Such behaviour of the neutron intensity could be explained by assuming that the generation of hadrons inside the monitor continues for 3 ms after the shower passage — an assumption, that fully contradicts to the commonly held views on EAS physics. Any attempt to explain this effect by the methodological errors [3] resulting from the counting losses in the measuring channels leads to the requirement of the existence of an unknown mechanism of hadron generation in which the hadron multiplicity is a factor $10^2 - 10^3$ higher than that predicted by usual EAS models [4].

It should be pointed out that the effect of delayed neutrons is threshold in its nature: it is observed only in the energy range above 3 PeV, i.e. above the knee of the spectrum of primary cosmic radiation, where a lot of unexplained anomalies in interactions of cosmic rays is observed.

Up to now neutron monitors have been based on expensive gas-filled counters. For the problem of neutron time distributions these counters have a principal shortage — they are too slow: the rise time their output pulses is about 1 μs which limits the maximum counting rate by $5 \cdot 10^5$ s^{-1}. Moreover, after the EAS cores pass through the gas-filled counters, their dead times may significantly increase introducing uncontrolled distortions into the neutron counting rate.

Estimations show, that the neutron measurements in condition of a 100 PeV EAS core require the detector capable to operate at a throughput of $2 - 3 \cdot 10^6$ s^{-1}.

Requirement of high operation payload may be satisfied if we should use plastic scintillation detectors for neutron registration. In fact, the decay time of typical scintillators is a few nanoseconds and the light yield is virtually linear in the considered EAS energy range. To make a scintillator to be neutron-sensitive a lithium- or boron-containing admixture may be introduced in its composition. In both cases detector is capable to register

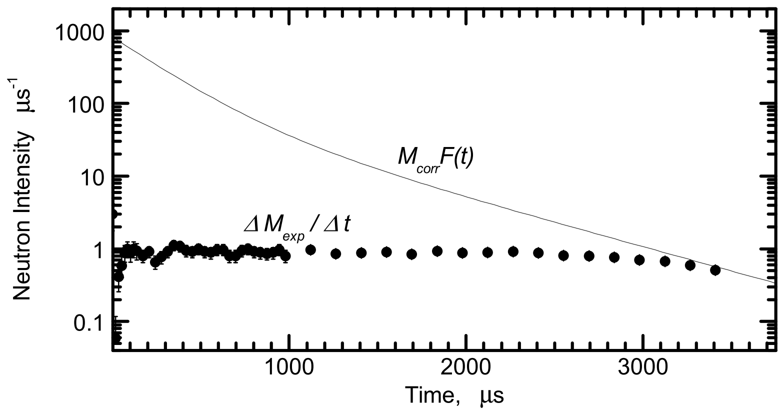

Figure 1. Time distribution of the neutron counting rate $\Delta M_{exp}/\Delta t$ in Tien-Shan neutron monitor for an EAS event with energy $\sim$ 20 PeV (dots) and the anticipated diffusion curve $M_{corr}F(t)$ (solid line).

the thermal neutrons, the reactions $^6Li(n,\alpha)t$ or $^{10}B(n,\alpha)^7Li$ being responsible for production of charged particles which cause light scintillations.

Using of boron is advantageous because the necessary isotope ^{10}B is present in sufficient amounts (19.9%) in natural boron giving a possibility to avoid expensive enrichment procedure.

2. The boron scintillation detector for neutron registration

For the purpose of neutron studies in cosmic ray physics (and, in particularly, for investigation of the anomalously delayed neutrons) special boron-containing scintillation detectors where designed by the joint research collective of LPI and IHEP [5]. Detector is based on the moulded SC-331 type polystyrene scintillator manufactured in the IHEP. The light yield in this scintillator is 56-60% of that of anthracene, the luminescence maximum is around 420 nm. The content of natural boron is 2-3 wt%.

Figure 2 shows the internal design of the neutron detector based on a thin scintillator having the thickness 5 mm and dimensions equal to those of PMT. Using optical cement the scintillator is glued to a light mixer (polymethyl methacrylate), which also acts as a neutron reflector. The other side of the mixer is glued to the entrance window of the PMT. To increase the efficiency of light collection both the scintillator and the mixer are coated with Tyvek reflecting paper.

In front of the scintillator is located a 5 cm thick polyethylene moderator of fast neutrons. Together with voltage multiplier, discriminators and pulse-shaping circuits, the whole set-up is placed inside a polyethylene cylinder which, simultaneously with playing the role of outer housing, serves as a neutron moderator too.

Figure 3 presents part of the amplitude spectra of pulses from boron scintillation detector mounted inside the neutron monitor. These spectra where measured in two modes: during simple cosmic ray monitoring and with triggering signal. The trigger was elaborated when EAS cores where passing through the monitor; counter pulses where analyzed in a time interval of 10 to 1500 μs after the trigger. In both cases the neutron peak is well-resolved against the wide background spectrum.

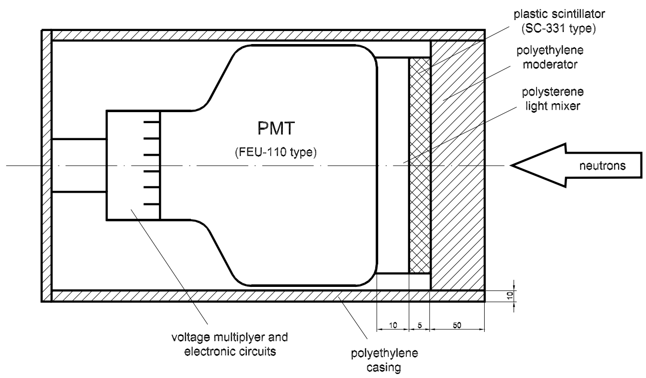

Figure 2. Internal design of the scintillation neutron detector.

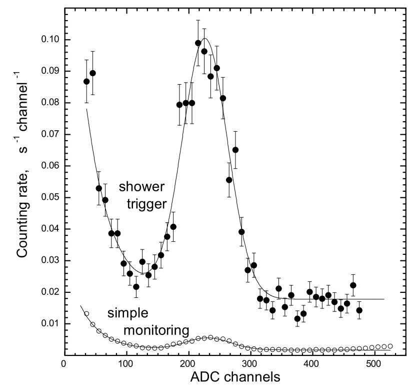

Figure 3. Fragments of neutron detector amplitude spectra around the neutron peak.

It is known, that the light yield in scintillators irradiated by α-particles is much lower then when they are exposed to β-radiation of the same energy [6]. In an SC-331 plastic scintillator the measured light yield from $^{10}B(n,\alpha)^7Li$-reaction's products is equivalent to the scintillation from a 110-130 keV β-particle [7], much lower then the signal both from relativistic charged particles of cosmic radiation (about 1 MeV) and γ-rays of neutron captures (for neutron monitor this is mostly 2.2 MeV radiation from $n(p,d)\gamma$-reactions in it's polyethylene moderator).

In the considered neutron detector this difference is used for separation of neutrons from γ-rays: internal electronic circuits of each detector contain separate discriminators tuned to the two amplitude thresholds, one of which corresponds to the region of neutron peak and the other — to the region of relativistic particles and the γ-rays of MeV-diapason.

The basic technical characteristics of scintillation neutron detectors are listed in the Table 1.

Table 1. Technical characteristics of the scintillation neutron detector

Duration of output signal	$\leq$ 50 ns
Dead time	$\leq$ 100 ns
Registration efficiency of the fusion-spectrum neutrons	$\geq$ 0.6
Non-efficiency in the 4π solid angle	$\leq$ 30%
Type of PMT (with the photocathode diameter 3")	FEU-110, FEU-139, FEU-184(Ti)
Power supply voltage	$\pm$ 12 V
Output signal at 50 Ω cable not shorter 400 m	Analogous TTL
Operation conditions: – design – temperature – humidity	 leakproof -30 ... 50 ∘C up to 95 %

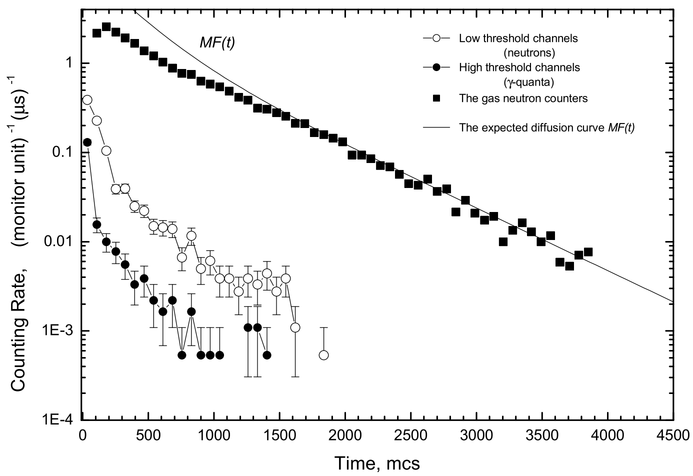

Figure 4. Time distributions of the boron scintillators signal in Tien-Shan neutron monitor.

3. First results concerning the neutron time distributions

At present time 24 boron scintillation detectors are mounted inside one standard NM64 type neutron monitor unit at Tien-Shan mountain station and data taking is going on. Figure 4 presents preliminary time distribution of the signals obtained from scintillation detectors in the passages of EAS cores with primary energy about 3-10 PeV. For comparison corresponding distributions for the gas neutron counters so as the expected diffusion curve $MF(t)$ are plotted in this figure too.

After the time 200-300 μs since the shower moment (when the diffusion of neutrons in the outer monitor's moderator is prevailing; see [2]) scintillation time distributions seems to go parallel to the expected $MF(t)$ curve, while at shorter times they have a much steeper shape. This steepness is a consequence of the compact (in comparison with the gas counters) shape of the boron scintillator's internal moderator, neutron diffusion in which predominats in the vicinity of shower moment.

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References

[1] Antonova V.P., Chubenko A.P., Kokobaev M.M. et al., Nuclear Physics B (Proc.Suppl.) 75A, 1999, 333.
[2] Antonova V.P., Chubenko A.P., Kryukov S. V. et al., J.Phys. G: Nucl. Part. Phys., 2002, vol.28, P.251.
[3] Stenkin Yu.V., Bakatanov V.N., Smirnov D.V. et al., Proc. of 27 th ICRC, Hamburg, 2001, p.1449.
[4] Chubenko A.P., A.L.Shepetov A.L., Antonova V.P. et al., Proc. of 28 th ICRC 2003, Tsukuba, p.69.
[5] Britvich G.I, Vasil'chenko V.G., Gilitsky Yu.V. et al., Instrum. Exp. Tech., 47, 5, 2004, p.571.
[6] Lyapidevsky V.K. and Ryazanov M.I., Zh. Tekh. Fiz., 70, 7, 2000, p.136.
[7] Britvich G.I, Vasil'chenko V.G., Kirichenko V.N. et al., Instrum. Exp. Tech., 5, 2002, p.644.