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Study of the response of a lithium yttrium borate scintillator based neutron rem counter by Monte Carlo radiation transport simulations

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ABSTRACT

The scarcity and the high cost of ^{3}He has spurred the use of various detectors for neutron monitoring. A new lithium yttrium borate scintillator developed in BARC has been studied for its use in a neutron rem counter. The scintillator is made of natural lithium and boron, and the yield of reaction products that will generate a signal in a real time detector has been studied by FLUKA Monte Carlo radiation transport code. A 2 cm lead introduced to enhance the gamma rejection shows no appreciable change in the shape of the fluence response or in the yield of reaction products. The fluence response when normalized at the average energy of an Am–Be neutron source shows promise of being used as rem counter.

1. Introduction

Neutron rem counters are widely used for monitoring purposes in nuclear facilities such as in reactors, reprocessing facilities, accelerators and in laboratories using neutron sources. While most such counters make use of either a BF_3 or a ^{3}He proportional counter, the latter method is preferred in neutron monitoring, particularly with moderated systems such as the rem counter, due to its comparatively larger (n,p) cross-section and its ability to operate under high pressure, which results in better efficiency. ^{3}He is obtained from the decay of tritium and its availability is steadily decreasing [1]. Moreover, bulk of the production goes into homeland security applications where the shortage is still felt [2] but anyway makes the ^{3}He gas expensive in the open market. This affects not only the availability of neutron monitoring instruments but also low temperature physics activities [3,4]. The urgency to replace ^{3}He as the preferred neutron detection material is widely felt with many alternatives being proposed [5] such as LiF/ZnS based scintillator [6,7], ^{4}He gas [8], silver lined proportional counter [9] etc.

In Bhabha Atomic Research Centre (BARC), a new lithium yttrium borate single crystal scintillator has been developed [10] that can in principle be used as a substitute for ^{3}He gas for detection and monitoring of neutrons. Being solid, they have much larger efficiency (~80%) for thermal neutrons [11] because of the density (2.5 g cm^{-3}) being higher than that of the gas. This is also expected to compensate for the loss of efficiency due to the use of natural B and Li in the crystal, in which the abundances of ^{10}B and ^{6}Li which contributes to the detection of the neutron are 20% and 7.6% respectively.

In this work, the response of this scintillator is studied to explore the suitability of using it as a detector for a neutron monitoring rem counter. Since the scintillator is also expected to respond to gamma photons, the study is also carried out with a lead layer surrounding the detector to increase the gamma rejection.

2. Materials and methods

2.1. Scintillator

The scintillator, a rare earth doped lithium yttrium borate (LYB, $Li_6Y(BO_3)_3$) was grown in the lab to various sizes. The Boron and the Lithium were present in their natural compositions. The emission spectrum was measured and found to have a broad band, peaking at about 420 nm with a smaller sharp peak at 580 nm [10, 11]. The average life time was found to be 25 ns making it suitable for high count rate applications which when used in a rem counter translates as the ability to measure high dose rates. The measured pulse height spectrum [11] from the crystal is shown in Fig. 1. The scintillator, polished to an optical finish, was coupled to a Hamamatsu (model E2979-500) photomultiplier tube (PMT) and a

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pulse processing chain consisting of pre amplifier, amplifier and a multi-channel analyzer. The setup was exposed to the thermal neutron column of the Dhruva reactor in BARC. While the higher pulse height from the ^{6}Li(n,α) reaction (Q value 4.78 MeV) is clearly distinguishable, the lower pulse height from ^{10}B(n,α) reaction is closer to the pulse height due to the electrons because of the lower Q value (2.3 MeV (94%) and 2.8 MeV (6%)). It should however still be distinguishable from the electronic discrimination point of view as the peak and the valley are clearly separable. The ^{10}B(n,α) reaction has a higher cross-section compared to ^{6}Li(n,α) reaction. The isotopic abundance of ^{10}B (∼20%) too is higher compared to the natural abundance of ^{6}Li (7.6%). It thus shows up as an intense broad peak which is about 10 times stronger than that from the ^{6}Li(n,α) reaction. In general, the ratio of the count rates from these two reactions will depend on the cross-section weighed with the fluence that is present in the detector volume, and the number of atoms of ^{10}B and ^{6}Li present in the detector. Like all scintillators, this crystal also responds to gamma photons

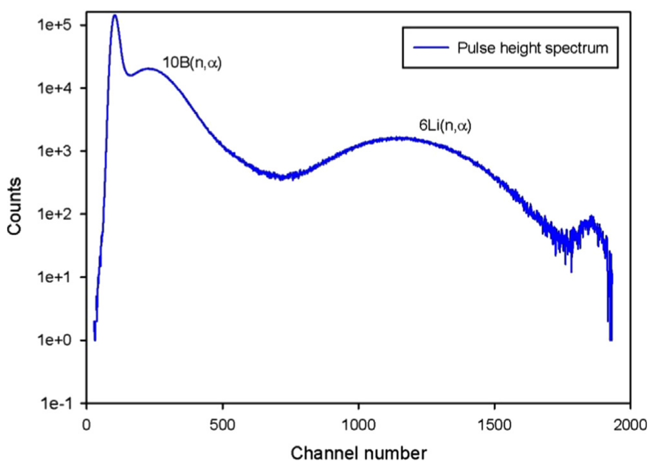

Fig. 1. The measured pulse height spectrum from LYB crystal when exposed to neutrons.

and this should be taken into consideration when used to measure neutrons.

2.2. Simulations using FLUKA Monte Carlo Code

The simulations were carried out with the FLUKA Monte Carlo code [12, 13]. A geometry similar to the design of a spherical neutron rem counter was modelled. For the purpose of the simulation here, a cylindrical scintillator of thickness 1 mm and diameter 10 mm has been used. From the center of the model, the outer HDPE (high density polyethylene) sphere has a radius 11.25 cm, a 0.1 mm thick Cd sheet at 2.96 cm radius and an inner HDPE of 2.95 cm radius. The Cd is used to reduce the fluence at lower neutron energies which otherwise would be high compared to the fluence to dose conversion coefficient at that energy. A cylindrical cutout, used to accommodate the photomultiplier tube (PMT) has a radius of 0.8 cm and a length of 12.5 cm from the outer edge. The dimensions are similar to that of conventional commercially available 9 in. rem ball. The center of the detector was placed at the origin. The cutaway view of the model obtained by FLAIR, a powerful graphical user interface [14] is shown in Fig. 2. A separate set of simulations were carried out with lead as a shield for the scintillator so that a significant fraction of external gamma rays are stopped before reaching the detector. This is expected to increase the rejection of gamma photons that may be present along with the neutrons. Neutrons were incident as plane parallel beams with radius equal to that of the outer sphere of the configuration. The usual direction (called 0° in this work) of incidence was from the side that is opposite to the PMT end (from left to right in Fig. 2). In the current configuration, the maximum lead thickness that can be accommodated is 2 cm in between the source of neutrons and the scintillator, and 0.3 cm each on both the lateral directions. The rear side was left open to make space for a PMT, which in the simulations was filled with air. Fig. 2 shows this arrangement also. For 662 keV photons (^{137}Cs), 2 cm of lead approximately corresponds to one tenth value layer (TVL). One TVL is the thickness of a shield that will result in a reduction of photon fluence by a factor of 10. Gamma rejection in this

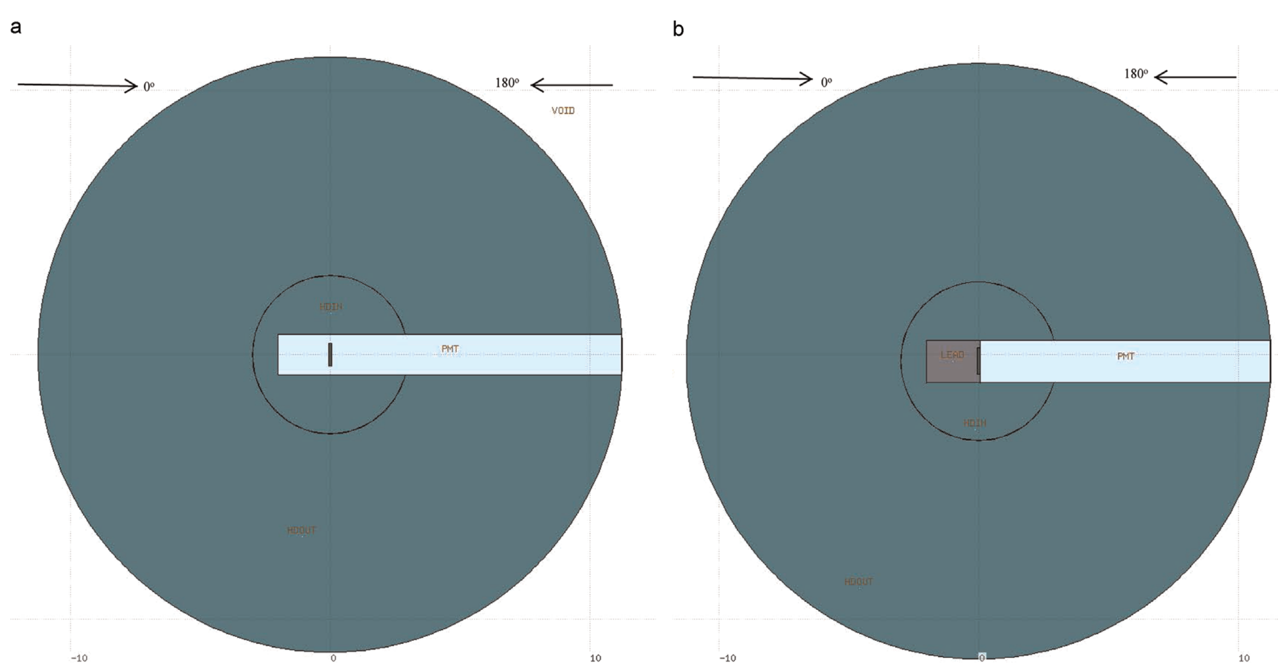

Fig. 2. The model of a rem counter with the HDPE and Cd (The circle dividing the high density polyethylene) used in the simulation. The configuration with lead is shown on the right. A plane parallel beam is incident from the left to the right and is referred to as 0° angle of incidence.