Neutron detection using liquid scintillator and study of polyethene and borated polyethene for neutron shielding

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1. Introduction

The background in rare event experiments is dominantly made up of gamma, muons and neutrons arising from radiogenic and cosmogenic sources. Direct dark matter experiments detect dark matter particles using the recoil produced by its interaction with the atoms in the detector. Neutrons mimic dark matter signals by producing similar recoils. Therefore, it is very crucial to understand the neutron background at the site where the experiment will be performed and reduce it as much as possible. In nature, neutrons are produced by radiogenic and cosmogenic sources. Examples of radiogenic sources are (i) Neutrons produced by (α, n) reactions due to α decay of U and Th isotopes present as impurities in materials in detectors and environment with lighter elements such as Ar, Si, Cu etc.(ii) Spontaneous fission of certain isotopes of U. Cosmogenic neutrons are produced by muon spallation and hadron showers produced by cosmic rays. The energy range of the neutrons extend from a few meV (thermal) to ~100 MeV (Fast).

Liquid scintillators are used extensively to detect and study fast neutrons. Due to the property of pulse shape discrimination (PSD), they are able to separate events due to gamma and neutrons in a mixed radiation field.

2. Setup and results

The data acquisition chain consists of the following:

1. **Source**: An Americium-Beryllium neutron source of Activity 1 mCi is used. The source produces roughly 2000 n·s^{-1} isotropically. Energy of neutrons is continuous upto 11 MeV.

2. **Detector**: The detector is a liquid scintillator manufactured by Eljen Technology Pvt. Ltd, USA. The cell dimension is 2" (height) × 2" (Dia). It is coupled to a 2" diameter Hamamatsu R7734 PMT. Liquid scintillator is model EJ-301 [2] having PSD property.

3. **DAQ**: A VME based data aquisition system is used. Signal from the detector is fed directly to V1730 digitizer [1] contained in a VME crate. It has Digital Pulse Processing with Pulse Shape Discrimination firmware using which pulses due to γ and neutrons can be discriminated. Charge integration technique is used in which the PSD parameter is defined as

$$\mathrm{PSD} = 1 - \frac{Q_s}{Q_l} \tag{1}$$

where, Q_s is the integrated charge in the short gate and Q_l is the charge integrated in the long gate.

The liquid scintillator was calibrated to the scale of electron equivalent energy using standard calibration sources such as ^{137}Cs and ^{60}Co. The compton edges were fit using gaussian and the energies corresponding to the channel Nos. were extracted. The pulse shape discrimination spectrum obtained from the detector is shown in figure 1.

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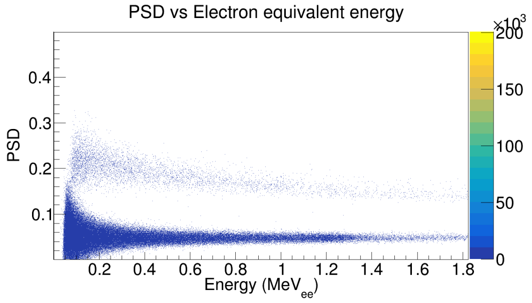

FIG. 1: PSD parameter vs. Electron equivalent energy. The top band corresponds to the neutron and the bottom band corresponds to γ. Width of the short and long gates were 40 ns and 250 ns respectively.

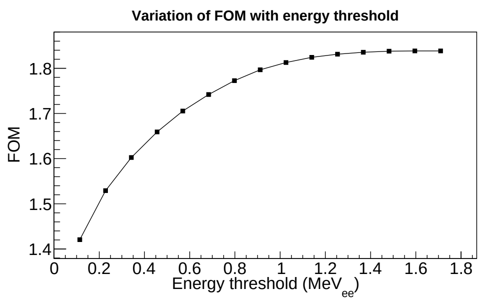

FIG. 2: Variation FOM with energy threshold

A. Figure Of Merit (FOM)

FOM gives an idea of the discrimination capability of the detector. Higher the FOM, better is the discrimination. FOM is defined as:

$$\mathrm{FOM} = \frac{\mu_n - \mu_\gamma}{\mathrm{FWHM}_n + \mathrm{FWHM}_\gamma} \tag{2}$$

where, μ_n is the mean of the projected neutron band, μ_γ is the mean of the projected gamma band, and $\mathrm{FWHM}_n, \mathrm{FWHM}_\gamma$ are the Full Width at Half Maxima of the projected neutron, gamma bands respectively.

The variation of the FOM with threshold energy is shown in figure 2. To obtain this graph, the events occurring above a given energy threshold were first projected on to the PSD axis. The resulting spectrum contained two peaks related to neutron and gamma which were fit by a gaussian to obtain FWHM and mean.

B. Shielding

We performed measurements with various thicknesses of pure and borated polyethene sheets (5% boron doping) [3]. The distance from the source to the detector was ∼20 cm. Polythene sheets were placed in between. Figure 3 shows the effectiveness of the materials in shielding the neutrons. A lead block of 10 cm thickness was also placed in front of the detector face to reduce events due to gamma.

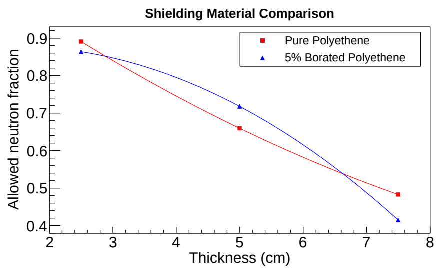

FIG. 3: Effectiveness of pure and borated polythene sheets in shielding the neutrons

3. Conclusion

A liquid scintillator detector has been characterized using digitizer based acquisition system. The detector has good pulse shape discrimination capability. Studies on pure and borated polythene shows that it is possible to reduce the flux of neutrons by 50% if shield of thickness 7.5 cm is used of either materials. A more rigorous study will be performed to determine the fraction of thermal and fast neutrons shielded by the materials by using specific detectors.

Acknowledgements

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References

[1] V1730/VX1730 user manual, CAEN s.p.a, UM2792, Rev. 2, 2016.
[2] EJ-301 Datasheet, Eljen technology, 2018.
[3] `http://www.boronrubbersindia.com`