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Neutron capture response of EJ-254 and a new boron-loaded organic glass scintillator

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***Abstract*—Organic scintillators doped with capture agents provide a detectable signal for both fast and slow neutrons. A new boron-loaded organic glass developed at Sandia National Laboratories enables such capability. This work characterizes the neutron capture response of the boron-loaded organic glass and provides a comparison to the response of the commercially available boron-loaded plastic organic scintillator, EJ-254. To isolate the neutron capture response, an AmBe source with polyethylene moderator was made incident on the boron-loaded scintillator surrounded by an array of EJ-309 observation detectors with pulse shape discrimination (PSD) capability. Events in the target scintillator were identified in coincidence with the signature 478.5 keV γ ray resulting from decay of the residual ^{7}Li nucleus following boron neutron capture, and charge integration was used to evaluate the response. The boron loading of the EJ-254 scintillator provides increased detection efficiency for slow neutrons, but the poor PSD between fast neutron and γ ray signals as well as the overlap of the capture feature with low energy γ rays may limit the applicability of this material in some scenarios. Comparatively, the boron-loaded organic glass exhibits good PSD between fast neutrons and γ rays, with events resulting from neutron capture lying on top of the neutron band in PSD space.**

I. Introduction

Nuclei that exhibit a high neutron capture cross section e.g., ^{10}B and ^{6}Li, can be loaded in organic scintillators to enable detection of both fast and slow neutrons [1], [2]. This capability is useful for a range of applications in national security, radiation safety, and neutron imaging [3], [4]. For example, in homeland security applications, organic scintillators doped with capture agents increase the detection efficiency for shielded sources of special nuclear material [5]. For antineutrino-based approaches to nuclear reactor monitoring, capture doped organic scintillators can improve rejection criteria to reduce fast neutron backgrounds [6].

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To support the application of organic scintillators for neutron detection over wide energy ranges, this work characterizes the neutron capture response of a boron-doped organic glass scintillator developed by Sandia National Laboratories in comparison to that of EJ-254, a commercially-available boron-doped plastic organic scintillator from Eljen Technology. The EJ-254 scintillator is comprised of a polyvinyltoluene (PVT) plastic matrix loaded with approximately 1% ^{10}B (for a 5% natural boron loading by weight). The organic glass composition studied in this work was a 90:10 mixture of bis(9,9-dimethyl-9H-fluoren-2-yl)(dimethyl)silane ('P2') : tris(9,9-dimethyl-9H-fluoren-2-yl)(methyl)silane ('P3'), along with 0.2 wt. % of 1,4-Bis(2-methylstyryl)benzene ('bis-MSB') and a loading by weight of XX % natural boron. The boron-doped organic glass scintillator monolith was melt-cast in an aluminum mold according to procedures described in the literature [7].

For neutrons below tens of keV, the number of photons produced by the recoiling protons from n-p scattering events is negligibly small and it is the residual nuclei following boron capture and subsequent breakup that provide scintillation efficiency via Coulombic interactions. That is:

$$^{10}B + n = \begin{cases} ^{7}Li + \ ^{4}He, & \text{Q= 2.792 MeV, 6\%} \\ ^{7}Li + \ ^{4}He + \gamma(478.5 \text{ keV}), & \text{Q= 2.310 MeV, 94\%} \end{cases} \quad (1)$$

With a 94% branching ratio, the residual ^{7}Li nucleus is populated in its first excited state, which decays via prompt γ emission with $E_\gamma = 478.5$ keV. This work uses this characteristic γ ray from the capture reaction to isolate the slow neutron response.

II. Experimental Methods

The identification of neutron capture events was accomplished using a method adapted from Sun et al. [8], where the target scintillator was placed near an AmBe source with several EJ-309 observation detectors placed at forward angles with flight paths ranging from $0.7 - 2$ m. The EJ-254 and boron-loaded organic glass targets used in this work were right circular cylinders of 5.08 cm dia. and 2.54 cm dia., respectively. A minimum of 5 mm of Pb and 7.6 cm of polyethylene was placed between the boron-loaded scintillator and the source, as shown in Fig. 1. The Pb shielding reduced contributions from the 59.5 keV γ ray produced by the AmBe source and the moderator slowed neutrons to increase the neutron capture efficiency. The acquisition master trigger

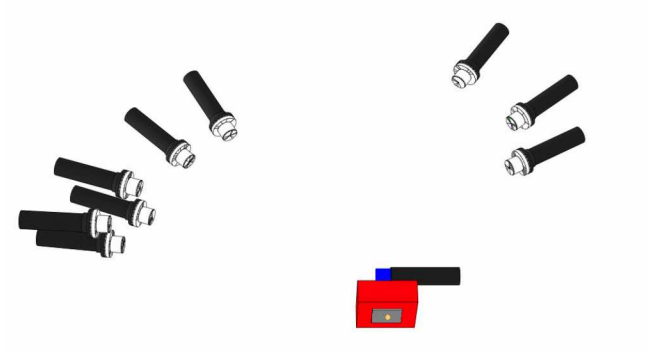

Fig. 1. Schematic of the experimental setup used to isolate neutron capture events. The boron-loaded scintillator is represented in blue, the polyethylene shielding in red, and the lead shielding in grey. The AmBe source (gold) was positioned flush against the lead shielding.

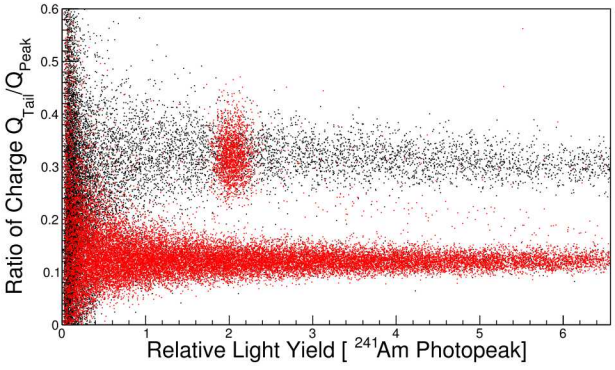

Fig. 2. PSD plot for the boron-doped organic glass scintillator as a function of light output, where the black points correspond to neutron scattering events and the red points correspond to neutron capture and γ-ray scattering events.

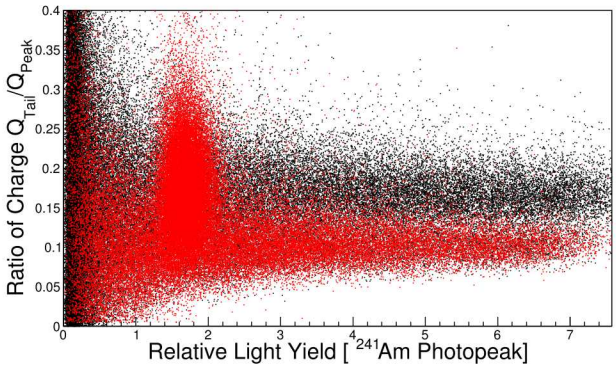

Fig. 3. PSD plot for the EJ-254 scintillator as a function of light output, where the black points correspond to neutron scattering events and the red points correspond to neutron capture and γ-ray scattering events.

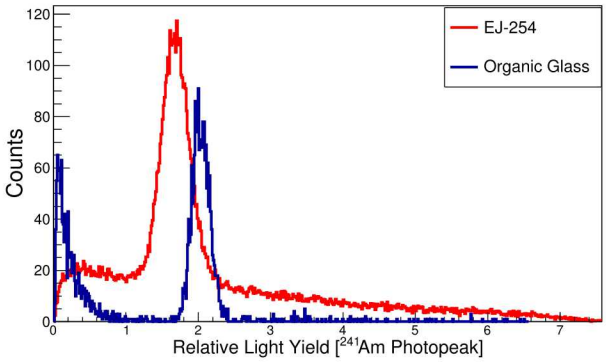

Fig. 4. Relative light output spectrum for capture-gated events for the EJ-254 (red) and organic glass (blue) scintillators.

required a coincidence between the target scintillator and at least one of the EJ-309 detectors within a 160 ns window. The light unit was calibrated using the 59.5 keV photopeak of a ^{241}Am source.

Figure 2 and Figure 3 provide PSD plots using charge integration for events in the target scintillator in coincidence with events in the observation detectors for the boron-loaded organic glass and EJ-254, respectively. The data were refined using PSD in the observation detectors and coincident time-of-flight constraints corresponding to neutron scattering events (black) and neutron capture events (red) in the target scintillator. The neutron capture events of interest have the same time signature as γ-γ coincident events, which give rise to the red band at low tail-to-peak charge ratios. The boron-loaded organic glass demonstrates capability for discrimination of fast neutron and γ-ray signals comparable to dual-mode organic glass scintillators [9], with the thermal neutron response feature overlapping the fast neutron band. In comparison, EJ-254 provides poor n-γ discrimination and neutron capture events overlap both the fast neutron and γ-ray bands.

Figure 4 provides projections of the neutron capture feature for the boron-doped organic glass and EJ-254 scintillator. Additionally, PSD constraints in the boron-doped organic glass scintillator were applied. The slow neutron feature is centered about approximately 1.6 and 2.1 relative light units for the EJ-254 and boron-doped organic glass, respectively, indicative of higher ionization quenching in the EJ-254.

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