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Development of a lithium-glass based composite neutron detector for He replacement

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We are fabricating two Li-glass based composite neutron detectors, cylindrical in shape (one 2" in diameter, 3" in height and another 5" by 5"), made of dye-loaded polyvinyltoluene embedded with 1.5-mm lithium-glass cubes composing 7% of the total mass. Initial simulation results of a ^{252}Cf source suggest that the 2" x 3" and 5" x 5" detectors will be roughly 1% and 10% efficient, respectively, for detection of unmoderated fission neutrons. Experimental evaluation of the detectors will be carried out in late summer 2012.

The idea of composite scintillators was explored by Knoll in the late 1980s [Kno87], but there has been a renewed interest in their development and optimization with numerous groups exploring composites based on lithium gadolinium borate (LGB) crystals for capture gated neutron spectroscopy [Men09], anti-neutrino detection [Nel11], and helium-3 replacement [Kaz11]. Motivated by the well-established ^{3}He shortage, we have sought to improve upon previous efforts exploring composite scintillators as neutron detectors by selecting an alternative neutron-sensitive, embedded scintillator material and optimizing the dimensions of the pieces of this material to enable more reliable gamma-ray rejection capabilities through PSD.

Kazkaz *et al.* showed that only signals produced by neutron capture on ^{6}Li could be reliably distinguished from γ events, encouraging selection of a different inorganic scintillator to optimize neutron detection efficiency [Kaz11]. There are numerous factors to consider when selecting an appropriate replacement for LGB in this application, including: scintillation light decay constant, which much be sufficiently long relative to that of the acrylic matrix to facilitate reliable PSD and γ rejection; the chemical composition and, specifically, the number of ^{6}Li nuclei per molecule, which should be high to maximize effective use of detector volume; the scintillation light output; and the material's index of refraction. Numerous alternative scintillators were considered, and KG2-type, ^{6}Li-enriched glass was selected for its closely matched index of refraction with the acrylic matrix, its desirable scintillation decay time, and its relatively high number of ^{6}Li nuclei per molecule.

Extensive Monte Carlo simulations have been carried out using the GEANT4 simulation toolkit. To analyze the simulation outputs, a 9% Gaussian spreading is applied to the raw, unbinned energy depositions in both the plastic and the ^{6}Li-glass cubes; this 9% resolution is based on experimental findings for an LGB detector used by Kazkaz *et al.*. Included in these simulations is the fact that the light output due to energy depositions occurring in the lithium glass by the alpha particle and triton resulting from neutron capture on ^{6}Li is quenched relative to light output from electron energy deposition in the lithium glass such that the neutron capture peak occurs at an electron-equivalent energy of 1.6 MeV (or 1.6 MeVee) [Fir61]. Figure 1 illustrates the procedure for determining the number of neutron events.

Simulations suggest that a 2" diameter, 3" tall cylindrical detector with 7% Li-glass by mass will have an intrinsic detection efficiency for fission neutrons from ^{252}Cf of $\sim$ 1%. Menaa *et al.* performed experiments using 2" x 2" cylindrical detector loaded with $\sim$ 20% LGB by mass and found its intrinsic detection efficiency for ^{252}Cf neutrons to be $(0.28 \pm 0.03)\,\%$ [Men09]. Similarly, simulations predict an intrinsic unmoderated fission neutron detection efficiency of $\sim$ 10% for a 5" x 5" cylindrical Li-glass composite detector (again 7% Li-glass by mass), which can be compared to the experimental results of Kazkaz *et al.* who found a comparably sized, LGB-based detector, with 1% LGB by mass, to have an intrinsic efficiency of $(0.416 \pm 0.007)\,\%$.

Selection of a small dimensions for the Li-glass cubes helps to minimize the number of γ-induced counts which occur inside the neutron-peak region of interest (NPR); according to the ESTAR library provided by NIST [Ber05], the range of a 1.5 MeV electron in lithium glass is

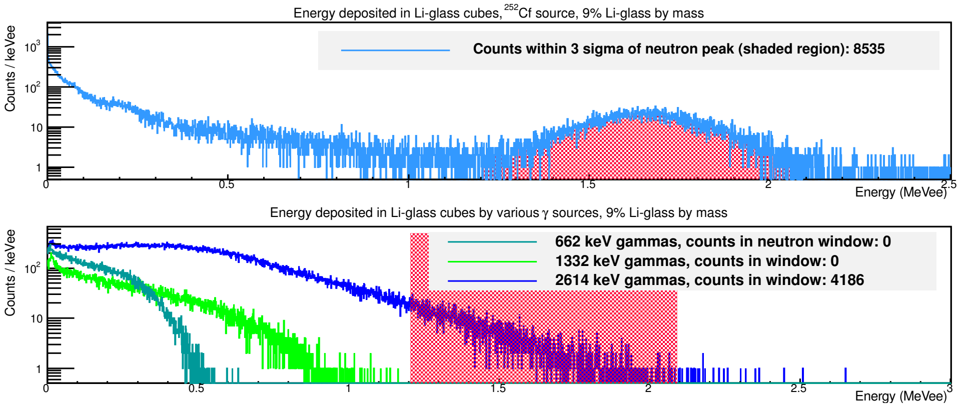

Figure 1: (Color online) Plot of the simulation output for a 2" diameter by 3" tall cylindrical, Li-glass based composite detector with 9% Li-glass by mass. (Top) The number of neutron counts is determined by fitting a Gaussian to the neutron peak centered around 1.6 MeVee and integrating the histogram to $\pm 3\sigma$, defining the neutron-peak region of interest (NPR, shaded). For this simulation, there were 10M primary decay events of a ^{252}Cf source, emitting isotropically, located 16.2 cm from the circular face of the detector. (Bottom) The energy spectra in the glass cubes for various γ-ray energies; the shaded region represents the NPR. In each simulation, there were 1M γ-rays of the designated energy generate 16.2 cm from, and directed towards the center of, the circular face of the detector.

calculated to be $\sim$ 3.5 mm: over twice the length of the side of a face of our cubes. Neglecting potential pile-up events, our detector should have no sensitivity to typical γ-ray backgrounds like ^{137}Cs, ^{60}Co, and ^{40}K. However, γ rays with an energy over $\sim$ 1.6 MeV could deposit sufficient energy in a Li-glass cube to appear in the NPR (see the bottom panel of Fig. 1). Current simulations do not consider the PSD capabilities of this composite material. Using PSD techniques, LGB detectors have achieved levels of gamma sensitivity on the part per billion scale [Kaz11].

Experimental results from the first 2" x 3" detector are expected in early August 2012, with results of the 5" x 5" model following soon thereafter. The detectors will initially be characterized using various neutron and γ-ray sources and will be compared directly to new measurements using an LGB-based composite detector and moderated ^{3}He tubes. Further studies may be undertaken using neutrons generated by the ^{7}Li(p,n)^{7}Be reaction.

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