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<th>Title:</th>
<th>6Li Foil Thermal Neutron Detector</th>
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In this paper we report on the design of a multilayer thermal neutron detector based on $^6$Li reactive foil and thin film plastic scintillators. The $^6$Li foils have about twice the intrinsic efficiency of $^{10}$B films and about four times higher light output due to a unique combination of high energy of reaction particles, low self absorption, and low ionization density of tritons. The design configuration provides for double-sided readout of the lithium foil resulting in a doubling of the efficiency relative to a classical reactive film detector and generates a pulse height distribution with a valley between neutron and gamma signals similar to $^3$He tubes. The plastic scintillator layers are tens of microns thick, which limits the energy deposited by gamma rays, providing the neutron/gamma discrimination. We used MCNPX to model a multilayer Li-foil detector design and compare it with the standard HLNCC-II ($^{18}$He tubes operated at 4 atm). The results of the $^6$Li configuration show higher efficiency and one third of the die-away time. These properties, combined with the very short dead time of the plastic scintillator, offer the potential of a very high performance neutron detector.
Introduction. With shortage of $^3$He gas, the other two most common thermal neutron capturing materials ($^{10}$B and $^6$Li) have become a major object of research for detector technology. Because of lithium metal’s chemical reactivity, the compound LiF is commonly used. Both films have an intrinsic efficiency of about 5% [1]. While the short range of $^{10}$B alpha particles makes this material advantageous for $^{10}$B-lined gas proportional counters, the $^6$Li tritons have about four times greater light output compared to $^{10}$B alpha particles. For scintillation applications, the most common use has been neutron sensitive ZnS(Ag)/$^6$LiF scintillation sheets sandwiched with wavelength shifters [2]. Using ZnS(Ag)/$^6$LiF allows up to 9mg/sm² areal density of $^6$Li, but because of severe charge absorption in LiF and light self-absorption in ZnS scintillator, only a small fraction of the particle’s energy is converted and transported to the PMTs as a light signal. The pulse height spectrum has a $1/E$ energy distribution, with most of the signal coming from noise and gammas. [3] The mismatch of refraction index of ZnS and non-scintillating converters and light guides additionally reduces the light transport along the lightguide.

Several years ago, we designed and built prototype $^6$Li lined ionization chamber with integrated body-moderator of HDPE. The prototype showed about 13% intrinsic efficiency for fast neutrons and negligible aging over a six month testing period. [4,5] Based on that experience we have developed a thermal neutron detector concept based on $^6$Li foil laminated with thin plastic scintillator film lightguide strips.

Detection concept. The long strips of $^6$Li reactive foil are placed between equal size long strips of PMMA lightguide material coated with thin scintillator film on both sides (Fig.1). Multiple layers of reactive film and lightguide are stacked in a sandwich construction for improved moderation and efficiency. The faces of the lightguide strips are interfaced to the PMTs by a fishtail lightguide. The double-sided readout of charged particles escaping the $^6$Li reactive layer doubles the intrinsic efficiency per layer while preserving a good pulse height distribution of energy transfer to the scintillator.

Gamma discrimination is achieved by low energy deposition in the thin scintillator film.

**Fig. 1 Lithium foil sandwich concept.**

Pulse height spectrum and intrinsic efficiency. In order to evaluate the performance of the sandwich detector, a set of Monte Carlo simulations have been performed using the MCNPX code; this version of the code allows one to follow the transport of the alpha and triton particles subsequent to $^6$Li(n,a)$^3$H nuclear reaction. Fig. 2 shows the results obtained from these calculations: the neutron reaction rate into the lithium film and the intrinsic efficiency for various event thresholds. It is worth mentioning the high tolerance of detection efficiency to variations of event threshold: increase of event threshold from 1-MeV to 2-MeV leads to dropping of intrinsic efficiency from -30% to -23%. Beside the tolerance to instability of detector and electronics, this feature allows operation at very high gamma fields without significant loss of efficiency.

**Fig.2 Neutrons reaction rate and intrinsic efficiency results as obtained by MCNPX code.**

Even if both the alpha and triton particles deposit energy in the scintillator film, taking a conservative approach we ignore the alpha’s contribution to the light pulse due to lower light yield; and use the triton’s energy deposition as an estimate for light pulse height distribution. Figure 3 shows the calculated pulse height spectrum for tritons. The gamma sensitivity is limited naturally by the 30 to 50 µm thickness of the plastic scintillator film.
Light transport experiment. We constructed an experimental detector consisting of 20" long by 2" wide and 0.25" thick strips of PMMA lightguide laminated with 200-µm plastic scintillator film coupled to Hamamatsu PMTs (model R6232). This detector was tested with 239Pu alpha source (the alpha particles with 5.1 MeV energy have same light yield as 2.7 MeV tritons) for light transport properties. The accumulated spectrum taken different positions of the 239Pu source in presence of constant exposure to gamma radiation from 137Cs source is shown in Fig.4.

Efficiency modeling of neutron detector assembly. Side-by-side MCNPX modeling of drop-in detector assemblies was performed for two typical applications: neutron detector for Radiation Portal Monitor (RPM) used for homeland security application and HLNCC-II neutron coincidence counter used in the nuclear safeguards applications. The RPM detector was modeled in MCNPX code as consisting of 9 Li films (thickness = 30µm) sandwiched between 10 strips of light guide. The dimensions are 150 cm by 50 cm by 1 cm and the sandwich is surrounded by 1 cm of polyethylene moderator. The detector efficiency was computed assuming a 252Cf source located 2 m from the detector. The HLNCC-II neutron coincidence counter was modeled as a polygon of 10 sides with 12 layers 6Li (thickness 50 µm) and 13 light guides strips in each side. The dimensions of the detectors are exactly the same for the 3He detectors in the HLNCC-II. The results of the simulation of the both detectors are summarized in Table 1. In both cases, the efficiency is greater than the standard arrangement using the 3He counters. Moreover the HLNCC equivalent with 6Li has a die-away time of ~16us; about 1/3 of that seen in the standard HLNCC-II counter.

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<th>Application</th>
<th>3He tube efficiency (%)</th>
<th>6Li Film efficiency (%)</th>
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<tr>
<td>RPM</td>
<td>0.12 [6]</td>
<td>0.49 (30µm foil)</td>
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<tr>
<td>HLNCC-II</td>
<td>17.5 [7]</td>
<td>34 (50µm foil)</td>
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Table 1

Conclusions. We have designed a thermal neutron detector based on lithium foil sandwiched between lightguide strips laminated with thin film of plastic scintillator. The double side readout of the lithium foil provides intrinsic efficiency per layer ~ 20-30% depending of event threshold setting. The pulse height spectrum measured with 239Pu and 137Cs sources shows good separation between gamma and charged particles responses and inherent insensitivity to instability of detector and changes in electronics gain. The MCNPX comparison model of the portal monitor and neutron coincidence well counter shows ≥ 2 times higher efficiency for 6Li compared to 3He, up to three times shorter die-away time and negligible dead time. The combination of these properties with the inherent insensitivity to detector and electronics instability makes this detector a good alternative of 3He technology.

References.

5. "Large area neutron detector based on 6Li ionization chamber with integrated body moderator of high density polyethylene." NSS 2004, Conference Record.