Fast Neutron Detection with Varying-Length Trans-Stilbene Scintillators

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***Abstract*–In recent years, solution grown trans-stilbene crystals have become widely used for gamma ray and fast neutron detection in many applications, including nuclear safeguards and nonproliferation. These crystals exhibit excellent pulse shape discrimination (PSD), enabling simultaneous detection and identification of gamma rays and fast neutrons. Stilbene crystals have been made widely available in 5 cm by 5 cm cylinders by Inrad Optics; production of cylinders up to 10 cm long have been demonstrated. Time-of-flight experiments using a 252Cf source have been performed to characterize 5 cm diameter stilbene crystals with 2.5 cm, 5 cm, 7.6 cm, and 10 cm lengths: all four crystals were coupled to photomultiplier tubes and symmetrically placed around the source, 1 m away. These data have been analyzed to obtain detector response functions (scintillation light output as a function of neutron energy deposited) for each of the four crystals. These functions can be used in Monte Carlo simulations to model the absolute detector response. Results will compare the performance of these stilbene cylinders as a function of length using the following quantities: neutron detection efficiency, gamma-ray detection efficiency, PSD figure of merit, and the total detector response function. Additionally, the measured detector response will be compared to Monte Carlo simulations using the MCNPX-PoliMi code.**

I. INTRODUCTION

IN recent years, new growth techniques for *trans*-stilbene crystals have enabled application in many areas, including nuclear safeguards and nonproliferation [1]. These crystals exhibit excellent pulse shape discrimination (PSD), which enables simultaneous detection of gamma rays and fast neutrons [2, 3]. Stilbene crystals have been made widely available in 5 cm by 5 cm cylinders by Inrad Optics; production of cylinders up to 10 cm long have been demonstrated.

II. EXPERIMENT DESCRIPTION

Time-of-flight experiments using a ^{252}Cf source have been performed to characterize 5 cm diameter stilbene crystals with 2.5 cm, 5 cm, 7.6 cm, and 10 cm lengths, shown in Figure 1. All four crystals were coupled to photomultiplier tubes and symmetrically placed around the source, 1 m away as shown in Figure 2. A 13-by-13 cm EJ-309 liquid scintillator was placed next to the source and used to determine the time at which fission occurs. Correlated pulses were recorded and analyzed to obtain detector response functions (scintillation light output as a function of neutron energy deposited) for each of the four stilbene crystals. These functions can be used in Monte Carlo simulations to model the absolute detector response.

Fig. 1. Stilbene crystals used for this experiment

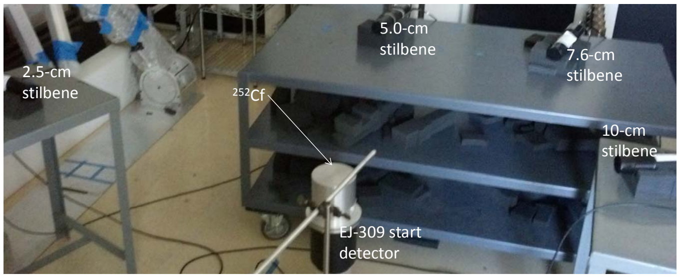

Fig. 2. Setup used for this experiment.

III. RESULTS

Stilbene is an organic scintillator that is sensitive to neutrons and gamma rays: neutrons interact primarily through elastic scatter on hydrogen nuclei, and gamma rays interact through Compton scattering on atomic electrons [4]. These interactions produce scintillation light that is detected as a voltage pulse in the light readout device (e.g., photomultiplier tube or silicon photomultiplier). Analysis of these pulses can classify each as a neutron or gamma ray using pulse shape discrimination. In this work, a digital charge integration technique was applied [5]. Figure 3 shows the PSD distributions for the 2.5- and 10.16-cm thick stilbene crystals. It is clear that the PSD of these two crystals is qualitatively similar.

The time-of-flight data were then used to separate ^{252}Cf fission neutrons by incident neutron energy. Figure 4 shows the time-of-flight data collected for the four stilbene crystals. The light output distribution is plotted within each neutron energy bin. The maximum light output deposited in the distribution is

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taken to be the light created by a full-energy deposition by a single scatter on hydrogen. Repeating this analysis across all neutron energy bins yields the light output function for each detector. Applying the relationship to the 5-cm stilbene gives the simulated light output distribution shown in Figure 5, which compares very favorably to its measured equivalent.

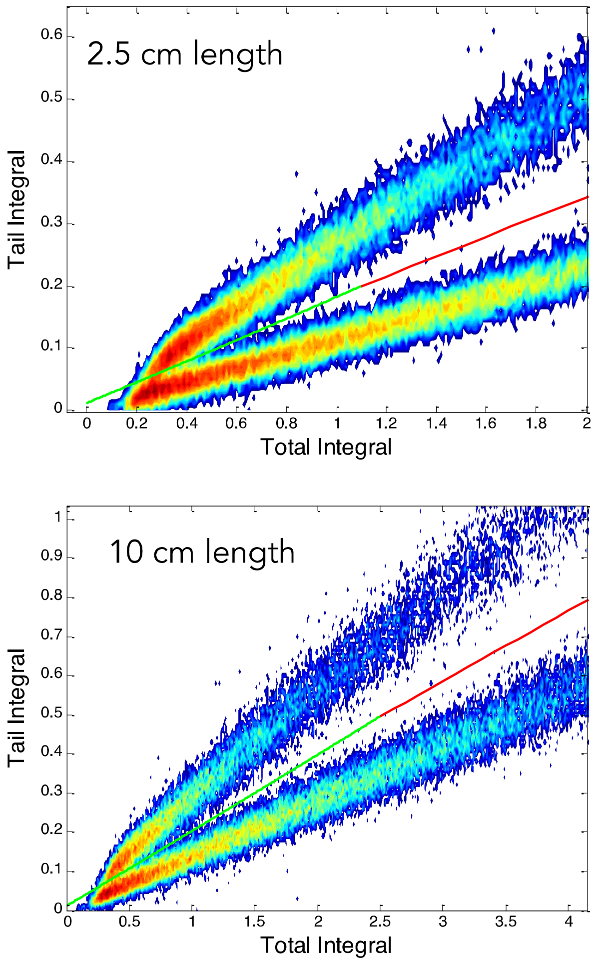

Fig. 3. Pulse shape discrimination performance for 5-cm diameter stilbene detectors with 2.5- and 10-cm lengths and a detection threshold of 36 keVee measured with a ^{252}Cf source.

Table I shows the simulated and measured neutron efficiency for varying length stilbene with a 36-keVee detection threshold. The neutron efficiency is determined intrinsically for a ^{252}Cf source positioned 20 cm from the front face of each scintillator. The neutron efficiency ranges from 17-33% for 2.54-7.62 cm lengths, increasing to 40% for a 10.16-cm long stilbene crystal.

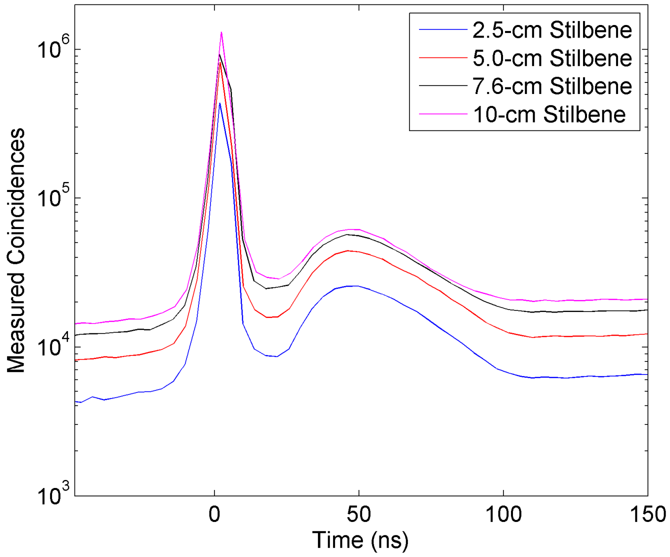

Fig. 4. Measured time-of-flight distribution for each stilbene detector.

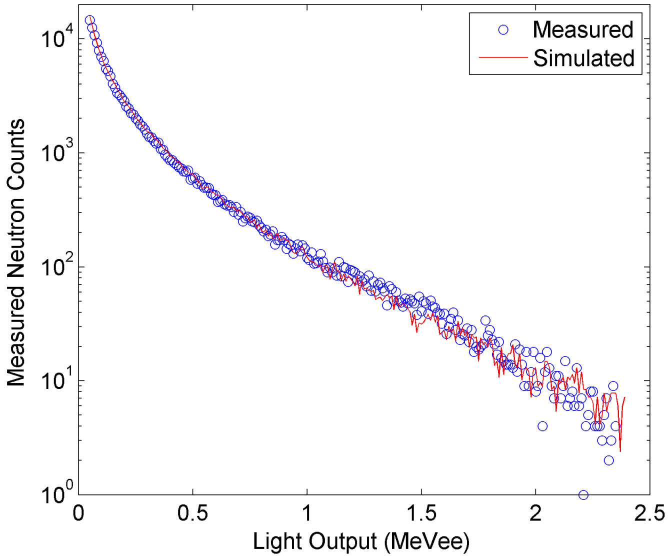

Fig. 5. Measured and simulated 252Cf neutron light output distribution for the 5-cm stilbene at a 50-keVee threshold.

TABLE I

INTRINSIC NEUTRON EFFICIENCY FOR VARYING LENGTH STILBENE MEASURED WITH ^{252}CF AT A 36-KEVEE DETECTION THRESHOLD.

Stilbene Length (cm)	Measured Efficiency	Simulated Efficiency
2.54	16.7%	18.7%
5.08	30.9%	29.2%
7.62	33.4%	34.6%
10.16	40.3%	37.2%

IV. CONCLUSIONS

It has been shown that a 1-m flight path is sufficient to measure the light output function for the stilbene scintillators. Implementing the light output function into Monte Carlo simulations yields a simulated response that compares very favorably to the measured neutron light output function, providing a tool for predicting the scintillator's response to more complex environments, geometries, and neutron sources.

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