Digital Neutron-Gamma Discrimination Performance of Stilbene in Comparison with Plastic Scintillators

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1. Introduction

Pulse shape discrimination (PSD) is a well-established method of separating fast neutrons and gamma-ray photons interacting within organic scintillation medium. The method is based on the difference in the decay time of fluorescence emitted within an organic scintillator as a result of an interaction between the ionising particle and the scintillant medium. The fluorescence decay time observed for heavy ionising particles, such as protons (resulting from neutron interactions), is longer when compared to electrons (resulting from gamma-ray photons interactions) [1]. The difference in the fluorescence decay rate formed a basis for neutron-gamma PSD techniques in organic scintillators [2]. In this paper Simplified Digital Charge Comparison (SDCC) method is employed to compare the PSD performance of the stilbene crystal with two plastic scintillator samples [3]. In order to evaluate the neutron-gamma separation performance of each scintillator, the figure-of-merit (FOM) was estimated for each scintillator.

2. Methodology

Various PSD techniques have been developed in digital domain to analyse pulses detected from organic scintillators. Charge Comparison Method (CCM) is becoming one of the most powerful PSD algorithms compared to other PSD techniques [1]. SDCC method is similar to CCM and preceding work advocates a superior discrimination performance in comparison with other digital PSD algorithms [4]. Detailed description of the SDCC method and its development was presented by Shippen et al. [3].

In this research, three organic solid scintillator samples (stilbene crystal, pure plastic and ^{6}Li Loaded plastic) were in turn exposed to a ^{252}Cf (half-life of 2.64 years) source located in a water tank at Lancaster University, UK. Both pure PSD plastic scintillator (25 mm diameter, 25 mm thick; LLNL reference 5706) and ^{6}Li loaded PSD plastic scintillator (40 mm diameter, 25 mm thick; LLNL reference 9023) samples were provided by the Lawrence Livermore Laboratory (LLNL), USA. A single stilbene crystal (20 mm diameter, 20 mm thick) was obtained from Inrad Optics [5]. The experimental set-up is shown in Fig. 1. The detector front was placed 15 cm away from the source and 10 cm away from Pb shielding, which was utilised to reduce the number of gamma-rays reaching the scintillator detector. The back of each scintillator sample was covered with EJ-510 reflective coating. Each sample was then coupled to an ET Enterprises 9107B PMT with EJ-550 silicone grease and the complete assembly was enclosed in a light-proof tube. The PMT anode was connected to a bespoke fast digitiser (150 MSps, 14-bit resolution ADC linked to a FPGA) and the digitised data were transferred to a laptop and subsequently processed by a bespoke script developed in Python.

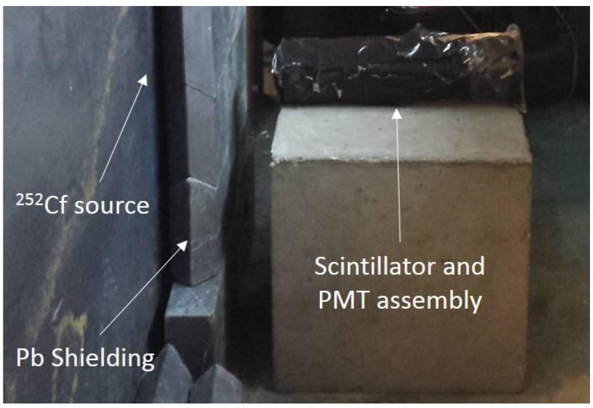

Figure 1: Experimental set-up. ^{252}Cf source is located in the centre of a water filled, metal tank. During experiments the source is moved to the edge of the tank pointed by the arrow on the left.

3. Results and Discussion

The FOM as defined in Eq. (1) [2] was calculated for each scintillator to compare their performance in separating neutrons from gamma-rays. Results are presented in Table 1. Scatter plots of PSD performed using SDDC method are shown in Fig.2. The FOM value for single stilbene crystal estimated at 1.033 was far higher than 0.761 obtained for the pure plastic scintillator sample. Pulse shape discrimination was unsuccessful in discriminating between fast neutron events and gamma-ray photons in ^{6}Li loaded plastic scintillator.

$$FOM = \frac{Peak\ separation}{FWHM_{\gamma} + FWHM_{n}} \tag{1}$$

Table 1: FOM and number of events recorded for the scintillators tested

Scintillator	Total	Gamma-rays	Neutrons	FOM
^{6}Li Loaded plastic	70368	-	-	-
Pure plastic	76428	38359	38069	0.761
Stilbene crystal	60394	33184	27210	1.033

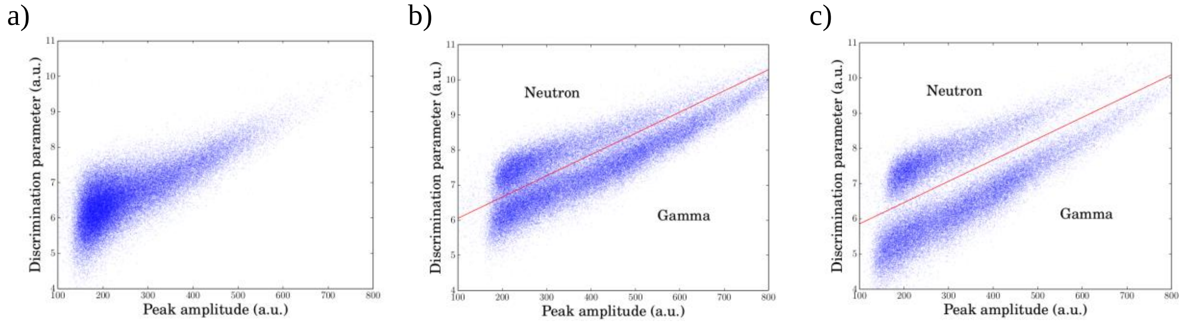

Figure 2:PSD discrimination plots using SDCC method: a) ^{6}Li loaded plastic b) Pure plastic c) Stilbene crystal

Three solid organic scintillators were exposed to a ^{252}Cf fission source, and the collected data discriminated between neutrons and gamma-rays using SDCC technique. Single stilbene crystal shows superior neutron-gamma separation performance. ^{6}Li loaded plastic scintillator failed to separate neutrons from gamma-ray photons. The difference in discrimination quality is associated with the doping of the former, which enables neutrons thermalised within the organic detector to be captured by the high neutron capture cross-section of ^{6}Li. As such, ^{6}Li loaded plastic scintillator can be beneficial for certain application [6] but neutron capture events are difficult to separate from gamma-ray photons.

4. References

[1] F. D. Brooks, "A scintillation counter with neutron and gamma-ray discriminators," *Nucl. Instruments Methods*, vol. 4, no. 3, pp. 151–163, Apr. 1959.

[2] G. F. Knoll, *Radiation Detection and Measurement*, 4th ed. Hoboken: John Wiley & Sons, 2010.

[3] D. I. Shippen, M. J. Joyce, and M. D. Aspinall, "A Wavelet Packet Transform Inspired Method of Neutron-Gamma Discrimination," *IEEE Trans. Nucl. Sci.*, vol. 57, no. 5, pp. 2617–2624, Oct. 2010.

[4] K. A. A. Gamage, M. J. Joyce, and N. P. Hawkes, "A comparison of four different digital algorithms for pulse-shape discrimination in fast scintillators," *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 642, no. 1, pp. 78–83, 2011.

[5] Inradoptics, "Stilbene Single Crystals - Data Sheet."

[6] M. J. I. Balmer, K. A. A. Gamage, and G. C. Taylor, "Comparative analysis of pulse shape discrimination methods in a 6Li loaded plastic scintillator," *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 788, pp. 146–153, 2015.