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Pulse Shape Discrimination in Stilbene-H Detectors using DRIFT Software

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1. Introduction

Neutrons are inevitably accompanied by gamma rays produced by neutron sources. Therefore, it is essential to distinguish neutrons from gamma rays in neutron detection. Pulse shape discrimination (PSD) is one of the major techniques to solve this problem. There were previous approaches to separate these signals using a stilbene-H organic crystalline scintillator on a fast neutron source, with PSD Figure of merit (FOM) values showing 1.79 [1]. Scintillation lights of stilbene-H originate from neutron-induced recoil protons and gamma-ray-induced recoil electrons. Recoil proton shows higher decay time than the recoil electrons, allowing the detector to discriminate between neutron and gamma-ray peaks.

In this study, PSD of Cf-252 was preliminarily conducted using simulations before actual experiments. Pulse shapes have been generated artificially from extracted data that contains simulation information. PSD plot was acquired through these pulses using the charge comparison method (CCM). In addition, FOM was calculated based on the threshold.

2. Method and Results

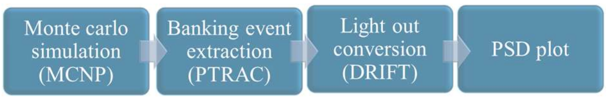

Fig.1. Overall flowchart of study

As shown in Fig.1, the Stilbene-H, Cf-252 simulation has been designed using Monte Carlo N-Particle (MCNP) 6.2. Under this setup, PTRAC output data has been extracted. Based on this data, scintillation has been calculated using the Detector Response Function Toolkit(DRIFT). Finally, PSD plotting using the CCM method with different thresholds has been done.

2.1. MCNP6.2 Simulation setup

The setup consists of a 3-inch diameter stilbene detector encased in aluminum with a thickness of 0.153 cm. As shown in Fig.2, eight detectors are equally spaced at 45-degree intervals, positioned 50 cm away from the Cf-252 point source.

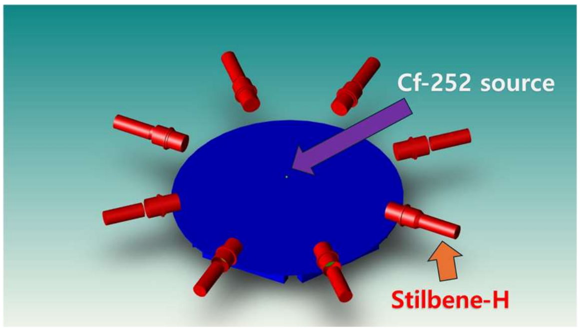

Fig.2. 3D geometry of MCNP6.2 simulation

2.2. Particle Track Output (PTRAC)

PTRAC is a tool for extracting particle reaction types, and information of position, energy, and direction. This information makes it possible to simulate scintillation light produced by the recoil proton, an electron from stilbene-H

2.3. Light out conversion (DRIFT)

DRIFT is software that post-processes PTRAC information to simulate pulses induced by scintillation light. DRIFT considers the photomultiplier tube (PMT) effect, tracking source particle information, and digitizer setting to generate this pulse.

2.4. Pulse shape discrimination (PSD)

For stilbene-H, neutron pulse shows a higher decay time than gamma-ray pulse. Due to delayed fluorescence, neutrons show heavier tails. Based on this principle, CCM can distinguish generated pulses by computing the ratio of pulse integrals. Above the tail is called the slow component which corresponds to the Q_{slow} area of Fig 3 and the region below the tail is called the fast component which is the Q_{fast} area. Fig 4 illustrates the scatter plot for given slow and fast components defined in formulas (1) and (2)

$$Q_{slow} = \int_{t_{fast}}^{t_{slow}} q(t)\, dt \qquad (1)$$

$$Q_{fast} = \int_{t_{begin}}^{t_{fast}} q(t)\, dt \qquad (2)$$

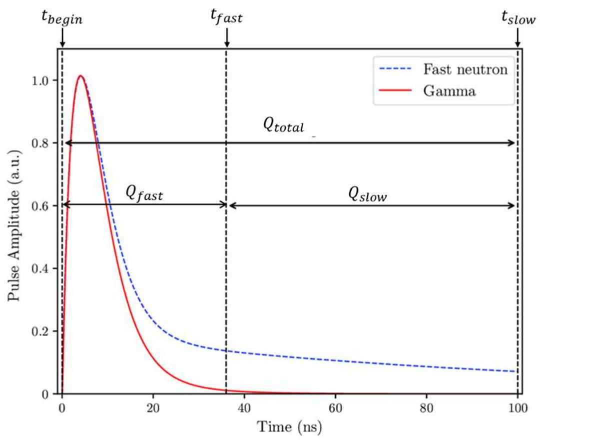

Fig.3. Schematic diagram of the pulse shape comparison between gamma-rays and neutrons [2]

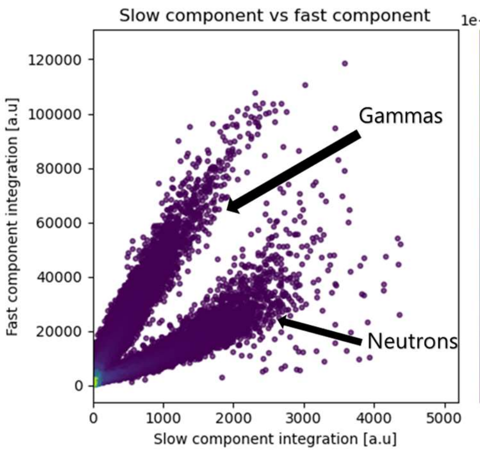

Fig.4. Scatter plot for slow component vs fast component

As evident from Fig.4, it is difficult to distinguish neutron and gamma-ray-induced signals at low-charge events. Thus, it is necessary to select a threshold for PSD. The threshold is set based on the total charge in formula (3). The ratio between the slow component and the total PSD parameter can be defined as formula (4). FOM can be described as a formula (5). Fig. 5 and Fig. 6 present PSD results, showing that a threshold of 10,000 provides more enhanced performance compared to 5,000. The FOM values are summarized in Table .1.

$$Q_{total} = \int_{t_{begin}}^{t_{slow}} q(t)\, dt \quad (3)$$

$$PSD\ parameter = \frac{Q_{slow}}{Q_{total}} \quad (4)$$

$$FOM = \frac{(Distance\ between\ two\ peaks)}{(Sum\ of\ FWHM\ two\ peaks)} \quad (5)$$

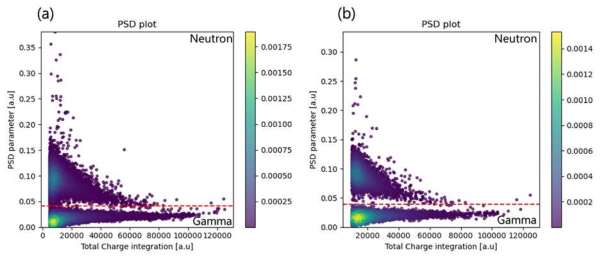

Fig.5. PSD scatter-density plot of Cf-252 with threshold (a) 5,000 (b) 10,000

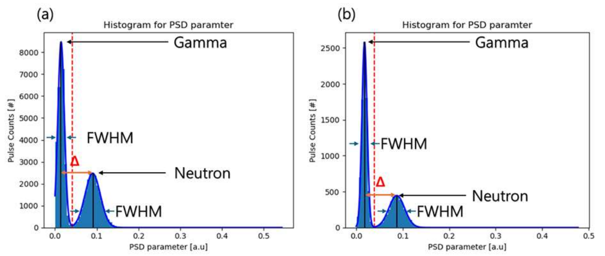

Fig.6. Derivation of the figure of merit (FOM) with a threshold (a) 5,000 (b) 10,000

Table I: Parameters used to calculate figure of merit

Threshold (a.u)	5,000	10,000
FHWM (Gamma)	0.0183	0.0132
FHWM (Neutron)	0.0434	0.0399
Distance	0.0756	0.0693
FOM	1.225	1.306

3. Conclusion

We successfully achieved PSD using the DRIFT software under simulated conditions. This approach provides reliable results, particularly when real-world experiments are not feasible. The data obtained from this study can serve as valuable cross-validation, contributing to the further refinement and validation of the neutron stilbene detector.

Acknowledgments

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[2] Cieslak, M., K. Gamage, and R. Glover, Critical Review of Scintillating Crystals for Neutron Detection. Crystals, 2019. 9: p. 480.