A preliminary study on the characteristics of neutron and gamma ray pulse shape discrimination using EJ276G plastic scintillator.

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1. Introduction

It is important to classify dangerous substances such as radioactive materials and nuclear weapons from aviation and port imports. Portable detectors are commonly used, and many studies have been conducted to distinguish substances using neutrons and gamma rays.

Since gamma rays are also sensitive to detectors by Compton scattering while measuring fast neutrons, it is necessary to differentiate gamma rays generated by neutron processing. Gamma rays are present in the background and inevitably occur during neutron generation, such as nuclear decay. Furthermore, gamma rays are generated by neutron activation.

There is a pulse shape discrimination (PSD) method that separates neutrons from gamma rays, and PSD has been studied in various ways. In this paper, we performed PSD using charge comparison method (or charge integration method), and optimized the PSD performance by changing EJ276G plastic scintillator geometry through neutron source.

2. Materials and Methods

2.1 EJ276G plastic scintillator

In general, liquid scintillators (BC501) and organic single crystalline scintillators (Anthracene, Stilbene) are known for good levels of PSD. Plastic scintillators have been reported to be significantly inferior to organic crystalline and liquid scintillators [1]. However, plastic scintillators are widely used because they are non-toxic unlike older liquid scintillators, have excellent stability at various temperatures and can be easily processed into desired geometries [2]. And unlike Stilbene, plastic scintillators have strong mechanical strength and price advantage. Because the PSD systems are applied at industrial sites, PSD capable EJ276G plastic scintillator was used to distinguish between neutrons and gamma rays.

2.2. Pulse Shape Discrimination method

Pulse shape discrimination is a method of using the difference in mechanism for different types of radiation. In general, organic scintillators use a method of dividing by the attenuation of light depending on the types of radiation.

In organic scintillators, secondary radiation is protons and electrons by neutrons and gamma, respectively, which cause different shape of attenuated light due to their different linear energy transfer (LET). Fig. 1 shows the observed differences in alpha particles, fast neutrons and gamma rays in stilbene [3].

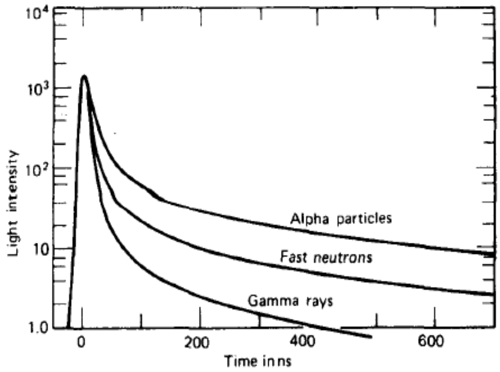

Fig. 1. Time dependence on the intensity of light by different types of radiations in stilbene [3]

In this study, the charge comparison method was used to distinguish neutrons from gamma rays by comparing the total charge (Q_{body}) of the pulse and the delayed charge (Q_{tail}) at the peak.

PSD was calculated using a developed neutron tagger module (NGT 400) to digitize the shape of the signal. It is controlled by a computer through an Ethernet connection. The total pulse width for the charge comparison and delay from the peak to tail start time can be adjusted by NGT 400 [4].

2.3. Optimization methods

Performing PSD requires finding optimal conditions. Optimization methods for PSD include control of pulse width, delay time, threshold and plastic scintillator geometry. In this paper, optimization was performed in terms of count per second (CPS) and PSD performance by changing the geometry of the plastic scintillator. Although CPS does not affect PSD performance and PSD performance is evaluated by figure of merit (FoM). But CPS is importance because our goal is to apply PSD systems at industry. If cps were low, it can be measured for a long time to measure, but since neutrons and gamma rays must be distinguished within a limited time, PSD performance and CPS were considered in this study.

3. Experiments and Results

3.1. Experiment settings

This experiment focuses on two aspects of PSD performance and count per second of a 7.8μCi ^{252}Cf source with variation such as 1 × 1 × 1 cm, 1 × 1 × 3 cm, 1 × 1 × 5 cm, 1 × 1 × 10 cm scintillator thickness. And a silicon photomultiplier (Hamamatsu S13360-6025CS) was used. S13360-6025CS has a 25μm pixel pitch and 7.5x 10^5 gain [5].

The plastic scintillator was measured under the same conditions with a source, the total pulse width of 800 ns and a delay time of 75 ns at the pulse peak. To perform PSD, DC power supply and NGT 400 including PSD logic were used. The measurement picture is shown in Fig. 2.

Fig 2. Experimental setup of a ^{252}Cf source, EJ276G scintillator and SiPM

3.2. MCNP simulation

Monte Carlo N-Particle (MCNP) transport code was performed to determine how neutrons and gamma rays react depending on the thickness of the plastic scintillator. 252Cf source emits 3.7675 neutrons [6] and 10.3 gamma rays [7] through spontaneous fission reaction with a 3.09% probability. neutrons have a Watt fission spectrum, and the formula is as follows.

$$f(E) = C\,exp(-E/a)sinh(\sqrt{bE}) \quad (1)$$

Neutrons and gamma rays transfer energy to protons and electrons within a scintillator, where secondary radiation generates signals. Therefore, the flux was calculated according to the thickness of the scintillator by designating protons and electrons as a tally. This result is shown in the Fig 3.

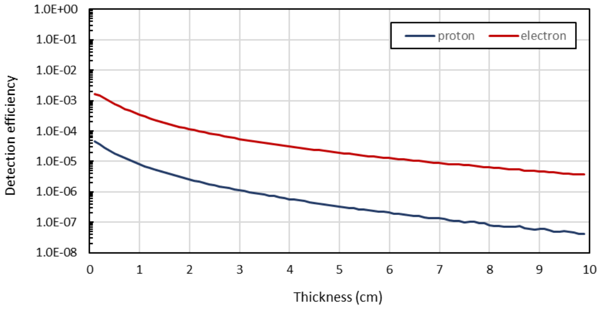

Fig. 3. Detection efficiency according to the thickness.

3.3. Results and Discussions

In terms of count per second, the highest result was 648.5 cps when the thickness of plastic scintillator is 3 cm. The result of the count per second for each thickness is shown in Fig. 4.

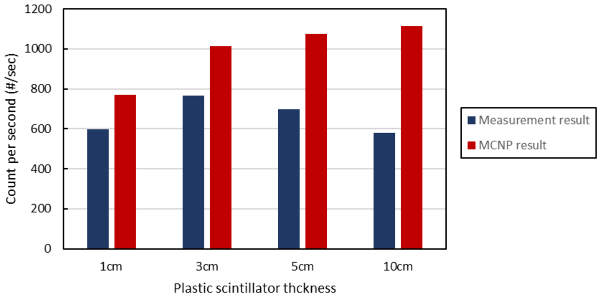

Fig. 4. Comparison of measurement and MCNP simulation results according to scintillator thickness

Considering CPS, the plastic scintillator 1 × 1 × 3 cm geometry showed the best results. The detection efficiency is affected by the geometry of the source and the detector, the energy of source, and the distance between source and detector, etc.

In ^{252}Cf source with the average energy 2 MeV neutrons and 1 MeV gamma rays, the detection efficiency decreases significantly with the thickness of the EJ276G scintillator. As a result of measurements, the reaction of secondary radiation (charged particles such as protons and electrons) produces visible light and is refracted by the reflector to enter the sensor, but as the thickness of scintillator increases, loss of light may be considered due to efficiency degradation. To accurately assess the incoming light emitted by radiation into the sensor, Geant 4 simulation should be used, which will be performed in the following study.

Fig. 5 shows result of PSD between neutrons and gamma rays using the charge comparison method in 1 × 1 × 3 cm geometry.

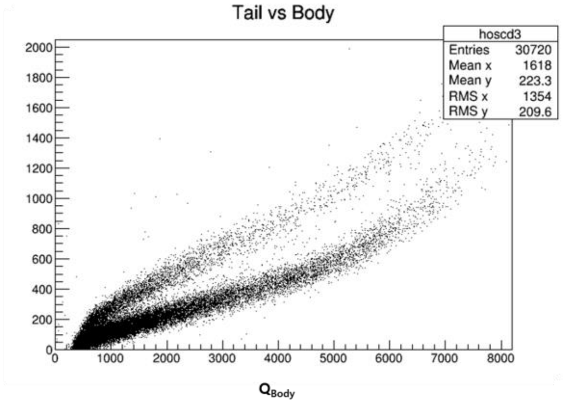

Fig. 5. Pulse shape discrimination in 1 × 1 × 3 cm geometry x_{axis}: total charge, y_{axis}: delayed charge at the peak

High-energy radiation can be saturated because plastic scintillators cannot accommodate the full energy. When saturation occurs, energy linearity is lost, and the Fig. 5 shape appears to be saturated by gamma rays around 6000 channels. To accurately analyze this, we will perform it with a high energy source such as electron accelerators.

4. Conclusion

This study is a preliminary optimization for distinguishing neutrons and gamma rays generated by D-T generator and 15 MeV electron accelerators such as high flux conditions. At the laboratory level, the best result was obtained with the plastic scintillator thickness of 3 cm using a ^{252}Cf source.

In further study, we will evaluate the PSD performance through Figure of Merit (FoM), an index that compares PSD performance, and conduct experiments in 15 MeV electron accelerators under high flux conditions.

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