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FAST NEUTRON DISCRIMINATION USING THE STILBENE SCINTILLATOR

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In this research, we have studied a speed system for neutron flux estimation used in experimental works with radiation protection design and for applications where materials identification based on neutron backscattering is crucial. The most effective approach is neutron-gamma discrimination using the stilbene scintillator. We performed a discrimination with the charge integration technique. The data acquisition was implemented using a high sampling rate oscilloscope. Crystalline stilbene is an organic scintillator that is well-suited for fast neutron identification in environments with high gamma-ray-associated irradiation.

Keywords: *Charge integration; scintillators; neutron gamma discrimination; landmine detection; neutron backscattering*

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1. INTRODUCTION

In this research, we have studied neutron gamma discrimination using the stilbene scintillator for applications where neutron flux estimations are crucial. One of the approaches is to use charge integration. Organic scintillating materials are frequently used for measurements that require sensitivity to gamma and fast neutron radiation due to their pulse shape discrimination (PSD) nature. The primary reaction for neutron detection is elastic neutron scattering [1, 2]. Experimental particle type identification is commonly taken using both charge integration and pulse shape discrimination methods. Recent research works in PSD methods demonstrate the effectiveness of charge-integration along with the new techniques [3]. The pattern-recognition method offers a short data processing time. A classical neutron gamma discrimination [4] can operate in a wide dynamic range up to 4MeV and demonstrates a lowest energy threshold down to 30 KeV but has a specific requirements for setup tuning. A few works demonstrate a great pulse shape discrimination capability for simultaneous detection of gamma-rays, slow and fast neutrons using only the one detector [5]. Recent algorithms of neutron/gamma discrimination, such as the use of neural networks [6]. For portable applications, for example, in evaluative tasks, data could be taken with digital oscilloscopes [7]. The minimum requirements for an oscilloscope are a sampling rate of 1 GS/s, 8-bit vertical resolution, and a bandwidth of 200 MHz. The described method's precision is comparable to the classic technique of zero crossing of two signals from the last dynode and photocathode, with further signal analysis on the time to digital converter (TAC) and spectrometer. In particular, the charge-integration method allows for highly accurate discrimination between photons and neutrons at high-energy depositions. This paper describes the algorithm and experimental details of the algorithm implementation for neutron gamma discrimination using the oscilloscope.

2. MATERIALS AND METHODS

The raw scintillation pulses were recorded with the oscilloscope GW Instek GDS-3504 [10] Digital Oscilloscope 500 MHz 4 GSa/s. It accumulated more than 100k pulses from the stilbene scintillator size of 40 mm x 40 mm, wrapped in PTFE tape. The leading-edge trigger threshold was set as the lowest possible 50 mV according to baseline noise and in terms of energy < 1 MeV. The data was obtained using a Pu-Be neutron source 10^5, which produces neutrons and instant gamma-rays. A used photomultiplier tube, PMT Hamamatsu R1307 [9], operating at 972 V, was installed in a dark box. To avoid signal distortion, it was used one-stage buffer amplifier with a 2 us integration time directly connected to the oscilloscope. An internal oscilloscope termination of 50 Ohms is used to avoid signal reflection. Fig. 1 presents the block scheme of the experimental setup used for data accumulation. The Pu-Be source is installed 15 cm from the detector. The stilbene crystal was coupled with optical glue Cargile [8] to the PMT window, a single-stage amplifier connected directly to the oscilloscope. Selected trigger holdoff (timing gate) was in the range of 300 ns.

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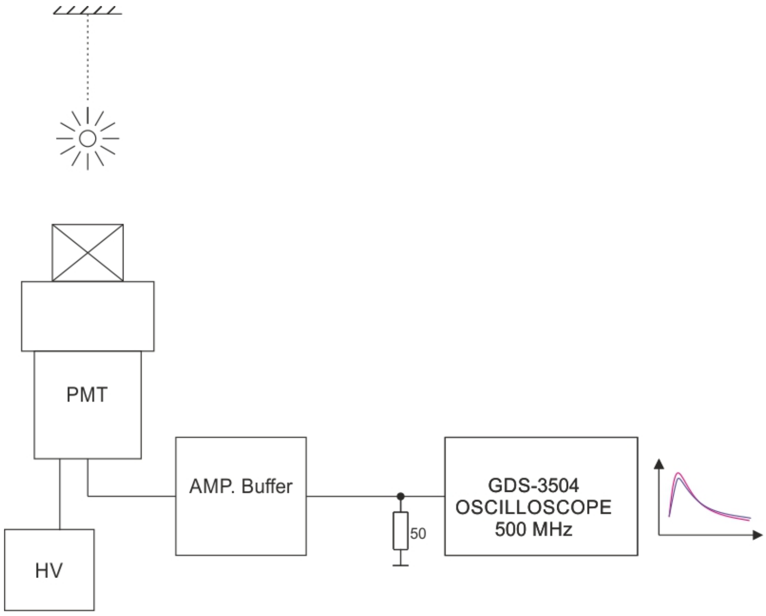

Figure 1. Experimental setup. Equipment used to measure the n-y discrimination by the charge integration method.

3. ALGORITHM AND DATA PROCESSING

The charge comparison method provides the most common pulse shape discrimination (PSD). The ratio between neutron 1 and gamma rays could be measured based on charge comparison of the entire signal Q total and the charge of the slow part of the signal tail Q slow.

$$R = Q_s/Q_t \tag{1}$$

Typical neutron and gamma-ray pulse signals are shown in Fig. 2 The ratio Qs/Qt is the main criterion of the method to classify pulses as neutron or gamma interactions with the scintillator. Neutron pulses – red line, gamma – blue line. The ranges of integration Qs (from 50 to 200 ns) have been fitted to have the best discrimination in terms of figure of merit (FOM).

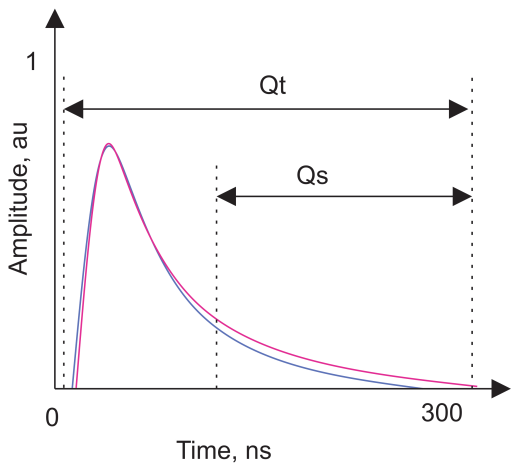

Figure 2. Charge integration principle, long gate Qt and the slow gate Qs selected for the charge comparison method.

Finally, to calculate the quality of neutron/gamma discrimination of the stilbene scintillator used the figure of merit (FOM), which is:

$$FOM = D/(FWHM_n + FWHM_\gamma) \tag{2}$$

Both neutron and gamma are semi-Gaussian functions; D is a metric of peak separation. To account for a variation of rise time for the pulses with the different amplitudes (rise time correction), the constant fraction discrimination function (CFD) was applied to the accumulated dataset. By varying the slow gate position to the long gate, it was solved the best position for the FOM was solved during the fitting process. An algorithm has been developed that is capable of automatically calculating the area integrals for predefined gates (Q_t and Q_s). Using the Python code, the raw amplitude

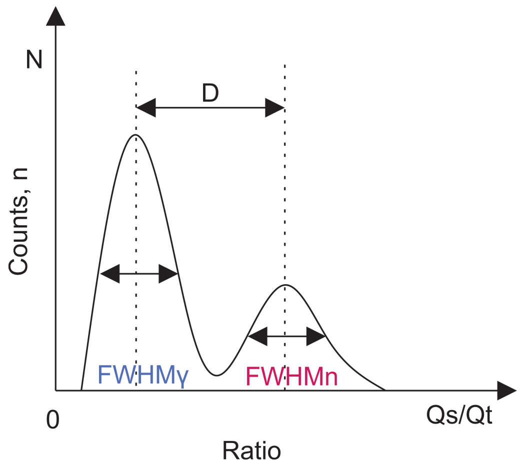

Figure 3. FOM calculation: distance D between neutron and gamma peaks, full widths at half maximum for gamma and neutron peaks.

pulses were recorded from the oscilloscope during the exposition time to the host PC. After gate selection, for each recoded pulse, the Ratio Qs/Qt was calculated. At the end of the ratio calculation, the resulting FOM is used to adjust the gate and recalculate the FOM.

4. EXPERIMENTAL RESULTS

Similar results but with different equipment were examined by many researcher groups [11, 12] and our implementation following the main principle of charge integration. As a result, the measured FOM for stilbene scintillator was 0.715.

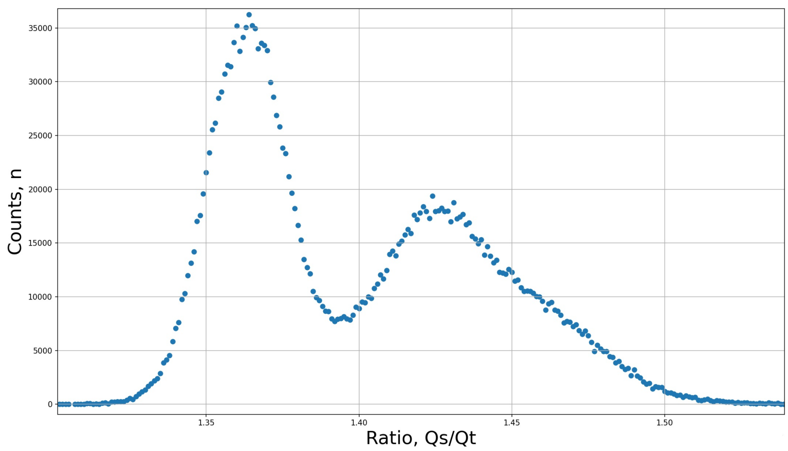

Figure 4. The n-y discrimination spectra for stilbene scintillator 40 mm x 40 mm, PMT Hamamatsu R1307, Pu-Be source.

The shaping time of the amplifier was 2.0 μs for all expositions, which is longer than the scintillation decay time. The conventional organic scintillator stilbene corresponds to standard parameters in experiments, and it's possible to use a simplified acquisition path to evaluate the discrimination ratio.

5. DISCUSSION AND CONCLUSION

Our research shows a comprehensive approach to measuring FOM with modern oscilloscope equipment. The quality of the stilbene scintillator may affect the resulting FOM. High-grade discrimination could be achieved with the simplified electronic path, compared to classic zero-crossing (ZC) techniques, which utilize a more complex timing circuit [link]. An obtained experimental dataset could be used for further analysis, for example, to train AI-based recognition models [link]. The energy threshold of the detecting system could be estimated with calibration at different energy sources [13]. The charge integration method is effective for 100 keV electron energy with a range up to 4 MeV. The drawback of the charge comparison method is mainly the higher lowest threshold energy. The method needs an oscilloscope with a bandwidth of at least 500MHz, vertical resolution might be 8-bit, but a 12-bit ADC will provide a better particle identification (in a noisy environment). PMT dynamic gain is important to achieving better discrimination at energy applications below 50 keV. A fitting procedure and data processing have been written using Python. Our approach demonstrates potential applications for this setup in portable systems, especially in cost-efficient systems.

6. DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7. ACKNOWLEDGMENTS

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ДИСКРИМІНАЦІЯ ШВИДКИХ НЕЙТРОНІВ З ВИКОРИСТАННЯМ СЦИНТИЛЯТОРУ СТИЛЬБЕНУ

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У цьому дослідженні ми досліджували систему швидкісної оцінки потоку нейтронів, яка використовується в експериментальних роботах з проектування радіаційного захисту та для застосувань, де ідентифікація матеріалів на основі зворотного розсіювання нейтронів є критично важливою. Найефективнішим підходом є нейтронно-гамма дискримінація з використанням сцинтилятора стильбену. Ми реалізували дискримінацію за допомогою методу інтегрування заряду. Збір даних було здійснено за допомогою осцилографа з високою частотою дискретизації. Кристалічний стильбен – це органічний сцинтилятор, який добре підходить для швидкої ідентифікації нейтронів у середовищах з високим опроміненням, супутнім гамма-випромінюванням.

Ключові слова: *інтегрування заряду; сцинтилятори; нейтронно-гамма-дискримінація; виявлення наземних мін; зворотне розсіювання нейтронів*