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Analysis of three digital n/γ discrimination algorithms for liquid scintillation neutron spectrometry

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HIGHLIGHTS

► We describe three digital n/γ discrimination algorithms.
► Effects of both digital filters and simulated pile-up events were studied.
► The CC and SDCC algorithms are preferred in low count-rates fields.
► The PGA algorithm with a digital filter is favorable in high count-rates fields.

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ABSTRACT

In mixed neutron/γ radiation fields, particle identification based on different filter algorithms and radiation intensities is an important issue for liquid scintillation neutron spectrometry. We have compared the performance of three algorithms for digital neutron/γ discrimination in a deuterated liquid scintillator. The effects of both digital filters and simulated pile-up events on the performance of these techniques were investigated. The discrimination methods utilized are the digital charge comparison (CC) method, simplified digital charge collection (SDCC) method and pulse gradient analysis (PGA) method. The results show that the SDCC and the CC methods are preferred choices when applied in low count-rates fields, whereas PGA method with a seven-point average running filter is favorable when pile-up signals constitute a large fraction of the detected events. All these discrimination approaches are potentially suitable for developing a compact digital neutron spectrometer in mixed neutron/γ radiation fields for use in various applications.

1. Introduction

Liquid scintillators have been extensively used in nuclear physics as neutron detectors due to their excellent pulse shape discrimination (PSD) properties and fast timing performances. Because liquid scintillators are sensitive both to neutron and γ-ray radiation, an accurate and stable discrimination method is necessary. Several methods based on conventional NIM-standard analog modules have been used to separate neutrons from γ-rays, such as the zero-crossing method and the rising time method. These analog PSD modules only allow the number of events identified as neutrons or γ-rays to be counted (together with their pulse height), and a reprocessing function of the signal data is impossible after the experiment (Kaschuck and Esposito, 2005).

Digital pulse processing is playing an increasingly important role in many research fields. Development of the analog-to-digital converter has opened up new possibilities for digital PSD methods. In the past decade, commercial high-speed digitizers and digital oscilloscopes with high performances have become available, which allow the exploration of digital PSD techniques for high-count-rate neutron and γ-ray spectrometry (Esposito et al., 2004). Many digital n/γ discrimination techniques have been tested, such as the artificial neural network method (Liu et al., 2009), charge comparison method (CC) (Flaska and Pozzi, 2007; Kaschuck and Esposito, 2005), digital zero-crossing method (Nakhostin and Walker, 2010), simplified digital charge collection method (SDCC) (Gamage et al., 2011; Shippen et al., 2010) and pulse gradient analysis method (PGA) (D'Mellow et al., 2007). The application of various digital PSD methods can potentially achieve an enhanced n/γ discrimination compared to the analog techniques. Additionally, the digital data can be stored and transferred via USB for subsequent analysis, providing a flexible reprocessing function of the original data. Such reanalysis could be used to investigate alternative discrimination techniques,

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which can be applied to check the reliability of the results (Kaschuck and Esposito, 2005).

Digital filters have been applied in various n/γ separation algorithms, such as the five-point binomial smoothing filter (Jastaniah and Sellin, 2004), fifteen-point moving average filter (Hawkes et al., 2010) and Butterworth filter (Kaschuck and Esposito, 2005). They are used to reduce high-frequency noise and improve the signal-to-noise ratio of the data because the pulse shape is often corrupted by noise. Likewise, pile-up events are a major concern during high-count-rate operations. A pile-up rejection electric circuit is used to reject the subsequent inputs until the initial input pulse has terminated in analog modules, which leads to information losses and a reduction in the detection efficiency. In the digital domain, several attempts have been made to identify and reconstruct pile-up events (Marrone et al., 2002; Weijun Guo et al., 2005).

Few studies have focused on the stability of various digital neutron/γ discrimination methods under the risks of different digital filter configurations and pile-up events. The aim of this study was to identify appropriate digital neutron/γ discrimination techniques that are potentially suitable for the application of fast liquid scintillation neutron spectrometry in different situations such as reactor physics, neutron dosimetry, and the detection of illicit nuclear material. The remainder of the paper is organized as follows. The experimental details are presented in Section 2, and Section 3 provides a description of three different discrimination algorithms as well as their separation results. Section 4 discusses the dependence of the algorithms on digital filters, and Section 5 examines the immunity of these techniques to pile-up events. A conclusion is given in Section 6.

2. Experimental details

A BC537 scintillation detector was exposed to a mixed radiation field produced by an americium–beryllium (Am–Be) neutron source. The detector was surrounded by lead shielding blocks (5 cm in thickness) and placed at a distance of 50 cm from the source. Fig. 1 shows a diagram of the experimental setup. The signals from the anode of the detector were directly digitized using a high-speed digitizer. The raw digitized pulses were captured by the LabVIEW software on an event-by-event basis. The data were then transferred to a computer for offline processing. The detector was the BC537 (5.08 cm× 5.08 cm) deuterated liquid scintillator with an Electron Tubes 9807B photomultiplier (PMT), and the PMT was supplied with a negative voltage of 1150 V. The NI PXI-5154 digitizer takes samples at 2 GHz with an amplitude resolution of 8 bits. This setup and its use in acquiring the data considered in this work are described in detail in Chen Xiaohui et al. (2012).

3. Discrimination algorithms and performances

The two types of pulses recorded by the BC537 were found to have different decay rates as shown in Fig. 2. On the basis of this feature, three different digital algorithms for n/γ discrimination have been considered below.

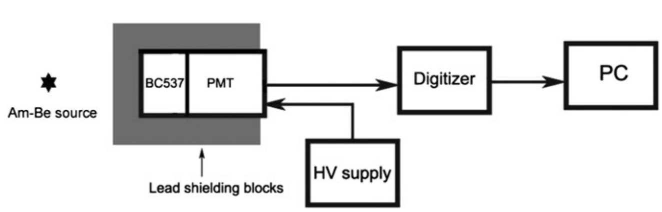

Fig. 1. Diagram of the experimental setup.

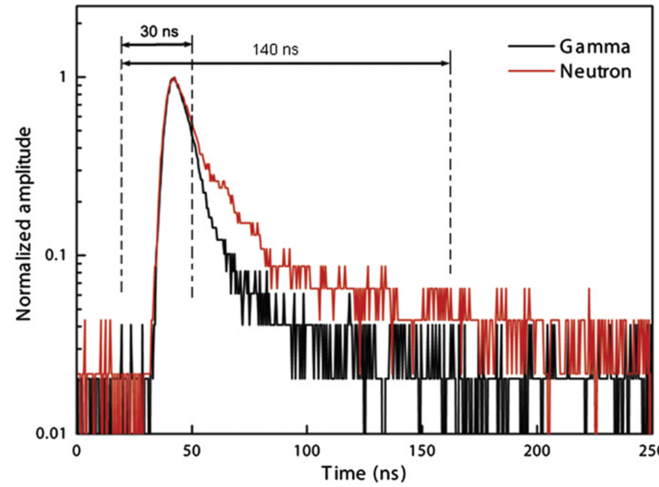

Fig. 2. Examples of raw digital pulse obtained with an 8-bit 2 GSamples/s digitizer for neutron and γ-ray from the BC537. The signals approximately correspond to 500 keVee (keV electron equivalent). The neutron pulse clearly decays more slowly than the γ-ray pulse. The pulses have been normalized, and the sample interval is 0.5 ns.

3.1. Digital charge comparison (CC) method

The CC method, which uses the ratios of the pulse integrals over different time intervals to separate neutrons from γ-rays, has been widely studied in the past. The charge ratio (R) is calculated in Eq. (1):

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

where Q_s and Q_f are the integration associated with the slow and fast component of the pulse, respectively. As shown in Fig. 2, the optimal time intervals of Δt_s and Δt_f were found to be 140 and 30 ns, respectively. A neutron-induced pulse has a higher R value for the same peak amplitude compared to a γ-ray pulse due to its slower decay rate.

3.2. Simplified digital charge collection (SDCC) method

The frequency analysis in Shippen et al. (2010) indicates that the CC method can be optimized by simply squaring each sample in the time domain that falls in the region of interest of the digital pulse. The SDCC method, inspired by the Wavelet Packet Transform, is characterized by a discrimination parameter D, which is calculated in Eq. (2):

$$D = \log\left(\sum_{t=a}^{t=b}\left(x_t^2 + x_{t+0.5}^2\right)\right) \tag{2}$$

where x_t and $x_{t+0.5}$ are the sample amplitudes at time t and $t+0.5$, respectively, and a and b are the samples corresponding to the start time and end time of the pulse region of interest, respectively. The optimum time interval should be determined by the specific apparatus concerned. In all of our cases, the value of a is 70 ns, and the value of b is 210 ns. Similarly, for the same peak amplitude, the D parameter corresponding to a neutron event is larger than that for a γ-ray event.

3.3. Pulse gradient analysis (PGA) method

The neutron pulse exhibits a slower decay to the baseline which is characterized by a gradient that is smaller on the trailing edge of the pulse. It is this feature that was exploited in the PGA technique