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PULSE-SHAPE DISCRIMINATION FOR IDENTIFICATION OF NEUTRON SOURCES USING THE BC-501A LIQUID SCINTILLATOR

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ABSTRACT

This summary describes a pulse-shape discrimination method that can be used to distinguish neutrons from gamma rays measured with liquid scintillation detectors. This method is used to obtain accurate neutron pulse-height distributions. This information is then used to identify the neutron source, which is the main objective of this work. The PSD method is based on offline pulse analysis. A fast oscilloscope Tektronix TDS-5104 in combination with a liquid scintillation detector BC-501A was used to detect and store the neutron and gamma-ray pulses. The Matlab® scripts were written to post-process the data. An optimized ratio of tail-to-total integral is used for particle identification. The tail integration range, the total integration range, the pulse-height threshold, and the location of the classification point were optimized using "known" neutron and gamma-ray pulses. Californium-252 and americium-beryllium neutron sources were used to test and optimize the PSD method. To simulate possible source surroundings, several shields were tested between the source and the detector to assess their influence on accuracy of source identification. This investigation was very important to reveal the limitations of the proposed source identification method when working under different and realistic measurement conditions. This work has applications in the areas of nuclear nonproliferation and homeland security.

Key Words: neutron source identification, neutron/gamma discrimination, neutron pulse-height distribution

1. INTRODUCTION

Accurate knowledge of the spectrum of neutrons emitted by nuclear materials is of great interest in many research applications, such as nuclear nonproliferation, international safeguards, nuclear material control and accountability, national security, and counterterrorism. Therefore, it is very important to develop methods that allow fast and robust identification of neutron sources by means of unfolding neutron spectra. In safeguards applications, it is essential to correctly identify various neutron sources such as californium-252 (Cf-252), americium-beryllium (Am-Be), or plutonium-240 (Pu-240). In addition, accurate neutron spectrum unfolding increases the sensitivity of assays performed on various nuclear materials [1].

Neutron and gamma-ray pulse-shape discrimination (PSD) using liquid scintillation detectors is a widely adopted technique in these fields. In contrast to thermal neutron detectors, liquid scintillators are able to detect high-energy neutrons and do not need to use moderating material. Generally, the decision time of currently adopted PSD techniques lies in the range of hundreds of nanoseconds [2, 3]. A shorter decision time would further increase the acceptable count rates in the assays performed on nuclear materials.

Neutron spectrum unfolding relies on the accurate identification of the pulse-height distribution generated by the neutron source in the detector. Because liquid scintillators are sensitive to both neutrons and gamma rays, a robust and efficient pulse-shape discrimination technique is essential to determine the *neutron* pulse-height distribution accurately. Once this distribution has been determined, neutron unfolding techniques can be applied to obtain the initial neutron energy spectrum. The neutron spectrum represents a unique "signature" of a neutron source and can be used for source identification. The drawback is that a small variation in measured pulse-height distributions leads to a large variation in the unfolded neutron spectrum. Thus, the PSD method must be very accurate to allow for correct identification of neutron sources. In addition, surrounding materials can significantly alter the measured pulse-height distribution. Therefore, their influence must be investigated in detail.

2. PSD METHOD

The phosphor oscilloscope Tektronix TDS-5104 with 1-GHz resolution was used to store tens of thousands of pulses from the anode of the liquid scintillator BC-501A. These pulses were used in subsequent analysis. The oscilloscope worked in fast-frame acquisition mode to capture the pulses with a high resolution. The BC-501A used in experiments is 7.7-cm thick with a diameter of 15.2 cm. In the first set of experiments, the time range was limited to 130 ns per pulse. However, in the full paper we will discuss performance of the PSD method for various time ranges.

To optimize the PSD method, neutrons and gamma rays were measured separately from different radioactive sources. The neutrons emitted by a Cf-252 source were detected using the time-of-flight (TOF) method, which allowed us to identify the neutron pulses in a gamma-ray background. The Cf-252 source was placed in the middle of an ionization chamber at a distance of 1 m from the detector. The ionization chamber served as a "start" detector to determine the time zero. The gamma-ray pulses were measured using a cesium-137 (Cs-137) source placed on the face of the detector.

2.1. Optimization of the PSD Method

A ratio of two areas obtained by integration of the pulse in various time intervals is used to discriminate neutrons from gamma rays. The area A_1 is the total area of the pulse while the area A_2 represents the tail of the pulse. The ratio R is defined as

$$R = \frac{A_2}{A_1} \quad (1)$$

The integral ratio R for the correctly applied PSD method is higher for most of the neutron pulses when compared to the gamma-ray pulses, as shown in Fig. 1. This feature can be used to separate the neutrons from the gamma rays. The relatively high value occurring in the gamma-ray histogram at position zero is attributable to the accumulation of low ratio values (negative R values are not possible). The cross point of the neutron and the gamma-ray curve has been chosen as a discrimination point to classify the particles detected. Above the classification point all pulses are classified as neutrons, whereas below this point the pulses are classified as gamma rays.

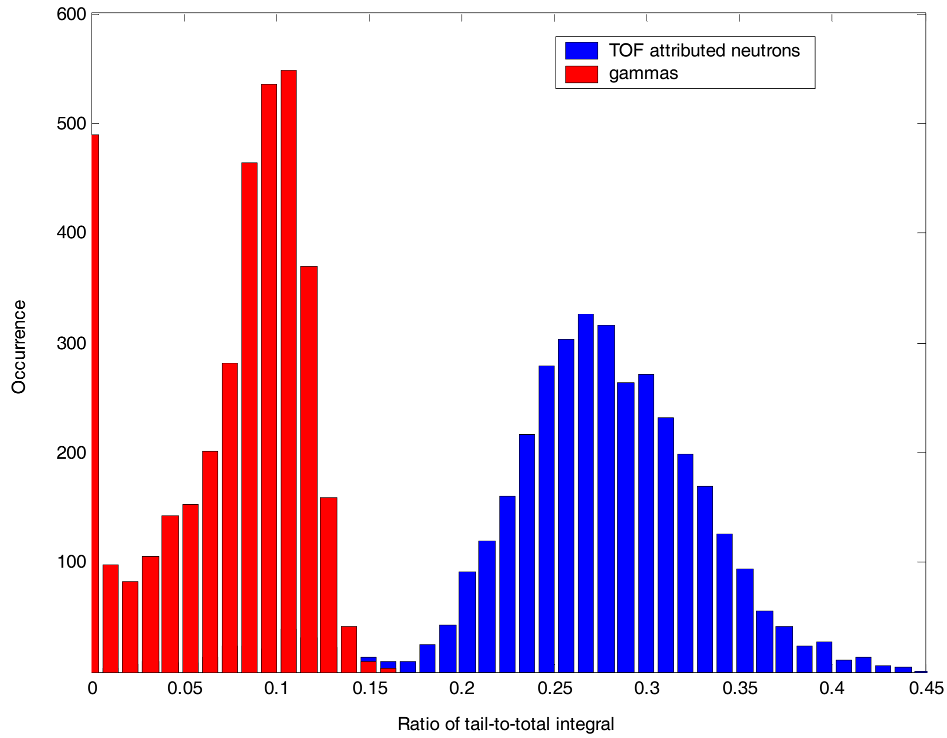

Figure 1. Histograms of neutron and gamma-ray pulses obtained by using the optimized range of the tail integral.

The number of misclassified neutrons and gamma rays can be minimized by optimizing the integration range of the total integral, the integration range of the tail integral, the location of the classification point, and the pulse-height threshold. All optimizations were performed with the purpose of minimizing the overlap area of neutron and gamma-ray distributions and will be discussed in the full paper in detail. In Fig. 1, the overlap area is approximately 3% of the total area of the neutron and gamma-ray distributions. Most of these pulses are neutrons, which means that almost no gamma rays are misclassified using the known pulses.

2.2. Application of the Optimized PSD Method

To develop and to test the optimized PSD method, the digital oscilloscope and scintillation detector described earlier were used. Fig. 2 shows an example of histograms created from the measured data with the Cf-252 source. In the case without shielding, no observable separation of the neutron and gamma-ray distributions occurs because the source was placed close to the detector (~10 cm), and thus, the probability of detecting a neutron simultaneously with a gamma ray was relatively high. In addition, most of the measured pulses were created by gamma rays, which further decreased the efficiency of the PSD method. The optimal ratio of neutron and gamma-ray pulses per acquisition will be discussed in the full paper.

Our studies demonstrated that particle discrimination can be improved by using a lead shield (2.2-cm thick in Fig. 2). The shield eliminated many, mostly low-energy gamma rays; thus more neutrons per acquisition were detected, and the neutron/gamma discrimination was improved. To improve the PSD method further, accidental coincidences resulting in the detection of a neutron and a gamma-ray at the same time were minimized by optimizing the source-detector distance.

The probability of accidental neutron and gamma-ray coincidences was calculated using the MCNP-PoliMi code [4], which follows each history event-by-event. The simulation is possible thanks to correctly modified secondary particle production in the MCNP- PoliMi. The calculations also helped us to determine the optimal source-detector distance.

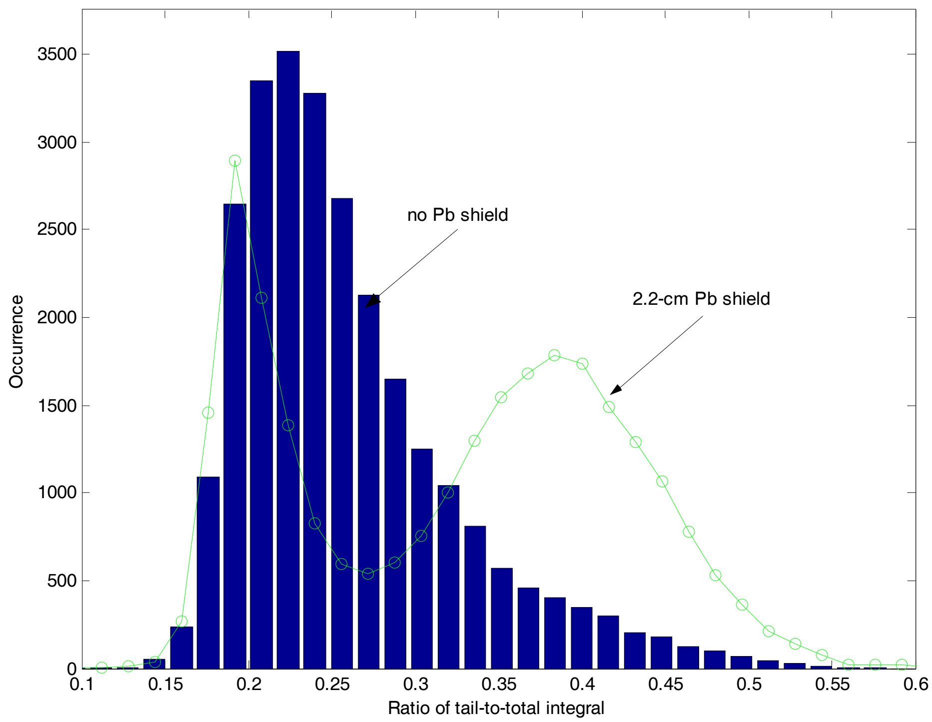

Figure 2. Histograms obtained by application of the optimized pulse-shape discrimination method to unknown data.

The full paper will include measurements performed with Cf-252 and Am-Be neutron sources. Several experimental setups will be investigated, with lead and polyethylene shields of various thicknesses between the source and the detector. These experimental results will be compared to simulations performed with the MCNP-PoliMi code.

3. CONCLUSIONS

A PSD technique has been optimized to classify the neutron and gamma-ray pulses measured with a liquid scintillation detector BC-501A. This offline method can be used to accurately discriminate neutrons from gamma rays originating from a neutron source. The main purpose of this method is to obtain accurate pulse-height distributions for source identification. A specific ratio of tail-to-total integral was proposed for classifying the particles and the final PSD optimization has been achieved by combining TOF measurements with Matlab® calculations. Cf-252 and Am-Be sources were used to optimize and test the PSD method. To reveal the influence of the potential source surrounding, several materials were placed between the source and the detector and their influence on the accuracy of the source identification has been determined. It should be stressed that the total integration time of the pulses was on the order of 130 ns, which is shorter than most integration times reported in the literature. The shorter integration time allows for higher count rates while retaining the accuracy of the PSD result.

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