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Measurements of Separate Neutron and Gamma-Ray Coincidences with Liquid Scintillators and Digital Pulse Shape Discrimination

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Nuclear Science and Technology Division

MEASUREMENTS OF SEPARATE NEUTRON AND GAMMA-RAY COINCIDENCES WITH LIQUID SCINTILLATORS AND DIGITAL PULSE SHAPE DISCRIMINATION

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ABSTRACT

The detection of correlated neutron and gamma-ray events has proven very useful for the identification of various nuclear materials. Indeed, since for a given material and geometry the time distributions of the correlated events are very characteristic, they represent and can be used as distinctive signatures of different material-geometry configurations.

Here we present a new application of a digital pulse shape discrimination (PSD) technique for the measurement of neutron and/or gamma-ray coincidences. The PSD technique is based on the standard charge integration method. The measurement method allows for the collection of fast coincidences within a time window of the order of a few tens of nanoseconds. The use of PSD allows for the accurate acquisition of the coincidences in all particle combinations. Specifically, separate neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences are acquired with two 25 by 25 by 8 cm liquid scintillation detectors. The measurements are compared to results obtained with the MCNP-PoliMi code, which simulates neutron and gamma-ray coincidences from a source on an event-by-event basis. This comparison leads to relatively good qualitative agreement.

Simulations of the separate neutron and gamma-ray contributions to the total cross-correlation function help to improve further the performance of experimental systems that aim at accurate identification of nuclear materials. This research has direct applications in the areas of nuclear nonproliferation and homeland security.

1. INTRODUCTION

Several techniques used in the field of nuclear safeguards rely on the measurement of neutron multiplicity distributions to assess and characterize fissile materials in various forms [1]. These techniques are based on the thermalization of neutrons from fission in polyethylene moderators and subsequent detection using He-3 counters.

More recent applications in the areas of homeland security and nuclear nonproliferation use organic scintillation detectors in liquid or plastic form. These detectors are sensitive to both fast neutrons and gamma rays [2]. Signatures that rely on coincidence measurements of neutrons and gamma rays from fission have been shown to be useful in the detection and characterization of nuclear materials [3, 4]. The coincidence distributions are of interest in the areas of nuclear nonproliferation and homeland security because they contain information that can be used to accurately identify and characterize fissile isotopes.

Recently, we have described the application of a digital pulse shape discrimination (PSD) technique [5] to the identification of shielded neutron sources [6]. In the present report, this PSD technique is used for the analysis of correlated neutron and gamma-ray events from a Cf-252 spontaneous fission source using two liquid scintillation detectors. The correlation is performed in a time window of a few tens of nanoseconds. The experiments are performed with and without lead shielding for a symmetric position of the source with respect to the detectors, and without lead for an asymmetric position. The use of the PSD technique allows the acquisition of separate neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences in the two liquid scintillators. The knowledge of these separate contributions is essential for further improvement of the existing measurement systems based on detection of correlated events.

This paper is organized as follows: Section 2 describes the experimental setup, Section 3 describes the experimental results, Section 4 presents the comparison of simulated and measured data, and Section 5 presents the conclusions and points to future work.

2. DESCRIPTION OF EXPERIMENTAL SETUP

The setup consists of two liquid scintillation detectors. The size of the active volume hosting the liquid scintillator is 25 by 25 by 8 cm. The detectors are placed on a steel cart, at a distance of 60 cm from each other. Initially, a Cf-252 source is placed at the center of the assembly. Figure 1 shows a photograph of the experimental setup.

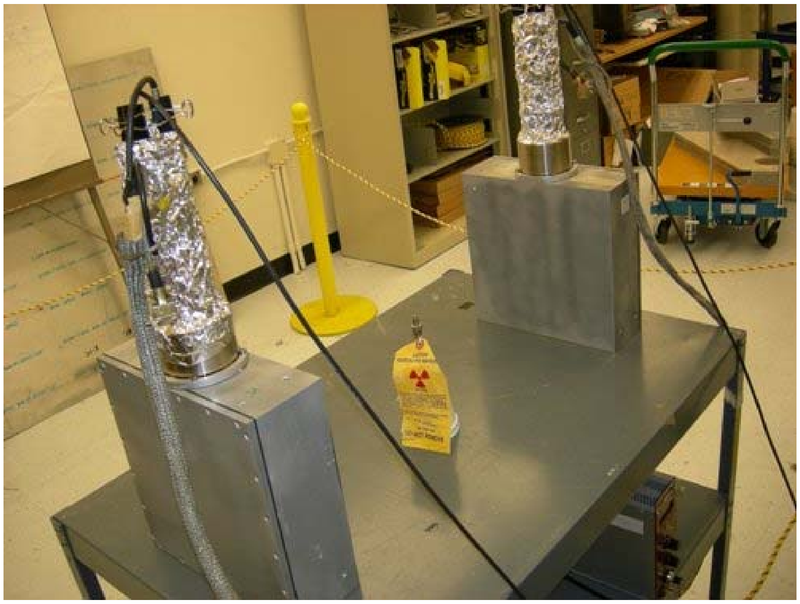

Figure 1. Photograph of the experimental setup.

The signals from the anodes of the detectors are acquired with a Tektronix TDS-5104 oscilloscope, which is controlled via a Matlab script. The voltages and the threshold used at the detectors were determined by standard energy calibration performed using a Cs-137 source. The source was placed at the center of the front face of each detector, in contact with the surface of the detector. The pulses generated by source gamma rays were collected and analyzed for both detectors to determine the pulse height distributions (Compton edges). The voltages at the detectors were adjusted until the pulse height distributions from the two detectors were fully aligned. Figure 2 shows the pulse heights for the two detectors at the voltages used in these measurements.

A Cs-137 source was also used to check if the detectors' pulses were aligned in time. This was done by placing the detectors close to each other with the source in between.

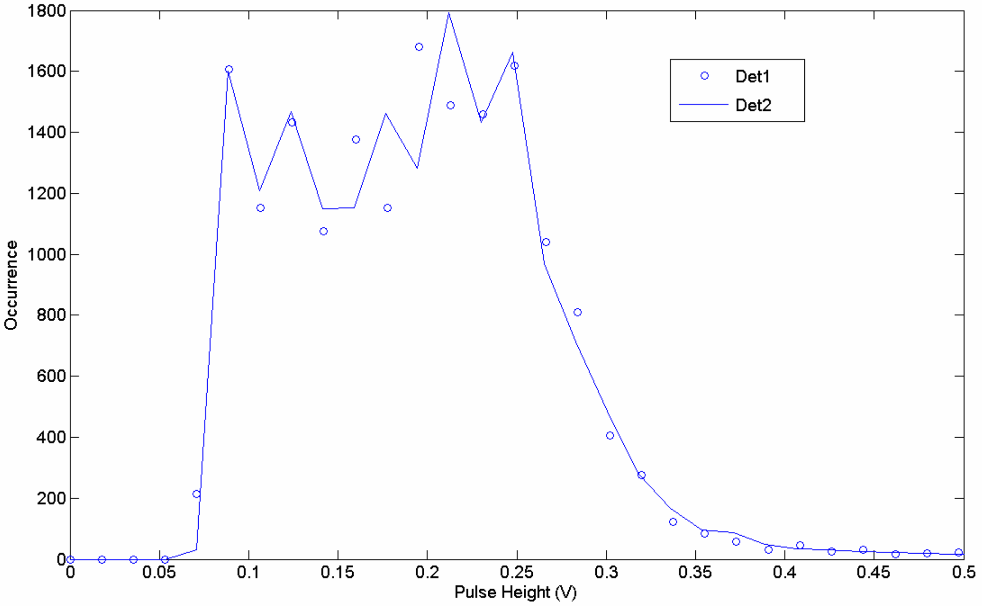

Figure 2. Pulse height distributions acquired using a Cs-137 source for both detectors used.

3. MEASUREMENT RESULTS AND ANALYSIS

Measurements were performed using the Cf-252 source with and without a lead shield of thickness 2.2 cm. The detection threshold was set to ~130 keVee (keV electron equivalent). The oscilloscope was triggered on the signal from detector 1, and pairs of pulses that satisfy given threshold condition were acquired using a Matlab script. The use of this script and of the digital oscilloscope extended the measurement time to approximately one week.[1] The pairs of pulses were then analyzed offline to determine the particle type that created them (neutron or gamma ray) and their time difference. An optimized digital PSD technique was used for the particle identification.

Figure 3 shows the measurement results for the bare Cf-252 source. The total cross-correlation function is subdivided into neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences. Symmetry about time zero is observed in the measured results; this is expected because of the symmetry of the experimental setup.

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[1] By using a pulse digitizer, the measurement time can be reduced to minutes.

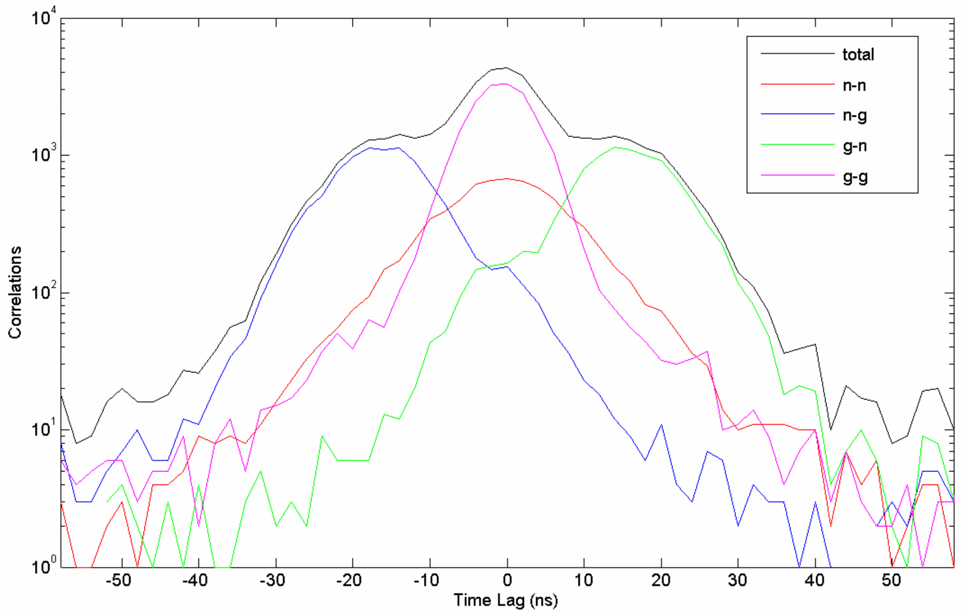

Figure 3. Measured detector–detector cross-correlation functions for bare Cf-252 source placed 30 cm from either detector. The total cross-correlation function is subdivided into neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences.

Figure 4 shows the measurement results for the Cf-252 source placed in the center of the detector assembly and shielded with 2.2 cm of lead. As before, the total cross-correlation function is subdivided into the contributions of different particle pairs. Comparison with Figure 3 shows the gamma ray attenuation by the lead shield, which results in lower gamma-ray─gamma-ray, neutron-gamma ray, and gamma-ray-neutron coincidences. Neutron-neutron coincidences are now predominant.

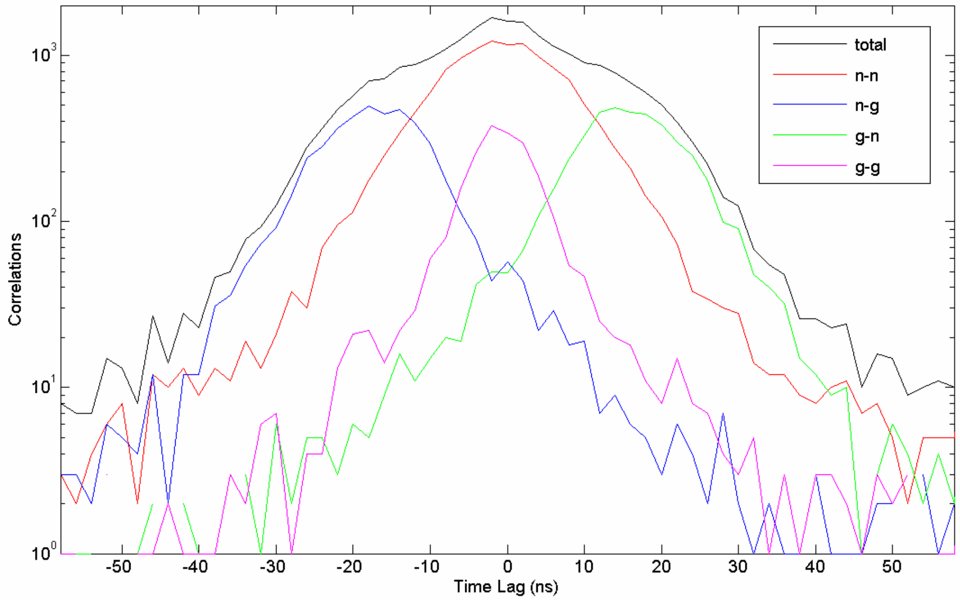

Figure 4. Measured detector–detector cross-correlation functions for Cf-252 source placed 30 cm from either detector and shielded with 2.2 cm of lead. The total cross-correlation function is subdivided into neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences.

Figure 5 shows the measurement results for the bare Cf-252 source placed 15 cm from detector 1 and 45 cm from detector 2; all measured partial contributions are shown together with the total cross-correlation function. The asymmetric positioning of the source can be observed in the correlation results, which are now also asymmetric about time zero. This result leads to the conclusion that the cross-correlation technique may be used to determine the position of a point-like source located between two detectors.

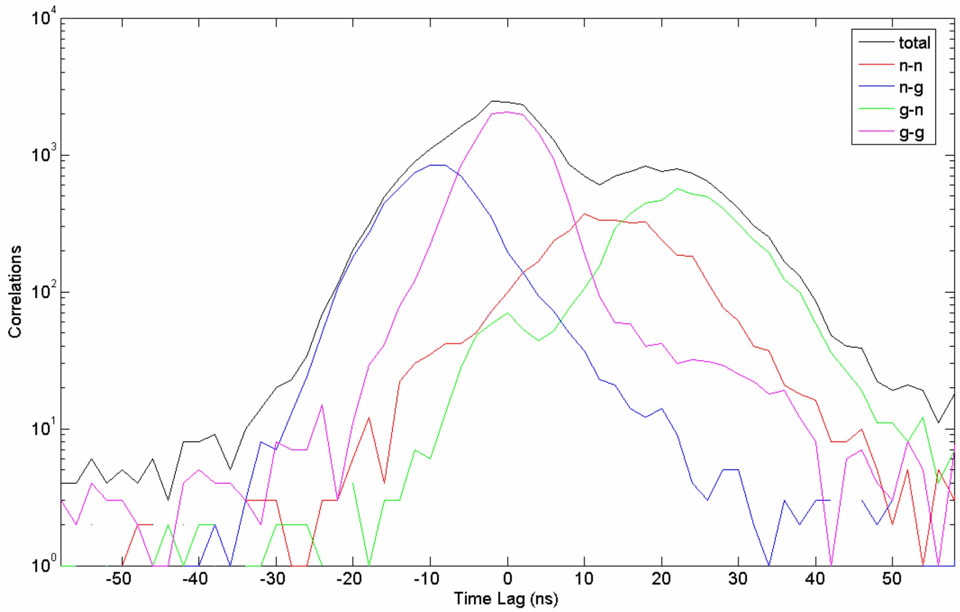

Figure 5. Measured detector–detector cross-correlation functions for Cf-252 source placed 15 cm from detector 1 and 45 cm from detector 2. The total cross-correlation function is subdivided into neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences.

4. COMPARISON WITH MCNP-POLIMI SIMULATIONS

The measurement configurations from the experiments described in the previous section were simulated using the MCNP-PoliMi code [7]. The code can simulate neutron–gamma correlations from a spontaneous fission source by choosing an option in the input deck. The detector response is then simulated via a specialized postprocessing code [8], which can compute not only the total, but also the partial cross-correlation functions. Figures 6, 7, and 8 show the comparison of the measured and simulated results for all the configurations discussed earlier. Because the experimental setup described above does not operate in real time, absolute comparison of the measured and simulated results is not possible. Instead, the results are normalized to the total number of correlations. In general we obtained relatively good qualitative agreement between the measurements and the simulations, which is a promising result for further experimental work on cross-correlation signatures of various nuclear materials. Further investigation is needed to explain the remaining unresolved differences between the measurements and the simulations.

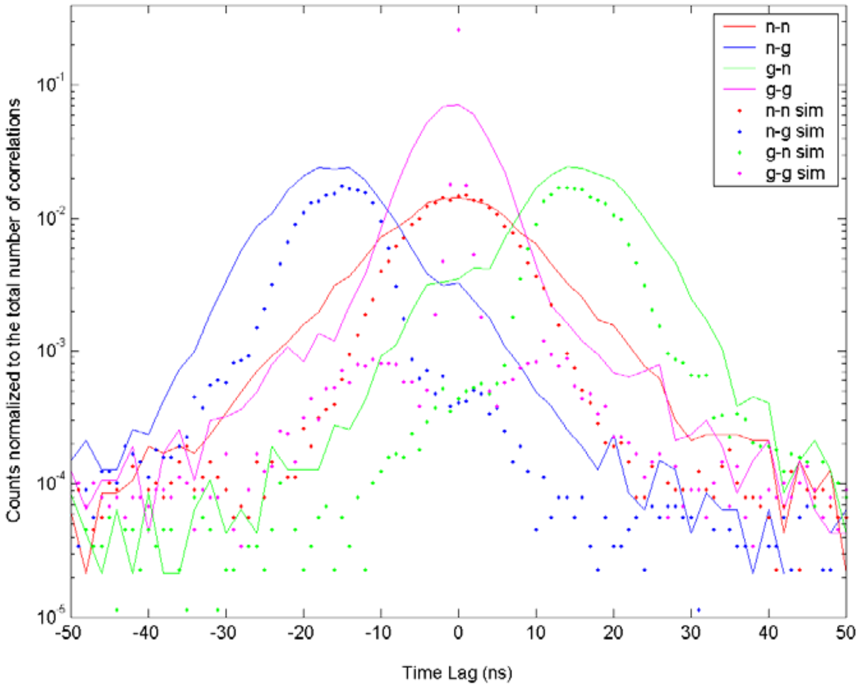

Figure 6. Measured and simulated detector–detector cross-correlation functions for the Cf-252 source placed 30 cm from either detector.

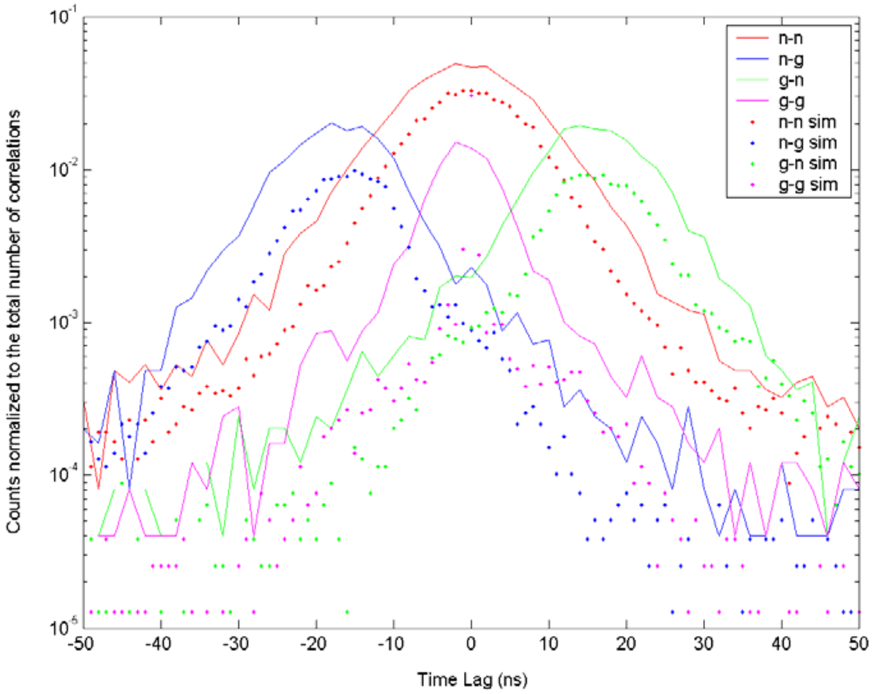

Figure 7. Measured and simulated detector–detector cross-correlation functions for the Cf-252 source placed 30 cm from either detector and shielded with 2.2 cm of lead.

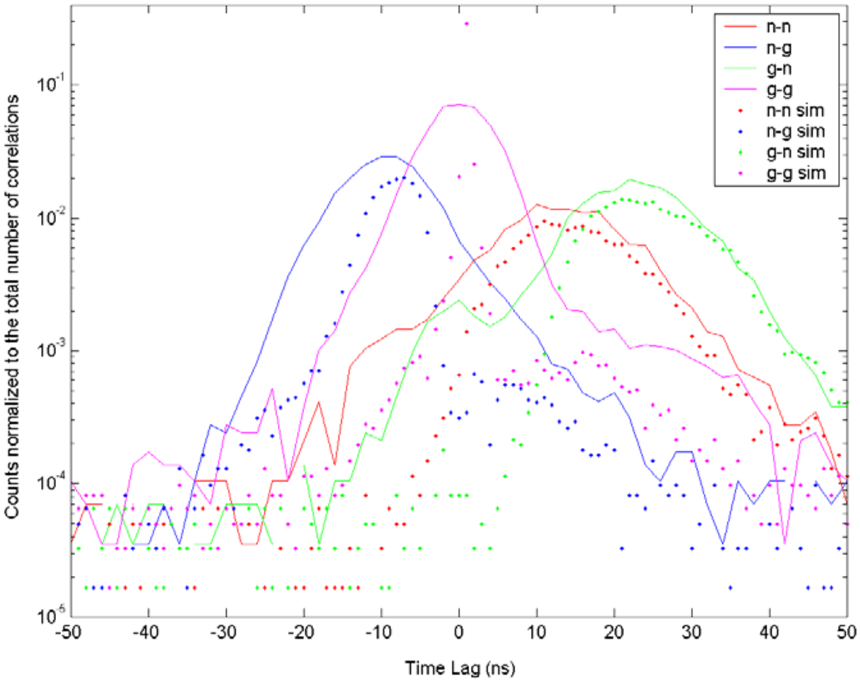

Figure 8. Measured and simulated detector–detector cross-correlation functions for the Cf-252 source placed 15 cm from detector 1 and 45 cm from detector 2.

5. CONCLUSIONS

A new application of a digital PSD technique to the measurement of cross-correlation functions with liquid scintillation detectors is presented. The PSD technique allows for acquiring separate neutron–neutron, neutron–gamma-ray, gamma-ray–neutron, and gamma-ray–gamma-ray coincidences. The knowledge of these separate contributions helps to further improve the existing measurement systems relying on detection of correlated events from a fissionable material. These correlated events can be used as material-geometry "signatures", and therefore are of great relevance and interest for nuclear nonproliferation and homeland security applications.

The measurement method is based on the detection and digitization of fast coincidences between pairs of neutrons and/or gamma rays. The correlated events are detected with two 25 by 25 by 8 cm liquid scintillators. The measurements were compared to simulation results obtained with the MCNP-PoliMi code, and relatively good qualitative agreement was obtained.

The data analyzed in this report was acquired using a fast digital oscilloscope (Tektronix TDS-5104); however, the same technique can be applied to data acquired with a fast digitizer which would result in significantly shorter measurement times.

6. ACKNOWLEDGMENT

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7. REFERENCES

1. D. Reilly, N. Enssling, H. Smith, and S. Kreiner, *Passive Nondestructive Assay of Nuclear Materials*, NUREG/CR-5550, LA-UR-90-732, 1991.
2. G. F. Knoll, *Radiation Detection and Measurement*, Third Edition, John Wiley & Sons, Inc., New York, 555–565 (2000).
3. J. T. Mihalczo, J. A. Mullens, J. K. Mattingly and T. E. Valentine, "Physical Description of Nuclear Materials Identification System (NMIS) Signatures," *Nucl. Instr. And Meth. A*, 450, 531–555 (2000).
4. J. A. Mullens, J. S. Neal, P. A. Hausladen, S. A. Pozzi, and J. T. Mihalczo, "Fast Coincidence Counting with Active Inspection Systems," *Nucl. Instr. and Meth. B*, 241, 804–809 (2005).
5. M. Flaska and S. A. Pozzi, *Optimization of an Offline Pulse Shape Discrimination Technique for the Liquid Scintillator BC-501A*, ORNL/TM-2006/120, Oak Ridge National Laboratory, Oak Ridge, Tennessee (2006).
6. M. Flaska and S. A. Pozzi, "Identification of Shielded Neutron Sources with the Liquid Scintillator BC-501A Using a Digital Pulse Shape Discrimination Method," *Nucl. Instr. and Meth. A*, 577, 654–663 (2007).
7. S. A. Pozzi, E. Padovani, and M. Marseguerra, "MCNP-PoliMi: A Monte Carlo Code for Correlation Measurements," *Nucl. Instr. and Meth. A,* 513, 550–558 (2003).
8. S. A. Pozzi, *Recent Developments in the MCNP-PoliMi Post-Processing Code*, ORNL/TM-2004/299, Oak Ridge National Laboratory, Oak Ridge, Tennessee (2004).

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