USE OF THE MCNP-POLIMI CODE FOR THE EVALUATION OF CROSS TALK EVENTS IN LARGE SCINTILLATION DETECTORS

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ABSTRACT

Cross talk effects are important in physics experiments that make use of adjacent non-capture detectors. This paper presents the use of the MCNP-PoliMi code and its postprocessor to evaluate the effect of cross-talk among neighboring cells in a liquid scintillating detector array, and between two detector arrays separated by a distance of 50 cm. Cross talk occurs when the same particle registers a pulse in two or more neighboring cells. In time-dependent coincidence measurements with fissile material, the occurrence of cross-talk events is undesirable because it generates correlated events that are unrelated to the spontaneous and induced fission events that are to be measured. A technique to simulate and evaluate cross-talk effects is presented.

The capability of the MCNP-PoliMi code to track particles scattering between adjacent detectors can be applied to other experiments in which detector arrays are used. Although cross talk between adjacent detectors is significant, that between detectors placed on opposite sides of a container is less than 1%, and therefore not important.

1. INTRODUCTION

Cross talk effects are important in physics experiments that make use of adjacent non-capture detectors. Large liquid scintillation detectors are used in passive nuclear safeguards experiments that rely on the measurement of correlated particles from fission. Recently, detectors having dimensions 25 by 25 by 8.2 cm have been acquired at ORNL and are being evaluated for the experiments. The use of large detectors is desirable to increase the absolute counting efficiency in these measurements. Each detector is coupled to one photomultiplier tube. Four such detectors are placed in a 2 by 2 array, having total dimensions 50 by 50 by 8.2 cm. These large detector arrays are under evaluation for the measurement of containerized plutonium objects. In the experiment, two such arrays are placed facing each other, and the plutonium object is placed in the center. The technique is based on the measurement of correlated neutrons and gamma rays from the spontaneous and induced fission occurring inside the fissile sample [1].

This paper describes a technique, based on the use of the MCNP-PoliMi code, aimed at evaluating the effect of cross-talk between neighboring cells in detector arrays. Cross-talk occurs when the same particle registers a pulse in two or more neighboring cells [2]. In the present analysis, the effect of cross talk for an array of liquid scintillators is evaluated. For such detectors, the occurrence of cross talk events is undesirable, because it gives rise to a correlated signal that is not directly related to the signal from fission occurring in the fissile assembly. The evaluation of cross talk is validated by comparisons with experimental data.

2. CROSS-TALK BETWEEN CELLS OF A DETECTOR ARRAY

The liquid scintillator considered here is composed of four detector cells. Each cell has dimensions 25 by 25 by 8.2 cm, so the detector array has dimensions 50 by 50 by 8.2 cm, as shown in Figure 1. In the experiment, each cell is attached to a separate photomultiplier tube.

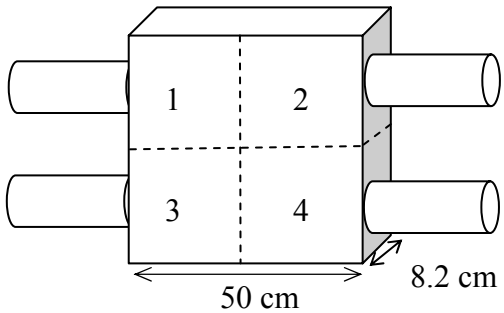

Figure 1. Sketch of detector geometry showing cells 1 through 4.

The simulation aimed at evaluating the neutron and gamma ray cross-talk between cells. A Cf-252 spontaneous fission source was placed at a distance of 25 cm from the center of the face of the detector. The simulations were performed with the MCNP-PoliMi code [3], which provides detailed information on the interactions of neutrons and photons within the cells that make up the detector. The output of the MCNP-PoliMi code was processed with a post-processing code that takes into account the light output at each particle interaction inside the liquid scintillator [4]. The detection light output threshold was set to 130 keVee (keV electron equivalent), which corresponds to a deposited energy of approximately 700 keV for the neutrons, and 130 keV for the gamma rays.
In this configuration, we first consider the probability of two detector cells giving a count, compared to that of just one cell giving a count. The simulation showed that for approximately 10 counts occurring in any one of the cells, there is one occurrence of two counts in separate cells. The result is reported in Table 1.

Table 1. Total counts in cells 1-4 and total counts occurring in two cells

Total counts in cells 1-4	Total pairs of counts
484,000	48,636

Each pair of counts occurring in the cells that constitute the detector is given by two distinct particles from the spontaneous fission of Cf-252, or by a cross-talk event. We will refer to the former instance as a “true” coincidence, and to the latter as a “cross-talk” coincidence.
The amount of cross-talk coincidences occurring in two neighboring cells can be determined by considering the cross-correlation function of the signals from the two cells. The MCNP-PoliMi simulation of the cross-correlation function of the signal from the two neighboring cells 2 and 4 is

shown in Figure 2. The total correlation (given by true coincidences and cross-talk coincidences) is shown with the solid line. In terms of particle types, the possible pairs that make up the correlation are: neutron-neutron, photon-photon, neutron-photon, and photon-neutron. The contribution of each pair to the total cross-correlation is also shown in Figure 2.

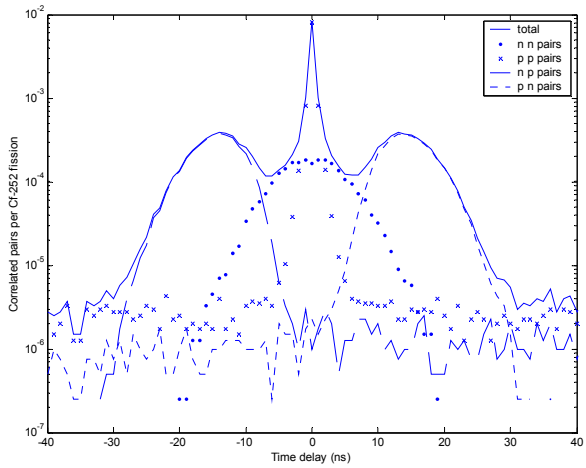

Figure 2. Cross-correlation between cells 2 and 4. Total is signature subdivided into neutron-neutron, photon-photon, neutron-photon, and photon-neutron pairs.

The cross-correlation function of the signals from cells 2 and 4 can be subdivided into true coincidences and cross-talk coincidences by using a feature of the MCNP-PoliMi code and its post-processor. In particular, the data output of the MCNP-PoliMi code contains a particle identifier that can be used to determine if a pair of detections were given by the same particle, or by two distinct particles. The result is shown in Figure 3.

At time lag equal zero, the photon cross-talk events constitute approximately 1/5 of the photon true events, whereas the neutron cross-talk events constitute approximately 1/6 of the neutron true events. Note the dip in the neutron-neutron cross-talk events at time lag equal to zero. On average, it takes a few ns for the neutron to travel from one detector to the adjacent one. Conversely, photon-photon cross-talk events occur with small time delays.

Figure 4 shows the cross-correlation between cells 1 and 4, which do not have a common side. As it can be seen, the cross-talk probability for this case is considerably smaller than the cross-talk probability for the case of neighboring cells. The cross-talk pairs are approximately 13% of the total in the case of neighboring cells, and only 2% of the total in the case of non-neighboring cells.

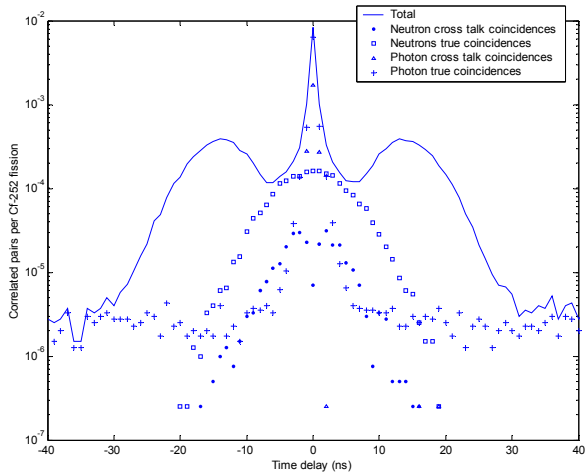

Figure 3. Cross-correlation function between detections in cells 2 and 4. Neutron-neutron and photon-photon contributions are subdivided into true coincidences and cross-talk coincidences.

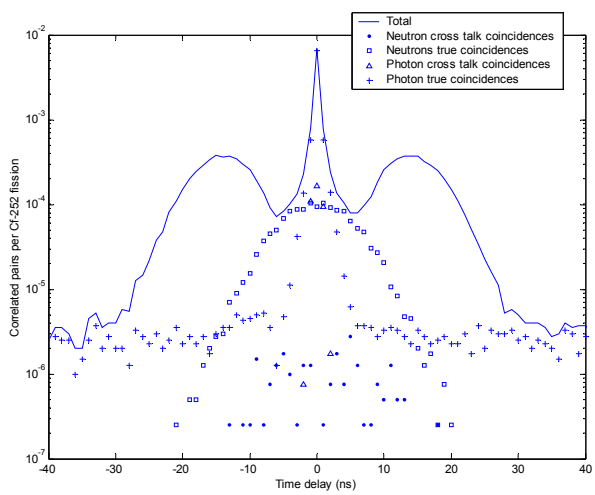

Figure 4. Cross-correlation function between detections in cells 1 and 4. Neutron-neutron and photon-photon contributions are subdivided into true coincidences and cross-talk coincidences.

Figure 5 shows the cross-correlation function between the signals from cells 2 and 4 for a Pu-240 spontaneous fission source placed at 25 cm from the center of the face of the detector. On average, each Pu-240 spontaneous fission emits 2.15 neutrons and 6.5 photons. This multiplicity is considerably lower than that of Cf-252. It is therefore to be expected that the cross-talk coincidences relative to true coincidences will be greater for Pu-240 than for Cf-252. For this configuration, the number of cross-talk coincidences was approximately 18.3% of the total coincidences in the case of neighboring cells, and approximately 3.4% in the case of non-neighboring cells.

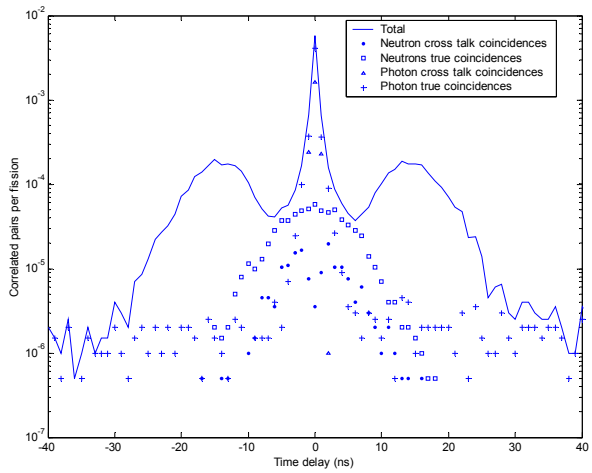

Figure 5. Cross-correlation function between detections in cells 2 and 4, for a Pu-240 spontaneous fission source. Neutron-neutron and photon-photon contributions are subdivided into true coincidences and cross-talk coincidences.

3. EFFECT OF CROSS-TALK ON BETWEEN-DETECTORS CORRELATION FUNCTIONS

Two simulations were performed to evaluate the effect of cross-talk in the passive measurement configuration for the assay of plutonium objects. Figure 6 shows a schematic view of the experimental setup. In this configuration, two detectors were placed facing each other and the plutonium object was placed in the center at a distance of 25 cm (radius of the AT-400 container) from each of the detector assemblies. The detectors size was 50 by 50 by 8.2 cm. Detector number 1 was a single cell. Detector 2 was subdivided into four cells of equal size, similarly to the setup considered in Section 2. The data output of the simulations was post-processed twice: the first time all the detections of detector 2 were considered in computing the cross-correlation function R_{12}, and the second time the algorithm eliminated all the counts that were due to cross talk between the cells that constitute detector 2.

The result is shown in Figure 7. The cross-correlation function R_{12} obtained by considering all the pulses in detector 2 is shown with the solid line. The dots refer to the case in which the detector 2 pulses were eliminated if they were due to cross-talk between cells.

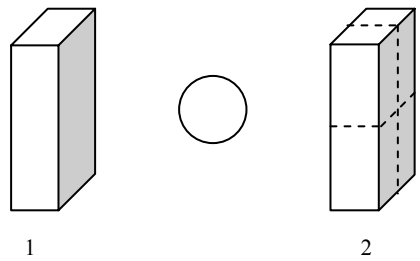

Figure 6. Schematic drawing of the detector assembly for the passive measurements on plutonium object. Detectors are numbered 1 and 2. (Not to scale).

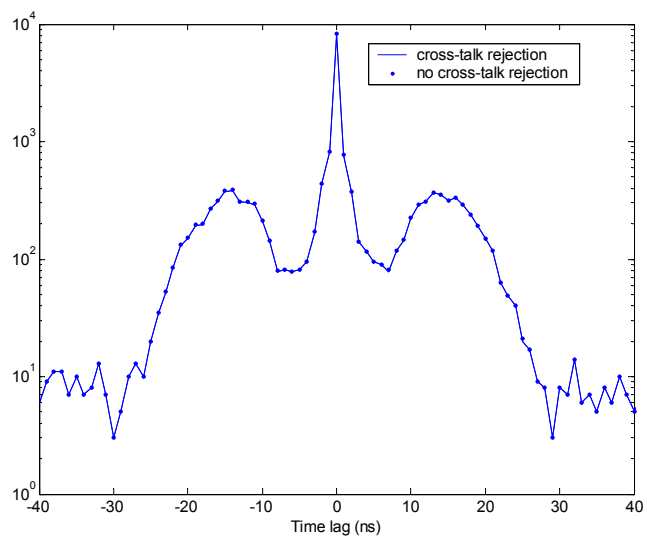

Figure 7. Cross-correlation function between detections in detectors 1 and 2. No cross-talk rejection is shown with dots, whereas cross-talk rejection is shown with the solid line.

As it can be seen, the effect of cross-talk is very small when considering the cross-correlation between detectors 1 and 2 (R_{12}). The number of rejected pulses due to cross-talk is approximately 225 every 20,000 pairs (~1.1%).

4. EXPERIMENTAL RESULTS

A series of experiments with the Nuclear Materials Identification System were performed using 4 large liquid scintillators in the configuration shown in Figure 1. A Cf-252 spontaneous fission source was placed at varying distances from the center of the face of the detector. The resulting cross-correlation functions for two adjacent detectors are shown in Figure 8.

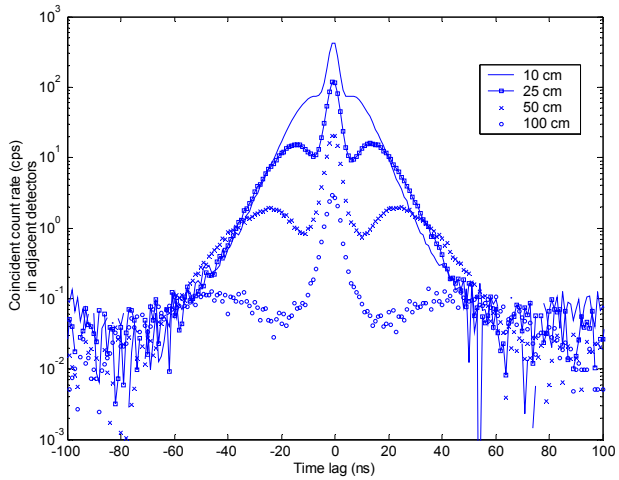

Figure 8. Experimental cross-correlation function between adjacent detectors of Figure 1, as a function of the distance of the Cf-252 source from the front face of the detectors.

Figure 9 shows the ratio of the number of counts in the gamma-gamma peak (time lags -5 to +5 ns) for adjacent detectors to the number of counts in the gamma-gamma peak for non-adjacent detectors, as a function of the distance between the Cf-252 source and the detector face. As expected, gamma-gamma cross talk coincidences when compared to gamma-gamma true coincidences increase with increasing distance.

The experimental data can be fit to a quadratic function of the distance between the source and the detectors

$$r = 7.9 \cdot 10^{-5} d^2 + 0.016d + 0.93 \tag{1}$$

where r is the ratio of the counts and d is the distance between the source and the detectors. The fit is shown in Figure 9.

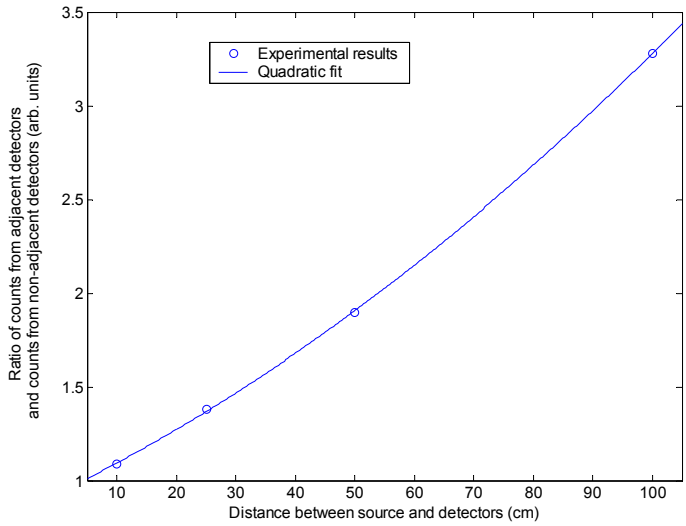

Figure 9. Ratio of number of counts in the gamma-gamma peak for adjacent detectors to number of counts in the gamma-gamma peak for non-adjacent detectors, as a function of the distance between the Cf-252 source and the detector face.

5. CONCLUSIONS

This work presented an analysis performed with the MCNP-PoliMi code to evaluate the effect of cross-talk between four cells that make up a liquid scintillating assembly. The setup consisted in a Cf-252 source placed at a 20 cm distance from the center of the front face of the detector. The results showed that the cross-talk between neighboring cells is considerable (approximately 13% of the total), whereas the cross-talk between non-neighboring cells was approximately 2% of the total. Cross-talk events between cells of the array were given in most part by photon scatterings.

When correlations between assemblies of four detectors are considered, the effect of cross-talk between assemblies is small. The simulations showed that approximately 1% of the correlated pairs were due to cross-talk between the cells, and these should not affect the interpretation of time-dependent coincidence measurements with arrays of such detectors on opposite sides of a container.

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