FISSION SOURCE LOCATION FROM PASSIVE NMIS THIRD ORDER TIME CORRELATION MEASUREMENTS

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ABSTRACT

The measurements presented in this paper show how passive time-correlation measurements with three scintillation detectors can be used to locate the position of a spontaneous fission source within a plane. The measurements allow the prediction of the measurement time for various intensity fission sources and various sized detectors at fixed locations within a room. The method relies on the simultaneous detection of two gamma rays from fission to define the time of fission, and the time of flight of neutrons to the third detector to define the distance to the source. Three detectors are required to locate fission sources in a plane. If the source is not located within the plane of three detectors, a fourth detector would be required. In these measurements, Cf-252 was used as a surrogate for plutonium.

INTRODUCTION

In the past, passive third order time-correlation measurements using the nuclear materials identification system (NMIS) [1] with three 9.5 x 9.5 x 10.2 cm plastic scintillators for rings of fission sources with diameter up to 50 cm have been investigated (the diameter of an AT400 container) [2-3]. The measurements showed that NMIS could be used to determine the diameter of the source rings to within a few millimeters. Other efforts were aimed at determining the shape of plutonium metal samples using a similar technique [4]. In this paper, we describe a method to determine the position of a spontaneous fission source within a circle having diameter 100 cm. A Cf-252 source is used as a surrogate for Pu-240 sources.

EXPERIMENT

In the present experiment, three liquid scintillators, having dimensions 25 by 25 by 8 cm, were placed on a circle having diameter 100 cm. In any practical application to locate a fission source, plastic scintillators would be used. Liquid scintillators were used because of availability. A schematic diagram of the experimental setup is shown in Figure 1. The NMIS measurement was performed using four channels: channel 1 was given by the Cf-252 source, placed inside an ionization chamber, and channels 2 through 4 were given by the three scintillators. The instrumented source provided the trigger pulse for the active measurements. The passive measurements were performed with only the three detector channels. The source was placed at varying distances from detector 2: 0, 12.5, 25, and 50 cm.

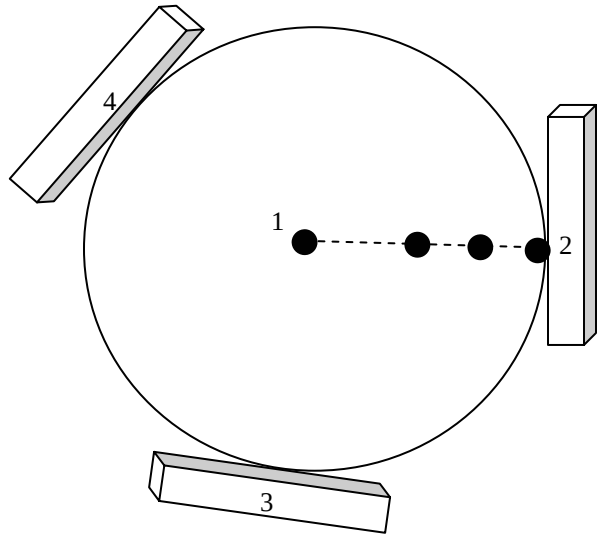

Figure 1. Schematic diagram of experimental setup showing four source positions.

The NMIS processor allows the measurement of time correlations between channels with 1 ns time resolution. Covariance and bicovariance functions are among the signatures that can be measured.
The distribution of two-way coincidence between pairs of counts over the time delay between them is given by

$$R_{xy}(\tau_{xy}) = E\left[x(t_x)y(t_y)\right] - \bar{x}\cdot\bar{y}$$

where $\tau_{xy} = t_y - t_x$. R_{xy} is known as the covariance between the two sequences of counts $x(t)$ and $y(t)$. The product of the means, $\bar{x}\cdot\bar{y}$, yields the rate of accidental coincidence between the two detectors. The covariance is thus the distribution of real two-way coincidences.
The extension of the covariance function to three sequences of counts yields the bicovariance function, or three-way coincidence:

$$R_{xyz}(\tau_{xy},\tau_{xz}) = E\left[x(t_x)y(t_y)z(t_z)\right] - \bar{x}\cdot R_{yz}(\tau_{xz}-\tau_{xy}) - \bar{y}\cdot R_{xz}(\tau_{xz}) - \bar{z}\cdot R_{xy}(\tau_{xy}) - \bar{x}\cdot\bar{y}\cdot\bar{z}$$

This distribution is a function of two delays, $\tau_{xy} = t_y - t_x$ and $\tau_{xz} = t_z - t_x$. It follows that the bicovariance function can be displayed as a three-dimensional surface. A

contribution to the bicovariance function occurs when detections in all three detectors are registered within a given time window.

The measurement is based on the fact that a spontaneous fission source emits multiple gamma rays and neutrons. Gamma rays travel to the detectors at the speed of light, whereas neutrons travel at a speed that is related to their energy. The average multiplicity of gamma rays is greater than the average multiplicity of neutrons for most fission sources. Moreover, the scintillator detection efficiency for neutrons is comparable to that of gamma rays in the energy range of interest. It follows that the triplets gamma-gamma-neutron and gamma-gamma-gamma are the most frequently occurring among all the possible triplets (other possible triplets are gamma-neutron-neutron and neutron-neutron-neutron).

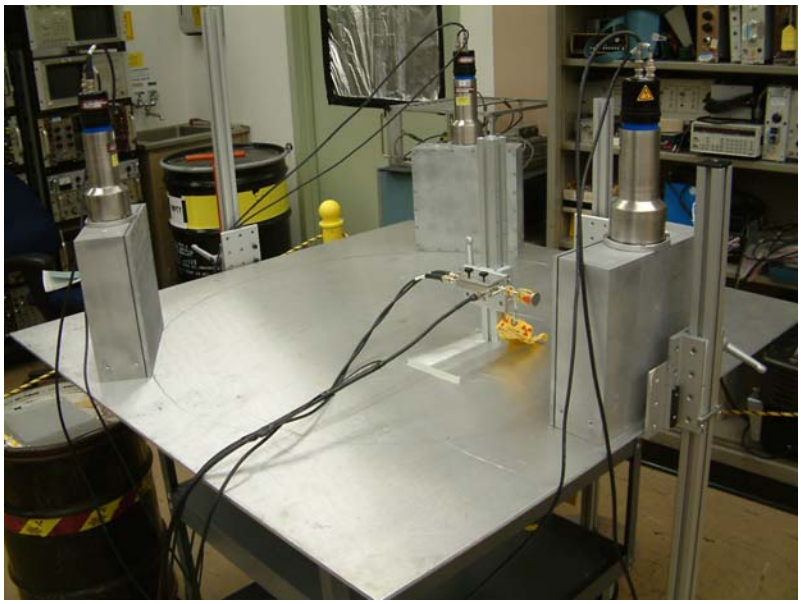

Figure 2. Photograph of experimental setup showing three scintillators and Cf-252 source.

RESULTS

The experiment was performed for the source at four positions inside the area shown in Figure 1. A photograph of the experimental setup is shown in Figure 2. The distance from detector 2 was equal to 0, 12.5, 25, and 50 cm. Figure 3 shows the measured bicovariance function for the source position in the center of the setup. The two axes represent the time delay $\tau_{xy} = t_y - t_x$ and $\tau_{xz} = t_z - t_x$, where t_x, t_y, and t_z are the times of detection registered by detectors 4, 3, and 2, respectively. There are four regions in the measured bicovariance. The peak centered at time lags 0 ns is given by gamma-gamma-gamma triplets: the gamma rays reach each detector in approximately 1.6 ns, and the time difference is essentially zero. The three symmetric ridges are given by combinations of gamma-gamma-neutron triplets. The length of the ridges is related to the neutron time of flight: the neutrons take 15 to 35 ns to reach the detector when the source is placed at 50

cm from each detector. Figure 4 shows the relationship between time of flight and neutron energy for a 50 cm flight path. Figures 5 through 7 show the measured bicovariance functions for source position equal to 25, 12.5, and 0 cm, respectively. The measurement time for each of these measurements was approximately 12 hours.

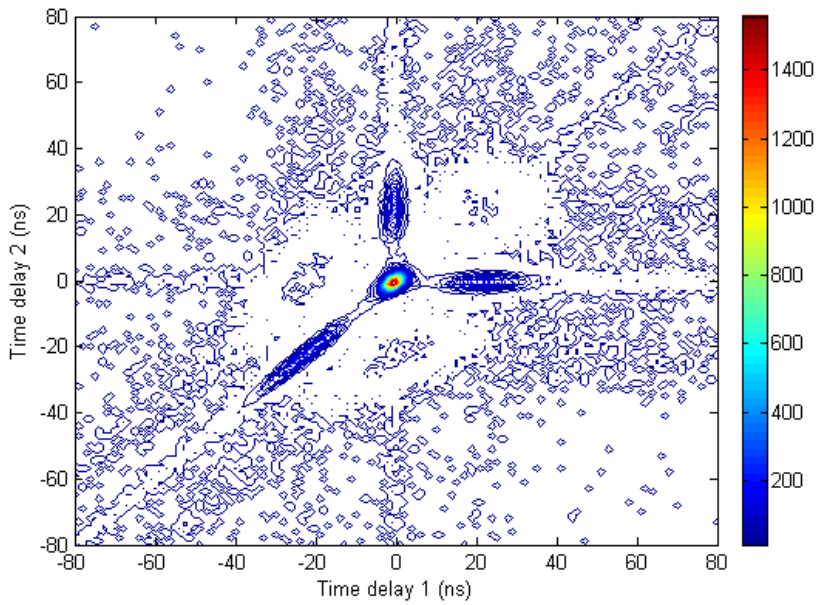

Figure 3. Three detector bicovariance function for source positioned at 50 cm from detector 2.

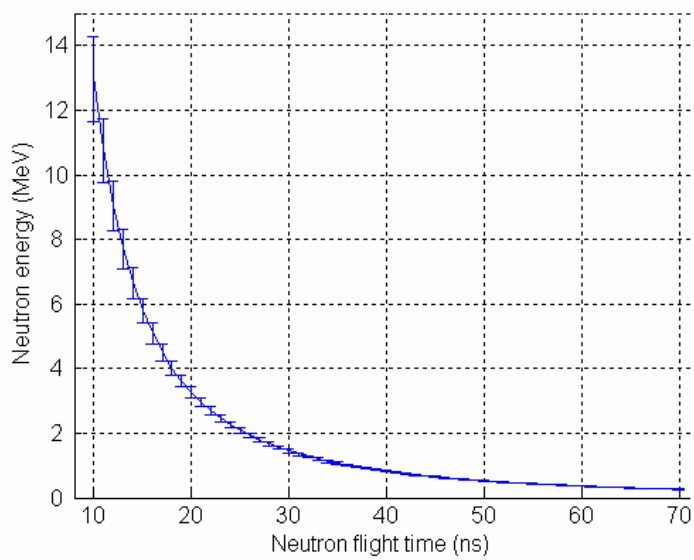

Figure 4. Relationship between neutron time of flight (ns) and energy (MeV). Error bars show error in the energy determination when the time of flight is known within ±1 ns

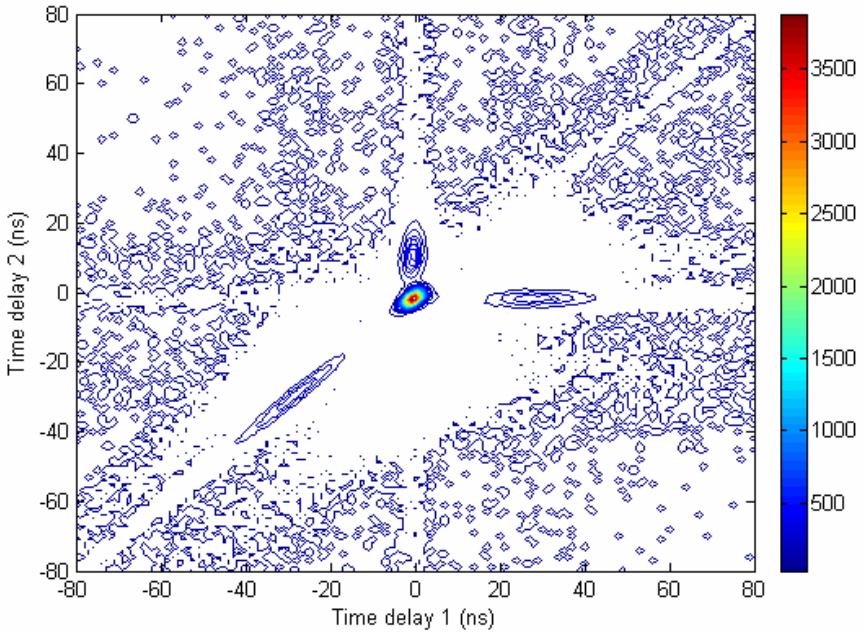

Figure 5. Three detector bicovariance function for source positioned at 25 cm from detector 2.

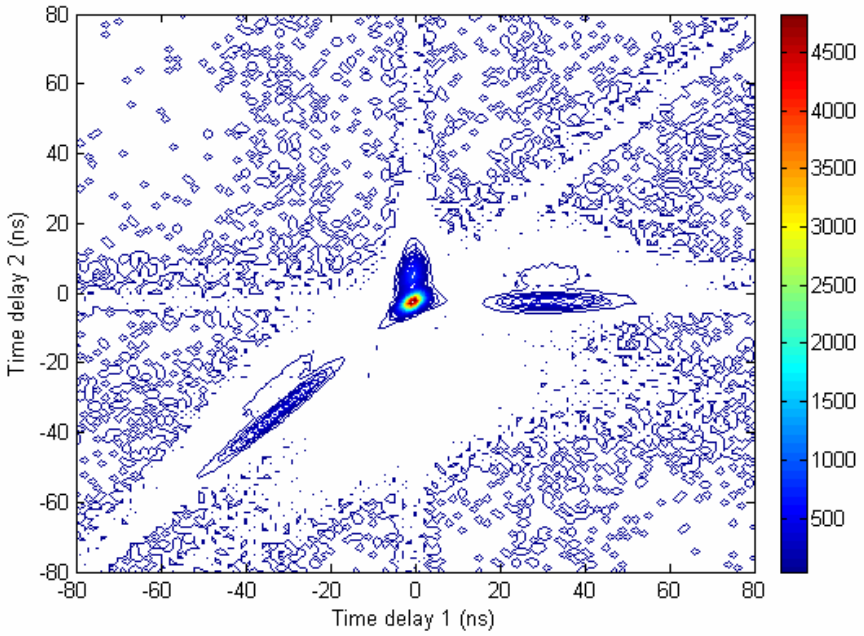

Figure 6. Three detector bicovariance function for source positioned at 12.5 cm from detector 2.

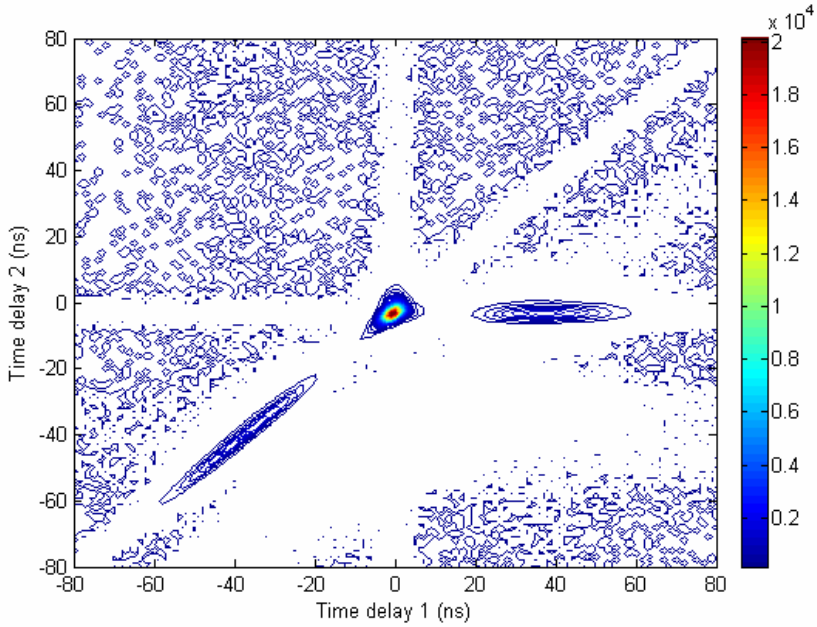

Figure 7. Three detector bicovariance function for source positioned in contact with detector 2.

ANALYSIS

The aim of the analysis was to determine the source position on the basis of the measurement of the detectors bicovariance functions. The integrals of the bicovariance functions measured at the four source positions are shown in Figure 8. The integral shown is performed along the axis labeled 'Time delay 1' in Figures 5 through 7.

Figure 9 shows the average time lag $\bar{\tau}_n$ of the neutron peak occurring at positive time lags in Figure 8 as a function of source position. The average time lag $\bar{\tau}_n$ is defined as the average in the interval ±2 ns about the maximum of the neutron peak.

The measured time lag $\bar{\tau}_n$ can be used to find the distance d with the following expression

$$d = \left(\bar{\tau}_n - a_2\right) / a_1 \qquad (1)$$

where d is the distance of the source to detector 2 and the values of coefficients a_1 and a_2 are given in Table 1.

Table 1. Coefficients of Equations (1) and (2).

	Coefficient in Equation (1)	Coefficient in Equation (2)
a_1	0.44 ns/cm	-0.0029 ns/cm^2
a_2	0.46 ns	0.61 ns/cm
a_3	--	-1 ns

The error in the prediction of the source position by using Equation (1) is less than 3 cm in all four cases considered.
A quadratic fit leads to the following expression for the distance:

$$\bar{\tau}_n = a_1 d^2 + a_2 d + a_3 \qquad (2)$$

where d is the distance of the source to detector 2 in cm and the values of coefficients a_1 , a_2 and a_2 are given in Table 1. Using Equation (2) the prediction of the distance of the source to detector 2 can be made with errors between 3 and 10 mm. It is possible that more sophisticated analyses will be able to further improve the distance prediction.

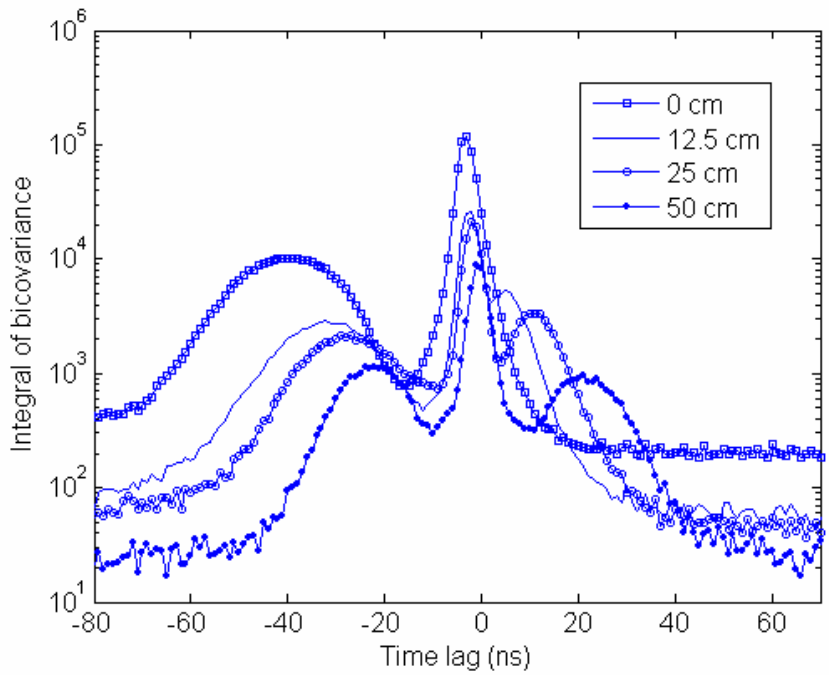

Figure 8. Integral of bicovariance function for different source positions with respect to detector 2.

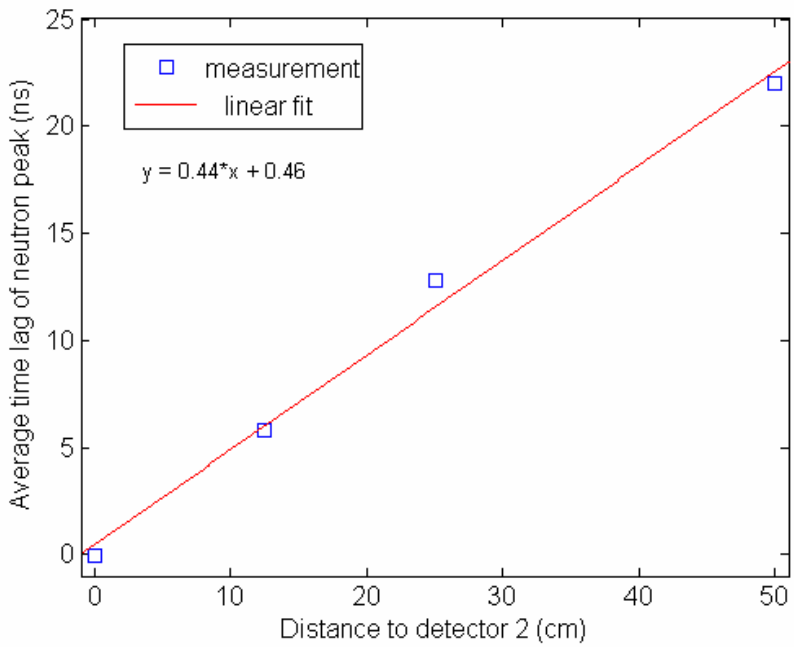

Figure 9. Average time lag of neutron peak as a function of source position with respect to detector 2.

CONCLUSIONS

We have performed preliminary measurements using three scintillators to determine the position of a Cf-252 spontaneous fission source within a circle of radius 50 cm. Cf-252 was used as a surrogate for plutonium. The proposed method is based on a simple analysis of the measured three-detector bicovariance function. We showed that the source position could be determined with errors less than 1 cm.

REFERENCES

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