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CALIBRATION OF SMALL PLASTIC SCINTILLATORS FOR IMAGING APPLICATIONS

Sara A. Pozzi, James A. Mullens, and John T. Mihalczo

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ORNL-27 (4-00)

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ORNL/TM-2004/298

Nuclear Science and Technology Division

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Date published: December 2004

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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Calibration of Small Plastic Scintillators for Imaging Applications

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ABSTRACT

This report presents the results of measurements and simulations performed with 12 small plastic scintillation detectors manufactured by Scionix for imaging applications. The scintillator is equivalent to a Bicron BC-420 plastic scintillator. A gamma calibration is presented to determine the voltage to be applied on each detector to ensure uniform detector operation. Time of flight measurements performed with a Cf-252 source are also presented. Comparisons between experimental data and data from the Monte Carlo simulations show good agreement for time lags of 0 to 70 ns.

Calibration of small plastic scintillators for imaging applications

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1. Introduction

Twelve small plastic scintillation detectors manufactured by Scionix are being studied for imaging applications [1]. The active volume of the detectors is 2.54 ×2.54 ×15.0 cm. First, a gamma calibration was performed to determine the pulse heights as a function of voltage on each detector. Then, the voltages were set so that the detectors had a uniform response. Time of flight measurements using Cf-252 and four detector channels were performed to verify uniform detector operation. A comparison between these measurements and Monte Carlo simulations is also presented.

2. Gamma ray calibration

A Cs-137 source was used to acquire pulse heights for each detector for voltages varying from −700 to −900 V. The acquisition was performed with the fast digital scope Tektronix TDS 5104. The pulse shapes were acquired and stored for offline analysis. The measurement time for the acquisition of 1500 pulses was approximately 2 s. In the measurements, the gamma source was placed on top of the detector, approximately halfway along the length of the detector's active region.

A histogram of the pulse heights was computed offline, and the corresponding Compton edge was identified by selecting the half-height of the maximum value for pulse height distribution. Figure 1 shows the results of these measurements as a function of voltage for the 12 detectors. Table 1 gives the voltages for the 12 detectors corresponding to a Cs-137 Compton edge of 100 mV. In these measurements, the discriminator is traditionally set at one-third of the Cs-137 Compton edge value.

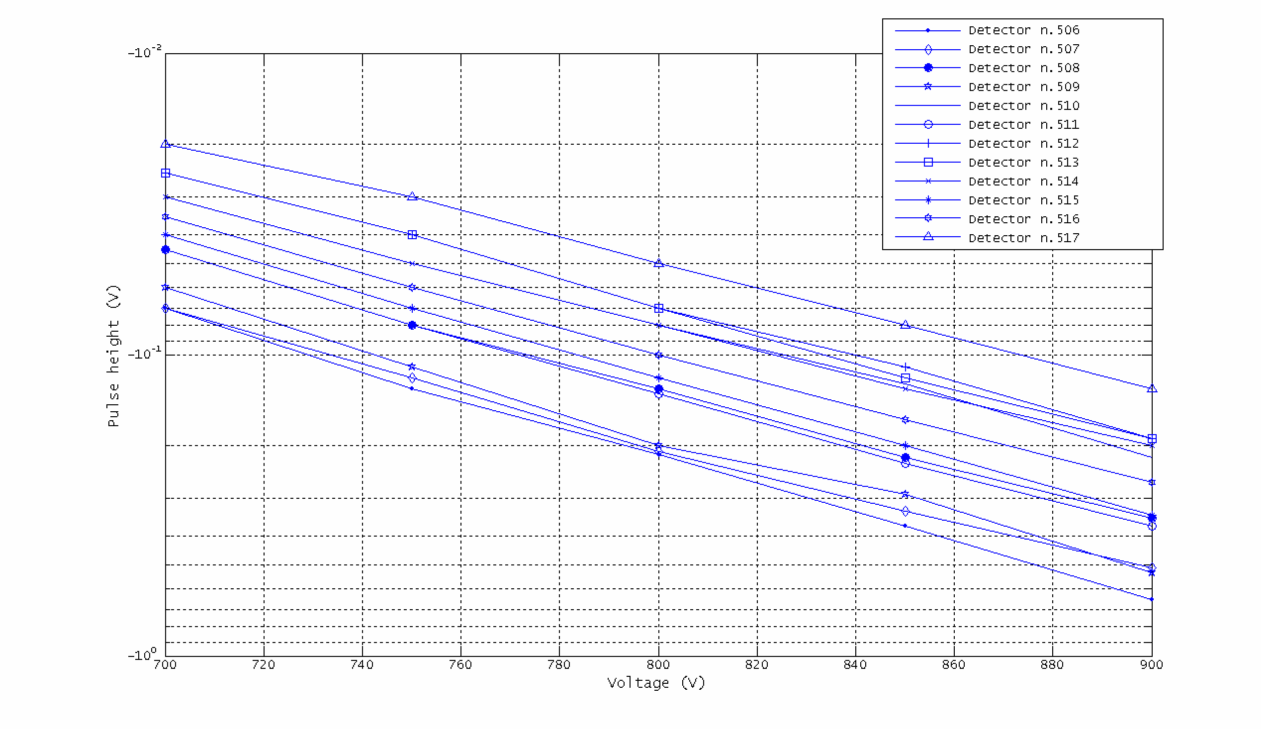

Fig. 1. Pulse height as a function of voltage for the Cs-137 Compton edge.

Table 1. Voltages corresponding to a 100-mV pulse height for Cs-137 Compton edge.

Detector serial number	Voltage (V)
506	-730
507	-735
508	-772
509	-743
510	-822
511	-772
512	-840
513	-832
514	-822
515	-785
516	-800
517	-875

Figure 2 shows the comparison of two pulse height distributions, corresponding to two different positions of the Cs-137 source on the detector. The pulse height distribution of Fig. 2(a) was obtained by placing the Cs-137 source on top of the detector, approximately halfway along the length of the detector's active region. The pulse height distribution of Fig. 2(b) was obtained by placing the source on the detector's front face. The data in Fig. 2 were taken with detector number 517 at −900 V. Visual inspection shows that the source positioning does not affect on pulse heights considerably.

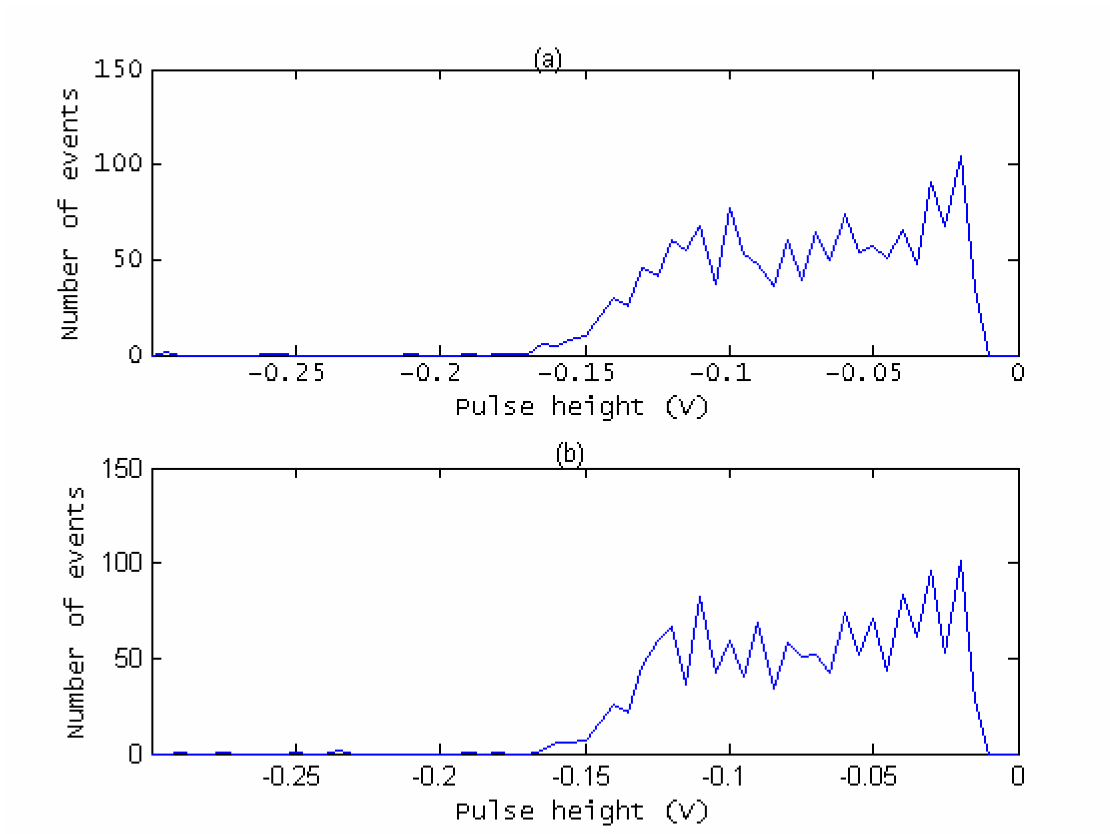

Fig. 2. Pulse height distributions for Cs-137 source placed on (a) detector top and (b) detector front.

3. Cf-252 time of flight measurements

Time of flight measurements were performed with the Nuclear Materials Identification System [2], using an instrumented Cf-252 source and four detector channels. The detectors were placed 100 cm from the Cf-252 source. The source-detector time of flight was acquired for four detectors at a time. The detectors were placed side by side on a metal cart, at a height of 89.5 cm from the floor, with a distance of 6 cm between detectors.

The detector voltages were adjusted according to the values given in Table 1. Using these voltages, a gamma ray energy deposition of 477 keV (the Cs-137 Compton edge) generates pulses with an amplitude of 100 mV. The CFD threshold on the detectors was set to one-third of the Cs-137 Compton edge—i.e., 33 mV. Because the gamma ray energy to light output response in scintillators is essentially linear, this threshold corresponds to a gamma energy deposition of approximately 159 keV. The source-detector time of flight was acquired with these experimental settings and is shown in Fig. 3 for four detectors (numbers 514 to 517).

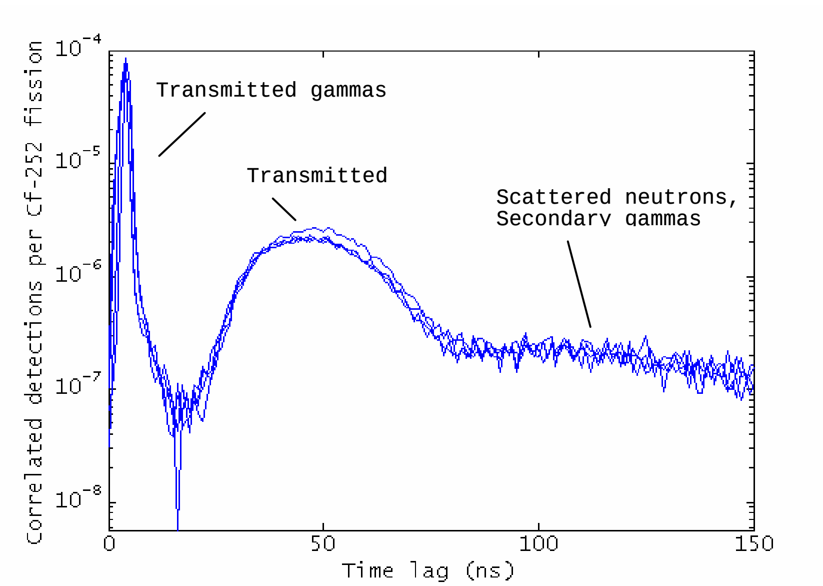

Fig. 3. Source-detector time of flight for detectors 514 to 517.

The source-detector time of flight shown in Fig. 4 was modeled using the MCNP-PoliMi code [3]. The parameters used in the post-processing code are given in Table 2. The light output threshold was determined using the calibration described in Section 2 and the considerations of the preceding paragraph. The neutron light output was measured for liquid and plastic scintillators in a previous study [4] and is

$$l = 0.0364 \cdot E_n^2 + 0.125 E_n \quad (1)$$

for the plastic scintillator BC-420, where l is the light output in MeVee, and E_n is the energy deposited by the neutron in a collision with hydrogen (MeV).

The neutron energy threshold for the settings used in the experiments can thus be determined to be approximately 1 MeV. In this study, the detector dead time was set to 0 ns. This can be justified by considering the absence of multiplication (no fissile material is present) and the small dimensions of the scintillators. It is therefore rare that more than one particle from each Cf-252 fission reaches a detector.

Table 2. Parameters used in the post-processing code

Parameter	Value
Dead time	0 ns
Pulse generation time	10 ns
Neutron energy threshold	0.99 MeV
Light output threshold	0.1590 MeVee

Figure 4 shows the result of one Monte Carlo simulation, for a source-detector correlation. The model included the metal cart on which the detectors were placed, the floor, two lab benches on either side of the cart, the detector PMT tube, and the aluminum housing of the detector. The number of Cf-252 source events was 200E6, and the run time was approximately 19 h. Figure 4 also shows the time of flight signature subdivided into its neutron and photon components.

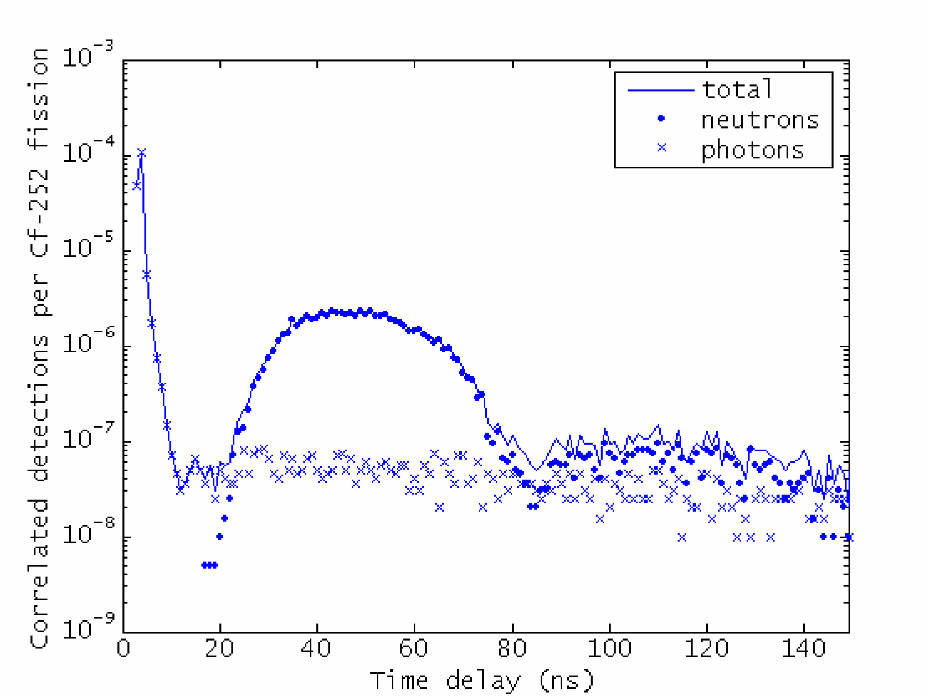

Fig. 4. Simulated time of flight distribution, with neutron and photon contributions shown.

Figure 5 shows a comparison of the Monte Carlo simulation and the experiment performed with NMIS. Both simulation and experiment were normalized to the total number of Cf-252 fission events. The result shown in Figure 6 is for one of the detectors placed at the beginning of the four-detector array. The agreement is very good in the gamma peak and in the neutron peak, up to time lags of approximately 70 ns. The “tail” in the measurement is consistently greater than that predicted by the Monte Carlo simulation. A possible explanation of this discrepancy is that the measurement was performed in a room that contained many scattering elements that were not modeled in the simulation. The percentage error of the MCNP-PoliMi prediction of the gamma and neutron peaks is given in Table 3.

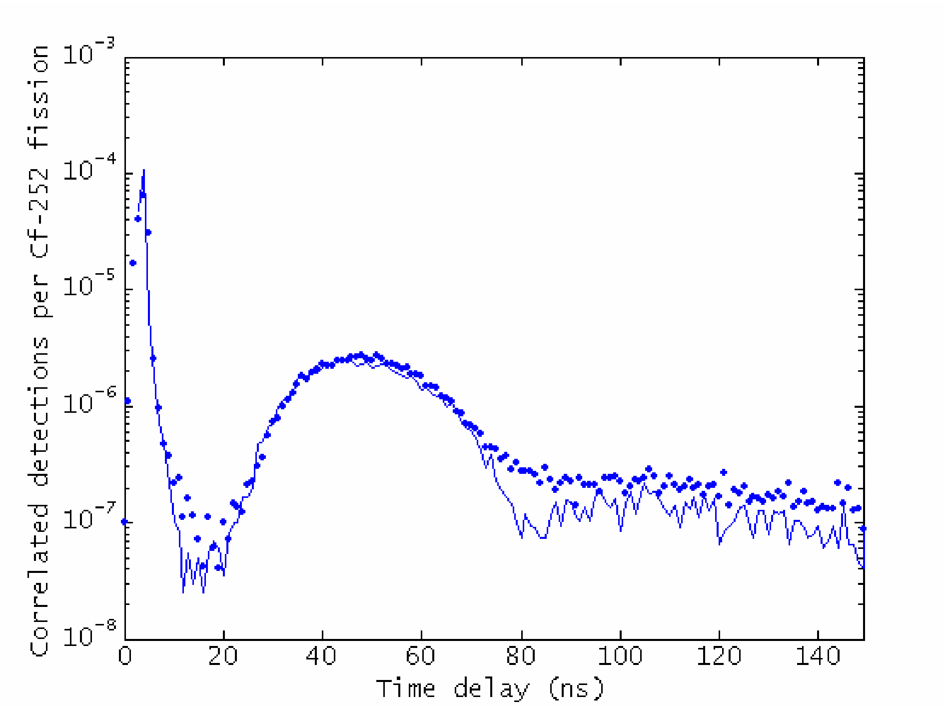

Fig. 5. Comparison between Monte Carlo simulation and measurement for source-detector time of flight.

Table 3. Percent error in the MCNP-PoliMi simulation of measurements: areas of neutron and gamma peaks (detector 1)

Parameter	Percent error
Gamma peak	+0.6
Neutron peak	−6.2

4. Conclusions

In this report, we presented the results of measurements performed on 12 plastic scintillators that will be used for imaging applications. A gamma ray calibration was performed using a Cs-137 source. This calibration allowed us to determine the operating voltages for the 12 detectors, which varied from −730 to −875 V. Time of flight measurements performed with an instrumented Cf-252 source were also performed. Monte Carlo simulations of these measurements showed good agreements in the 0 to 70 ns time lag. The error in the prediction of the gamma peak was lower than 0.6% and the error in the neutron peak approximately −6%. The ability to predict the results of these measurements gives confidence in the simulations that are being used to plan and analyze future measurements.

5. References

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