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MONTE CARLO MODELS OF NEUTRON DETECTION WITH ORGANIC SCINTILLATORS

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ABSTRACT

We describe the use of the MCNP-PoliMi code to simulate, on an event-by-event basis, the detection of neutrons by organic scintillators. The code keeps track of single neutron interactions, including the collision nucleus, the energy deposited, and the time distribution of collision events. We show that the total pulse-height response is given by the sum of many possible neutron histories, each composed of a certain number of neutron scatterings on hydrogen and/or on carbon. The simulated pulse-height distributions are compared to experimental data acquired using various neutron sources. Simulations and measurements of neutron pulse-height distributions are essential for neutron spectrum unfolding procedures. This work has applications in the areas of nuclear nonproliferation and homeland security.

Key Words: MCNP, MCNP-PoliMi, pulse-height distribution, neutron detection, organic scintillators, unfolding

1. INTRODUCTION

Organic scintillators, in both liquid and plastic form, are commonly used in systems for the detection of nuclear materials in nonproliferation and homeland security applications. Neutron detection in this type of detector occurs by multiple scatterings on hydrogen (H) and carbon (C), the main constituents of the scintillator. The analysis of the statistics of neutron collisions is important to understand the mechanism of neutron detection, and to perform subsequent unfolding procedures aimed at determining the incident neutron spectrum.

We describe the Monte Carlo simulation of neutron interactions within the detector material for various detector sizes and various incident neutron energies. The simulations are performed using the code MCNP-PoliMi [1], which allows event-resolved predictions of the interactions of neutrons with the detector material. A subsequent post-processing of the simulation results allows us to determine the number of elastic collisions that the neutrons undergo with the nuclei of H and C atoms, together with the amount of energy that is deposited as a function of the number of collisions. This paper also describes the light output generated by proton recoils in H and C nuclei as a result of collisions with energetic neutrons from monoenergetic and continuous sources. The total detector efficiency is determined as a function of the incident neutron energy. When the neutron energy exceeds 4.4 MeV, inelastic scattering of neutrons from C nuclei can occur, generating subsequent gamma rays. This effect is taken into account, and its contributions to the light output are discussed. Finally, simulation results are compared to experimental data acquired using neutron sources, such as Cf-252 and Am/Be.

2. MONTE CARLO SIMULATIONS

The Monte Carlo analysis allows us to calculate not only the average pulse height generated in the detector as a function of the *n* and *m* scatterings on H and C, respectively, but also the entire pulse-height distribution. One such distribution is shown in Fig. 1 for 1-MeV incident neutrons. Figure 1(a) shows the total pulse-height distribution, and Fig. 1 (b) shows the contributions to the total distribution from histories comprising *n* and *m* scatterings on H and C, respectively, with $n = 1$, 2, and 3 and $m = 0$ and 1. Figure 1(b) shows that multiple scatterings on H contribute to increasing the detector response at higher pulse heights; whereas, scatterings on C contribute to an increase in the detector response at lower pulse heights. The distribution labeled "Others" represents the cumulative contribution of all other combinations of *n* and *m* scatterings not shown separately.

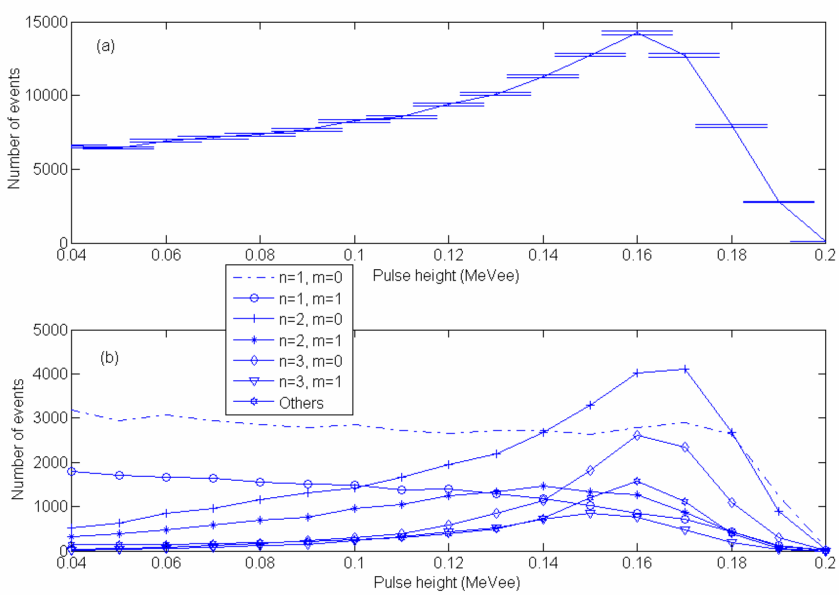

Figure. 1 Pulse-height distributions for 1-MeV incident neutrons. (a) Total pulse-height distribution is shown with error bars that represent statistical error. (b) Total pulse-height distribution is subdivided according to the total number of scatterings on H (*n* = 1, 2, and 3) and C (*m* = 0 and 1) in the neutron history. Error bars are not shown for clarity.

Figure 2 shows the simulated and measured neutron pulse-height distribution obtained using a Cf-252 source. The error in the Monte Carlo simulation was within the experimental error.

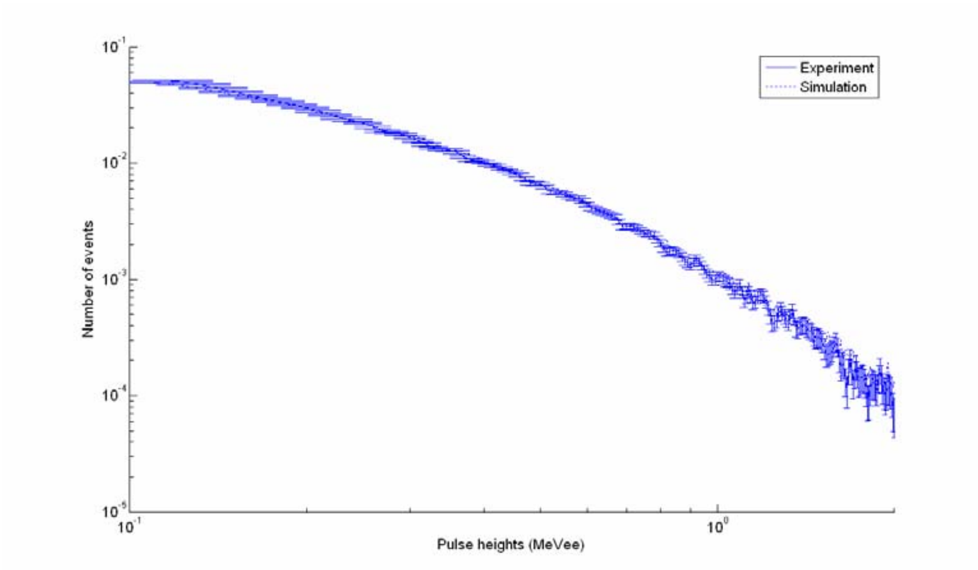

Figure 2. Pulse-height distributions for Cf-252 neutrons. Experimental data are shown with error bars; simulation is shown with a dotted line.

3. CONCLUSIONS

The statistics of neutron interactions within organic scintillation detectors is determined using a Monte Carlo approach based on the use of the MCNP-PoliMi code. The final paper will discuss the response of organic scintillators to neutron sources having varying energy spectra, such as Cf-252 and Am/Be. The simulated results will be compared with experimental data acquired in the laboratory.

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REFERENCES

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