Joint International Topical Meeting on Mathematics & Computation and Supercomputing in Nuclear Applications (M&C+SNA 2007)
Monterey, California, April 15-19, 2007, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2007)

PHOTONUCLEAR PHYSICS MODELS, SIMULATIONS, AND EXPERIMENTS FOR NUCLEAR NONPROLIFERATION

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ABSTRACT

This work illustrates a methodology based on photon interrogation and coincidence counting for determining the characteristics of fissile material. The feasibility of the proposed methods was demonstrated using the Monte Carlo–based MCNPX/MCNP-PoliMi code system capable of simulating the full statistics of the neutron and photon field generated by the photon interrogation of fissile and nonfissile materials with high-energy photons. These simulations were compared to the prompt time-of-flight data taken at the Idaho Accelerator Center (IAC) during and immediately after photon interrogation of a depleted uranium target. The results are found to be in very good agreement with the measured data for interrogation with 15-MeV endpoint bremsstrahlung photons at two different detector separation distances.

Key Words: MCNP; MCNP-PoliMi; Correlation measurement; Nuclear safeguards

1. INTRODUCTION

Recent efforts have focused on the development of new measurement systems for the identification of nuclear material enclosed in shielded containers having applications in the areas of nonproliferation and homeland security [1-3]. The detection of shielded

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highly enriched uranium is particularly challenging because uranium, in contrast to the even-numbered plutonium isotopes, has a very low spontaneous fission rate, making passive interrogation difficult. As a consequence, it becomes important to investigate active interrogation methods based on neutron or gamma-ray sources. Here, we propose a measurement system that is based on coincidence counting of neutrons and gamma rays from the photon interrogation of nuclear materials.

To determine the feasibility and sensitivity of such a measurement system, a Monte Carlo code system consisting of modified versions of the codes MCNPX and MCNP-PoliMi has been developed. The codes simulate the neutron and photon fields generated during the interrogation of fissile (and nonfissile) material with a high-energy photon source (of the order of 10 MeV). Photoatomic and photonuclear collisions are modeled and time-correlated detections and multiplicities are computed.

2. MONTE CARLO SIMULATIONS

Monte Carlo codes have been widely used to design and analyze measurements such as those considered here; however, when modeling the time-correlated events resulting from photon interrogation, the widely used Monte Carlo code, MCNPX, has some limitations. Specifically, when considering a single interaction, MCNPX deviates from physical reality and the particles resulting from photonuclear interactions are not modeled correctly on an event-by-event basis [4]. A modified version of MCNP4c called MCNP-PoliMi has been developed to simulate time-analysis quantities and include a correlation between individual neutron interactions and corresponding photon production [5].

2.1. Description of the MCNP-PoliMi Code System

MCNP-PoliMi is capable of running with all standard MCNP source types and includes definitions for several specific spontaneous fission sources. A photonuclear source file may also be generated using a modified version of MCNPX and read by MCNP-PoliMi. This source file is generated by simulating the interrogation of fissile material by the photon beam and recording relevant information on all photonuclear events, including photofission, (γ, n), and (γ, 2n) reactions. The information recorded to file includes the location and multiplicity of neutrons and gamma rays emitted by the photonuclear events. This source is read by MCNP-PoliMi, and the particles are transported through the system and into the detectors. The energy released during each collision in the detectors, the corresponding time, the incident particle type, and target nucleus are saved in a dedicated output file. A postprocessing code is then used to load the required data from this file and compute the detector-specific response.

2.2. Monte Carlo Model of Idaho Accelerator Center Experiments

Experimental data was acquired at the Idaho Accelerator Center (IAC) using a 15-MeV endpoint bremsstrahlung source and a depleted uranium target. The source diameter was assumed to be equal to that of the collimator. Time-of-flight measurements were made with two 2×2 inch, cylindrical plastic scintillation detectors. The detector, which was directly in line with the beam, was designated as the start detector; a lead-shielded stop detector was oriented 90° to the beam line. Pulses of source photons interact with the target, producing secondary particles; additionally, photons that do not interact serve as the trigger for the start detector. After the start signal, the stop detector is then active to detect the secondary particles that arrive with some time distribution after the start detector is triggered (time = 0 ns). This resulting distribution represents the time of flight of secondary particles arriving at the stop detector 111 cm from the depleted uranium target.

2.2. Monte Carlo Simulation Results

The MCNPX/MCNP-PoliMi simulations explicitly model the full statistics of the neutron/photon field generated from photonuclear events. In addition, a detector-specific postprocessing code is used to simulate the detector response to the incident particles. A few assumptions that differ from the actual experimental setup had to be applied. First, the linear accelerator (LINAC) tungsten converter was omitted in the simulations; this is equivalent to assuming perfect collimation. Second, in the postprocessing some detector-specific properties, such as threshold, dead time, and pulse-generation time, had to be assumed because their value in this experiment was not recorded. Finally, the data from IAC and the Oak Ridge National Laboratory (ORNL) simulation results were normalized to the total number of neutron counts. This was necessary because the precise number of photons on target and the detection threshold were not known. A comparison of the results is shown in Figure 1.

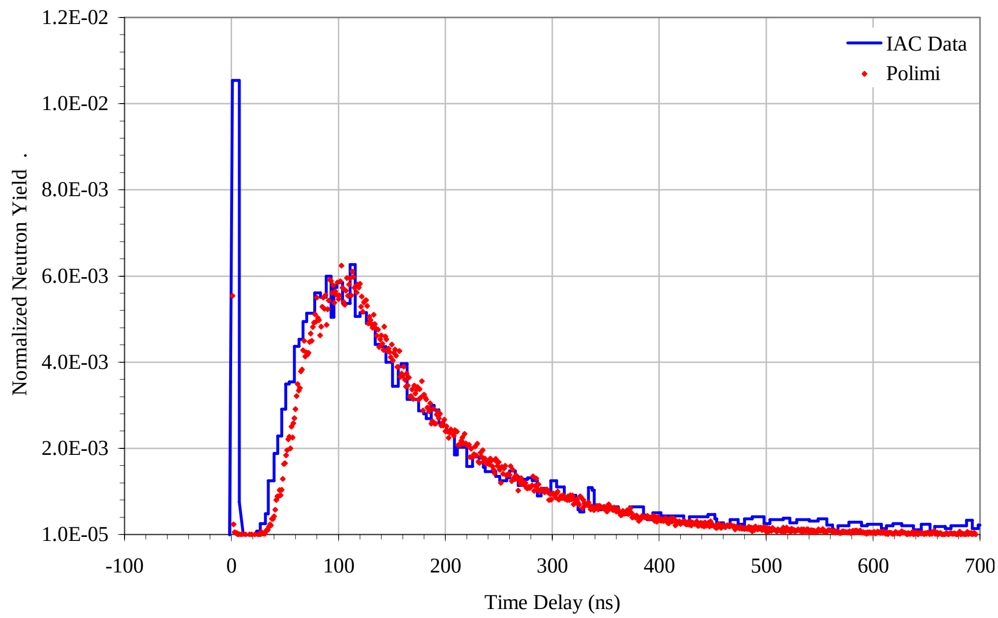

Figure 1. Comparison of MCNP-PoliMi calculations to experimental data from the Idaho Accelerator Center for 111-cm separation of the stop-detector from a depleted uranium target.

3. CONCLUSIONS

Although there is a slight shift in the initial time response, the results presented here clearly show that the MCNPX/MCNP-PoliMi code system is capable of accurately predicting the prompt correlated-detector response to uranium interrogation with high-energy photons. In fact, this code system calculates the full statistics of the neutron/photon field directly resulting from photonuclear interactions. This information is then analyzed by a detector-specific postprocessor. In this work, the physics of plastic scintillation detectors were simulated and the time correlations were determined. These capabilities result in a code system that accurately simulates the full interrogation process from source to detector response.

ACKNOWLEDGMENT

The Oak Ridge National Laboratory is managed and operated for the U. S. Department of Energy by UT-Battelle, LLC, under contract DE-AC05-00OR22725.

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