Neutron and Photon Multiplicities for Nuclear Material Detection and Identification

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INTRODUCTION

Several recent efforts have aimed at investigating the use of multiplicity counting for the detection and identification of nuclear materials. Traditional systems based on the use of active or passive well counters rely on the thermalization and subsequent detection of neutrons emitted by the fissile material.

More recently, systems based on the use of liquid or plastic scintillation detectors have been developed. Because scintillators are sensitive to both fast neutrons and gamma rays, the systems employing them extend the multiplicities that can be measured from neutron only to *joint neutron and photon*. Preliminary measurements and simulations performed with these types of measurement systems have shown promising results.

In this paper we describe an analytical derivation of the joint neutron and photon multiplicities emitted by fissile samples. The results obtained with the analytical approach are compared with results obtained with the Monte Carlo code MCNP-PoliMi for a few cases of interest.

ANALYTICAL APPROACH

In previous works the number of neutrons and photons emitted by a sample with spontaneous source and subsequent multiplication was investigated with both analytical methods and Monte Carlo simulations [1]. The starting point was the method of master equations, also known as Chapman-Kolmogorov equations. Closed-form implicit equations can be derived for the probability-generating functions of the distributions. Earlier these equations were used to find explicit solutions for factorial moments, taking into account the self-multiplication in the sample. Solutions up to the third moment can be found in the literature, and there is no practical reason to calculate higher moments because they are usually not measured. From the same master equations, we derive explicit expressions for the joint neutron and photon probability distributions, $p(n,m)$, where n is the number of neutrons and m is the number of photons emitted by the fissile sample. The derivation is achieved by the use of the symbolic computation language Mathematica®.

MONTE CARLO APPROACH

The Monte Carlo code MCNP-PoliMi [2] was used to simulate the distribution of the neutrons and gamma rays emitted by a fissile sample. The geometry for the simulations is shown schematically in Fig. 1. The fissile sample was a plutonium metal sphere having varying radius *r* and composition 80wt% Pu-239 and 20wt% Pu-240. The plutonium sphere was placed at the center of a tally shell. A spontaneous fission (Pu-240) source was uniformly distributed within the plutonium sphere.

The Monte Carlo simulation tracks neutrons and photons from the spontaneous fission sites with their correct multiplicities and spectra. Induced fission, absorption, scattering, and other relevant reactions in the plutonium sphere are also modeled. Outgoing neutrons and photons from the induced fissions are tracked with correct multiplicities and spectra.

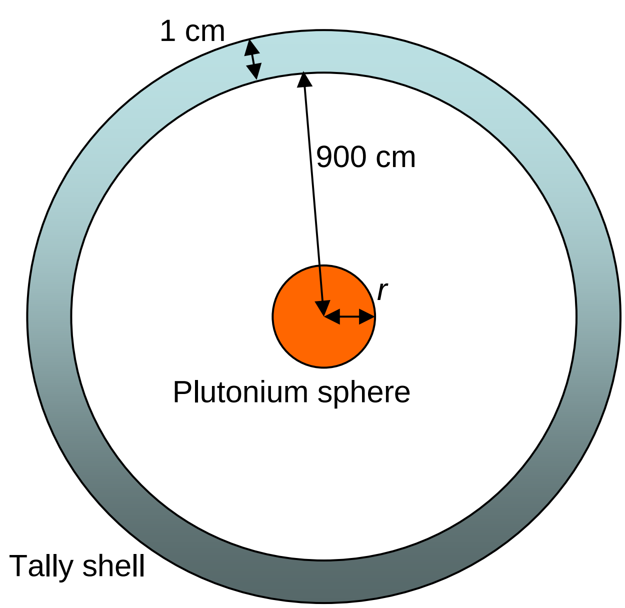

Fig. 1. Schematic diagram of MCNP-PoliMi simulation geometry. (Not to scale.)

A tally shell, with arbitrarily high density to ensure that all particles leaving the plutonium sphere interact with the shell, is placed around the plutonium sphere. (The shell is placed at a large enough distance from the sphere that the number of particles reflected back to the sphere is negligible.). A tally of the interactions within the shell is performed using the standard MCNP-PoliMi collision output file. This output file is then post-processed using a specifically developed code to calculate the probability distribution *p(n,m)* of obtaining *n* neutrons and *m* photons emitted by the sample from a given history.

Figure 1 shows the result of the Monte Carlo simulation for the joint distribution *p(n,m)* for the plutonium sample having mass 9,047 g. Figure 2 shows the distribution of the neutrons emitted by three plutonium samples of different masses. This distribution can be obtained by integrating the distribution of Fig. 1 along the axis labeled "number of photons." The results clearly show a tail for developing for increasing sample mass.

These results are in good agreement with those obtained from the analytical model.

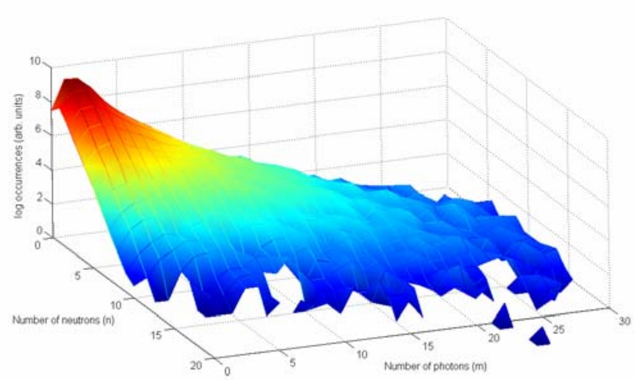

Fig. 2. Joint distribution of the number of neutrons and photons [*p(n,m)*] emitted by a plutonium sphere of mass 9,047 g.

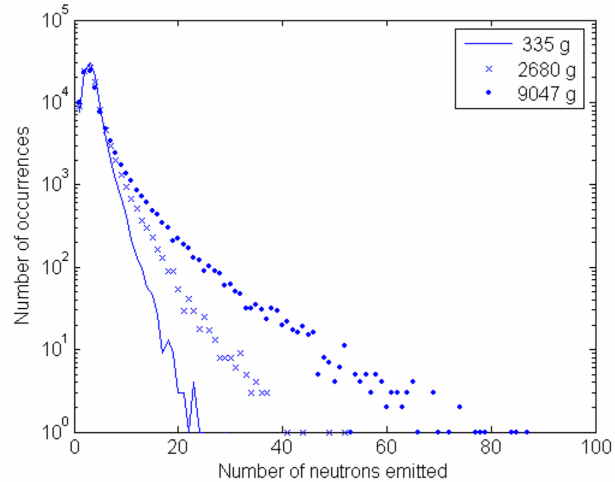

Fig. 3. Distribution of the number of neutrons emitted by three plutonium spheres of varying masses.

REFERENCES

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2. S. A. Pozzi, E. Padovani, and M. Marseguerra, "MCNP-PoliMi: A Monte Carlo Code for Correlation Measurements," *Nuclear Instruments & Methods in Physics Research Section A–Accelerators Spectrometers Detectors and Associated Equipment* **513**, pp. 550–558 (2003).