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E. H. Seabury
D. L. Chichester

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Monte Carlo Simulations of the Response of Shielded SNM to a Pulsed Neutron Source

E.H. Seabury and D.L. Chichester

Idaho National Laboratory, 2525 N. Fremont Ave., Idaho Falls, ID 83415

Abstract. Active neutron interrogation has been used as a technique for the detection and identification of special nuclear material (SNM) for both proposed and field-tested systems. Idaho National Laboratory (INL) has been studying this technique for systems ranging from small systems employing portable electronic neutron generators to larger systems employing linear accelerators as high-energy photon sources for assessment of vehicles and cargo. In order to assess the feasibility of new systems, INL has undertaken a campaign of Monte Carlo simulations of the response of a variety of masses of SNM in multiple shielding configurations to a pulsed neutron source using the MCNPX code, with emphasis on the neutron and photon response of the system as a function of time after the initial neutron pulse. We present here some preliminary results from these calculations.

Keywords: MCNP,MCNPX, Active Interrogation, Electronic Neutron Generator.
PACS: 25.85Ec , 28.20Gd

INTRODUCTION

Neutron active interrogation has been used in a number of systems designed to detect special nuclear material (SNM). Systems based on this technique have been designed to inspect cargo[1], vehicles, and smaller items[2] to determine if a nuclear weapon or other SNM-containing device is being moved along with legitimate cargo. These systems are generally designed to examine only one or two signatures of SNM, e.g. neutron die-away or neutron multiplicity, and ignore some other signatures such as buildup of fission product activities or specific fission product gamma line emission. At Idaho National Laboratory (INL) we are interested in examining the complete space of signatures expected from neutron irradiation of shielded SNM and developing technologies for detection. As part of that effort, we have undertaken an extensive campaign of modeling Active Interrogation scenarios using the MCNPX[3] Monte Carlo radiation transport code developed at Los Alamos National Laboratory..

Active Interrogation Signatures

The expected response of SNM to a pulsed neutron source is shown schematically in Figure 1 below. As can be seen in the figure, there are a number of signatures that vary as a function of time after the initial neutron burst. There are prompt gammas and neutrons after the neutron burst, neutron die away in between neutron pulses, beta-delayed neutron and gamma emission in the interpulse region, and beta-delayed gamma and neutron emission in the post-irradiation time period. All of these signatures can be used to detect SNM, in particular highly-enriched uranium (HEU) which is difficult to detect passively if it is well shielded. In order to examine these signatures, appropriate tallies have been incorporated into the simulations that have been undertaken.

MCNPX MODELS

The geometry of the models is relatively simple. A sphere of uranium is surrounded by spheres of near-shielding material, and this assembly is embedded in a 3 meter by 3 meter cube of bulk shielding material. A neutron source is placed 20 cm from the face of the bulk shield and an array of ^{3}He detectors is placed near the neutron source and bulk shield. The geometry is shown schematically in Figure 2. The composition of the near and bulk shielding materials, masses of SNM and location within the bulk shield of the SNM are shown in Table 1. For all the simulations, the SNM was composed of 90% ^{235}U and 10% ^{238}U. The neutron source used in the calculations was monoenergetic with either 2.5 MeV (deuterium-deuterium fusion) or 14.1 MeV energy (deuterium-tritium fusion). In all the simulations, the bulk shield is surrounded by air at sea-level pressure. The ^{3}He

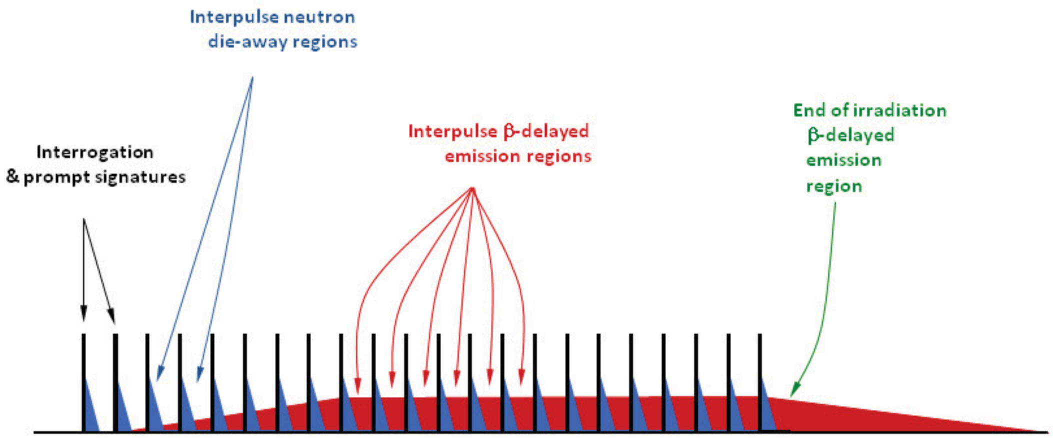

FIGURE 1. Response of SNM to a pulsed neutron source.

detectors are filled with 4 atmospheres of ^{3}He and are not shielded from the incident neutron source.

There are a number of tallies in the simulations. In addition to the ^{3}He detectors, there are tally locations above, behind, and to the sides of the bulk shield. The neutron and photon fluences are energy-binned and tallied as functions of time after the neutron burst at a number of locations around the bulk shield. Neutron captures in the ^{3}He gas of the detectors are tallied, fissions are tallied in the HEU sphere, and neutrons and photons are energy-binned and tallied as functions of time both into and out of the HEU sphere. In addition to the tallies described above, some mesh calculations of neutron fluence through the bulk shielding material were also performed.

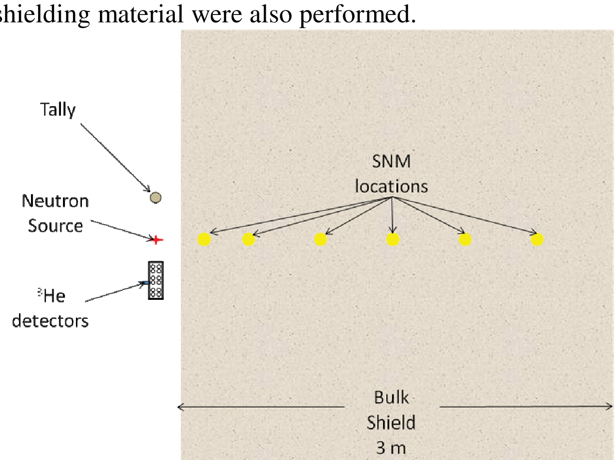

FIGURE 2. Model Geometry.

Example Case: Concrete bulk shield

The entire set of calculations summarized in Table 1 comprises over 2500 individual runs. Each combination of model parameters in the table constitutes a run, e.g. there are runs for 0-20 kg HEU, at distances of 0.2-2.5 m, with all near-shielding materials in the concrete bulk shield. The first subset of calculations has been performed at INL, namely all the models using the concrete bulk shield. The concrete bulk shield consisted of standard materials, at a density of 2.35 g/cm3. One of the first items to be calculated was the neutron fluence mesh throughout the bulk shield with a bare 20 kg sphere of HEU placed within the bulk shield, 0.5 meter from the shield face. A contour plot of this simulation for the 2.5 MeV (DD) source case is shown in Figure 3. As can be seen in the figure, the HEU sphere does multiply some of the incident neutron flux. The plot also shows that air scatter around the bulk shield provides much of the neutron flux around the edges of the bulk shield, with the center of the shield having very low neutron flux as would be expected.

One of the more interesting results from these calculations is examining the effect of the near shield around the HEU on various tallies. For example, Figure 4 shows the effect of the near shield material on the total photon flux for the 20 kg HEU sphere 0.2 meter into the bulk shield and with a 14.1 MeV (DT) source. It is noteworthy that with the HEU encased in a steel shield, there is less total photon flux outside the bulk shield than in the case where there is no HEU or steel present at all. The effect of the near shield on the counts in the ^{3}He detectors can be seen in Figure 5.

TABLE 1. Model parameters for MCNPX simulations

HEU Mass (kg)	Near Shield	Bulk Shield	Hidden Depth	Neutron Source (MeV)
0	None	Air	0.2 m	14.1
1	5 cm Pb	Concrete	0.5 m	2.5
2	5 cm Steel	Plywood	1.0 m	
5	1mm Cd	Steel (0.6 g/cc)	1.5 m	
10	Pb + Cd	Aluminum (0.6 g/cc)	2.0 m	
20		Polyethylene Borated poly.	2.5 m	

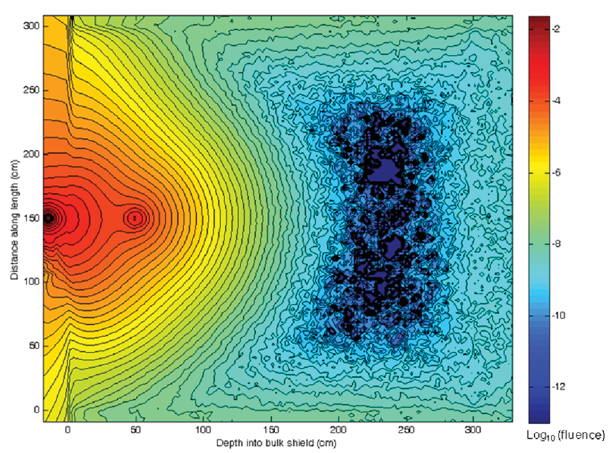

FIGURE 3. Mesh plot of neutron fluence in the concrete bulk shield for the 2.5 MeV neutron source and 20 kg HEU placed 0.5 meter from edge of bulk shield.

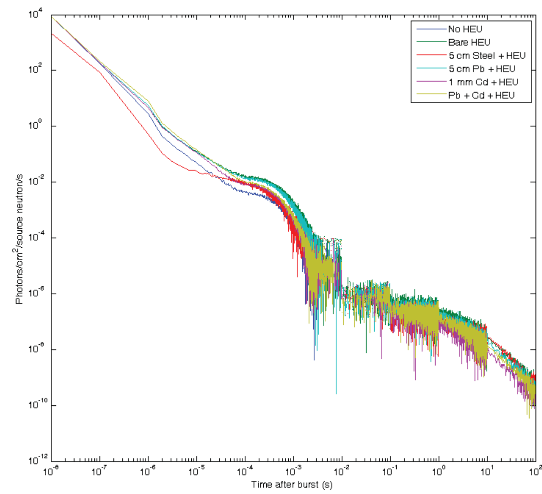

FIGURE 4. Total photon fluence outside the bulk shield as a function of time after the incident DT neutron burst for the 20 kg HEU 0.2 meter into the bulk shield case.

In this case, the HEU sphere had a mass of 10 kg and was placed 0.5 meter into the bulk shield. As can be seen in the Figure, 5 cm of lead shielding does not have a large effect on the counts in the detector. In contrast, the steel shield does have a significant effect, and the 1 mm Cd shield indeed gives rise to the most significant drop in count rates, as would be expected.

The effect of the depth within the bulk shield of the HEU can be seen in Figures 6 and 7. Figure 6 shows the total neutron fluence outside the bulk shield for the bare 20-kg sphere and DT neutron source case.

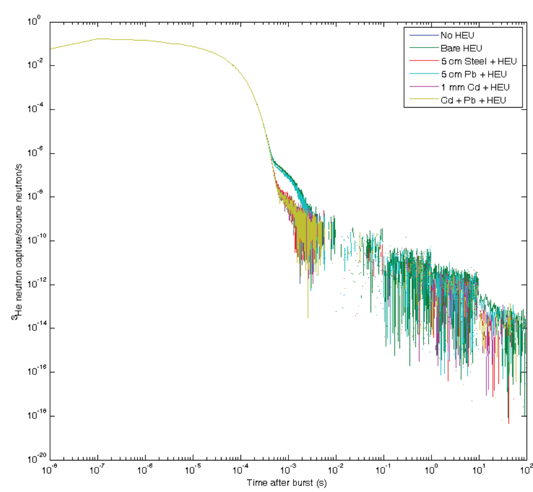

FIGURE 5. Effect of the near-shield material on neutron capture in all the ^{3}He tubes for the 10 kg, 0.5 meter, and DD neutron source case.

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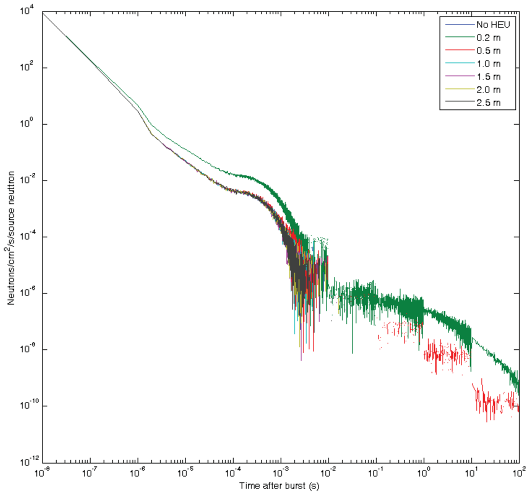

FIGURE 6. Total neutron fluence outside the concrete bulk shield as a function of hidden depth for the bare 20 kg, DT neutron source case.

As would be expected, the neutron counts seen in the tally drop as one places the HEU further and further into the bulk shield. The effect of the sphere placement on the number of fissions within the HEU can be are shown in Figure 7. In this case, the bare sphere contains 5 kg of HEU and is irradiated with a DD neutron source. With the sphere placed directly in the middle of the concrete bulk shield, the number of fissions observed drops by three orders of magnitude when compared to the sphere placed at 0.2 meter from the edge.

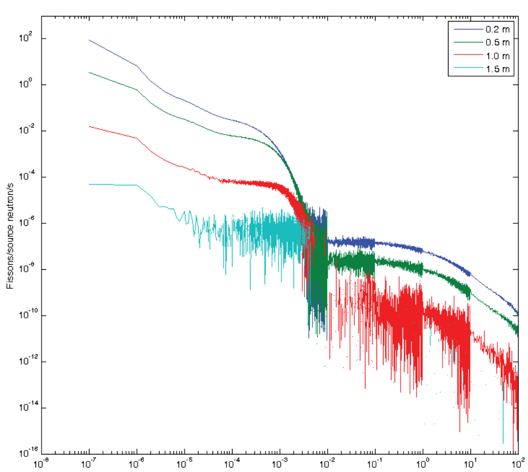

FIGURE 7. Total number of fissions in the bare 5 kg DD neutron source case as a function of hidden depth.fissions observed drops by three orders of magnitude when compared to the sphere placed at 0.2 meter from the edge.

CONCLUSIONS AND FUTURE WORK

The value of these calculations lies in their use for the design of future Active Interrogation systems and their associated neutron sources. Knowing the expected response of shielded HEU as a function of time will allow us to concentrate on signatures that can be most easily observed for a given shielding scenario. Knowing the expected count rates of neutrons and photons outside the bulk shield as functions of energy will allow us to design detectors of sufficient and appropriate efficiency to determine the presence of SNM.

The remaining calculations for the other bulk shield materials will continue and provide a complete set of results for a wide selection of shielding scenarios.

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