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SIMULATION OF CARGO CONTAINER INTERROGATION BY D-D NEUTRONS

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ABSTRACT

We present a robust 3D cargo container model based on a detailed CAD drawing of a cargo container, a D-D neutron generator interrogation source, and multiple detector array panels. Different active interrogation methods have been proposed to probe special nuclear materials hidden inside large cargo containers. Previous computer simulations used simplified models with homogeneous hydrogenous payloads or simply extrapolated results from previously acquired experimental data, e.g., active interrogation of nuclear waste drums. In the present case, we develop a realistic container model that can be filled with different cargo payloads, both heterogeneous and homogeneous. Our results show that detection of prompt fission neutrons as the signature of fissile materials will work for containers filled with hydrogenous payloads. In heterogeneous payloads, which can greatly reduce the fast neutron leakage, we find that fast fission neutrons are still able to leak out and be detected.

Key Words: fissile, uranium, active interrogation, neutron

1. INTRODUCTION

Active interrogation of special nuclear material hidden in cargo containers has become an important research topic for homeland security. While active interrogation techniques using high-energy (E_γ>3 MeV) β-delayed gammas from fission products of special nuclear materials have the potential to detect shielded fissile nuclear materials,[1,2] the background radiation has not been treated explicitly in these studies for neutron-based systems. A neutron source can produce significant numbers of decay gammas in the background depending on the materials inside the cargo containers and the type of concrete on the floor.[3] Although decay gammas from activation products in the surrounding materials using a photon interrogation source is expected to be lower, it is still necessary to overcome the background by selecting only high-energy gammas from fission products with specific half-lives.[4] Thus, counting high-energy β-delayed gammas is not a foolproof system especially when a neutron source is used. In this paper, several heterogeneous computer models of the cargo container and representative

payloads are created to study both the prompt and delayed signatures from fissile material. Results are also presented for a D-D neutron-based system using prompt neutrons as a signature for fissile materials.

2. SIMULATION PROCEDURE

The Monte Carlo N-Particle eXtended (MCNPX) code is chosen for our simulation effort because it has a broad range of features in terms of its validated physics models, extensive nuclear databases, parallel computation capability and the ability to handle complex geometries.[5] The model we have developed has an energy-angle dependent point D-D neutron source located 50 cm from the center of the cargo container's side panel. A 4.66-cm diameter 90% enriched uranium sphere is positioned inside the center of a 6 m × 2.5 m × 2.6 m ISO cargo container.

2.1. ISO Cargo Container Model

The accuracy of computed results depends on how accurately a scenario is defined. For instance, precise material descriptions are very important for evaluating the background for different neutron sources. Models that ignore elements or isotopes with low concentrations but high reaction cross sections can produce completely different results if most of the background is caused by the probing particles interacting with the ignored low abundance, but high cross section, elements. Figure 1 shows a MCNPVISED ray-traced picture of our MCNPX container model based on the CAD drawing of a real ISO cargo container. This ISO container model has corrugated panels, rails, corner posts and corner fittings made of different steel composites. Underneath its plywood floor are steel cross members and forklift pockets. The container is sitting on a thick concrete floor. Incorporating these feature details provides a much more realistic and accurate model of the neutron and photon transport.

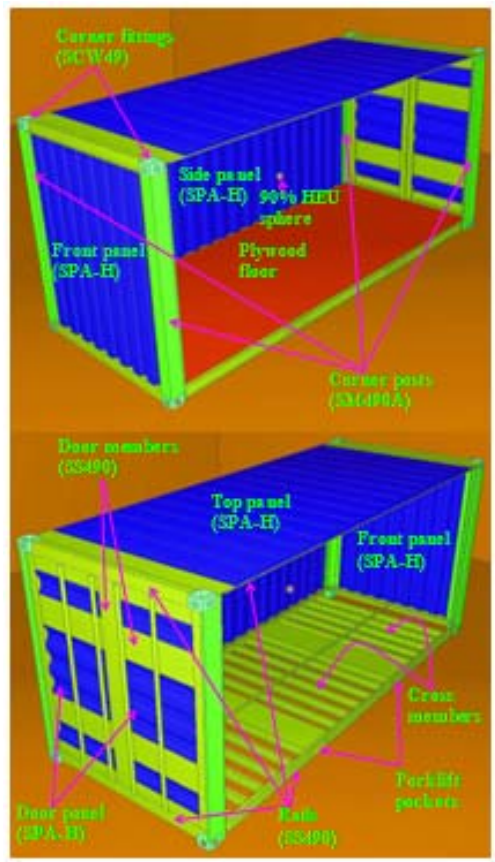

Figure 1. Front and back view of the ISO cargo container model.

2.2 Cargo Payload Models

Three types of cargo payloads have been simulated: (a) homogeneous oak wood, (b) bottled water, and (c) boxed laptop computers. Oak wood is modeled as cellulose ($C_6H_{10}O_5$) with a typical average mass density of 0.7 g/cm^3, corresponding to a hydrogen atomic density of 0.432 moles/cm^3. The bottled water contains 800 ml water in a glass bottle with density of 2.536 g/cm^3. The corresponding hydrogen atomic density is 0.111 moles/cm^3 (0.379 moles/cm^3 if homogenized). The laptop computer model is a simplified representation that includes the CPU heat sink, hard disc platter, lithium ion battery, etc. Figure 2 shows the MCNPX models as ray-traced by MCNPVISED.

3. RESULTS AND DISCUSSION

The MCNPX simulations computed the number of induced fissions per source D-D neutron to be 1.8×10^{-6} for the homogeneous oak wood model, 1.2×10^{-4} for the bottled water model, and 4.3×10^{-4} for the laptop computer modes. The detector array with a total area of ~25,000 cm^2 is set to count fast fission neutrons on the other side of the cargo container. While the source neutrons diffuse inside the container, with time frame between a few microseconds up to a few milliseconds before getting absorbed, their kinetic energy becomes less than 100 keV approximately 100 μs after they are born. Therefore, the detectors can start to count neutrons with 100 keV < E_n < 3 MeV 100 μs after the beam is off while fission neutrons with E_n>3 MeV can be counted any time during the irradiation. For the laptop computer model, ~6×10^{-6} fission neutrons per fission reach the detectors. For the bottled water model, ~2×10^{-7} fission neutrons per fission reach the detectors. For the homogeneous oak wood model, the number of fission neutrons per fission that reach the detectors is approximately 4 orders of magnitude lower than the bottled water model. This occurs because the uranium sphere is located at the center of the cargo container so any straight path from the point source to the uranium sphere will result in a higher areal density of hydrogen atoms for bottled water compared to oak wood. The induced fissions, in this case, are not caused by uncollided neutrons. These results suggest that the heterogeneity has improved the localized neutron moderation, increased low-energy neutron flux near the center of the container and increased neutron leakage to the detectors over the homogeneous model.

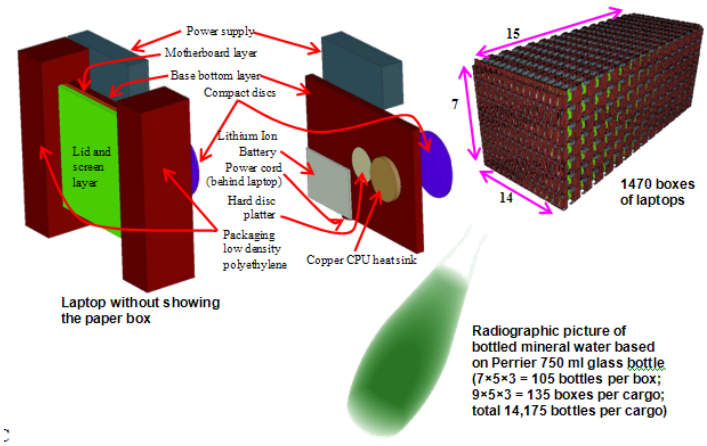

Figure 2. Heterogeneous payload models of laptop computers and bottled water for the simulation.

4. CONCLUSIONS

Our detailed computer simulations indicate that prompt fast fission neutron counting can be applied to most heterogeneous cargo payloads even for hydrogenous materials. In addition to the models presented in this paper, an automobile engine block payload model is currently being created as more scenarios are need to better understand how neutron interrogation will be affected by different payloads. For homogeneous hydrogenous payloads, photon based active interrogation system using photofission-induced gammas as the detected signature could be a more promising approach because fission gammas have a higher probability of escaping the hydrogenous materials without being absorbed.

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