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SIMULATIONS FOR ACTIVE INTERROGATION OF HEU IN CARGO CONTAINERS

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We describe the results of a Monte Carlo simulation to investigate the feasibility of using a pulsed deuterium-tritium (D-T) neutron technique for active interrogation of special nuclear material in cargo containers. Time distributions of fission neutrons from highly enriched uranium induced by a pulsed D-T neutron source were calculated for cargo containers with different hydrogen contents. A simple detector system with polyethylene and cadmium was modeled to calculate the two-group neutron flux at the detector.

I. INTRODUCTION

An active interrogation system based on a deuterium-tritium (D-T) fusion neutron source is being studied to investigate the feasibility of detecting special nuclear material (SNM) in cargo containers. Since a differential die-away (DDA) technique is being considered as the measurement technique for the application, Monte Carlo simulation was indispensable for designing an optimum detector system for the container inspection system. In this study, a series of calculations was performed to get time distributions of induced fission rates for highly enriched uranium (HEU) and neutron flux at the detector module for cargo containers with various hydrogen contents.

II. CALCULATION METHOD

The Monte Carlo simulations were performed with the latest version of the MCNPX (Monte Carlo N-Particle eXtended) radiation transport code, which is capable of fission multiplicity and coincidence tracking.[1] Evaluated cross-section data libraries with delayed neutron distributions were used for the simulations. Most simulations used 10^9 source particles for good statistics, and several tallies including the delayed neutrons were performed in each simulation.

For the MCNPX simulations, a 5-kg solid sphere of HEU was positioned in the center of a 0.5-cm-thick steel cargo container (2.4 m × 2.4 m × 6.0 m). The enrichment of the HEU in the ^{235}U was 93%, and the density was 19.07 g/cm^3. A 14.1-MeV monoenergetic interrogating neutron source was located 1 m from the container and centered on one of the 2.4 m × 6.0 m sides to align with the HEU. The HEU was either bare or located in the center of a cube of water (2.4 m × 2.4 m × 2.4 m) with density variations from 0.2 to 1.0 g/cm^3. A neutron detector module consisting of 1 cm of polyethylene and 1 mm of cadmium was positioned 5 cm from the container wall.

II. RESULTS AND DISCUSSIONS

The time dependence of the neutron fission rate immediately after the interrogation neutron pulse was calculated at the HEU sample for the first step. The typical induced fission rates of the 5 kg of HEU by the D-T neutron source ($\varphi = 5.0 \times 10^{10}$ n/s) are shown in Fig. 1 for various water densities. As shown in the figure, the fast energetic neutrons from the D-T generator have enough energy to induce fissions at the HEU in water shielding up to 0.8 g/cm^3, which represents hydrogenous food.[2]

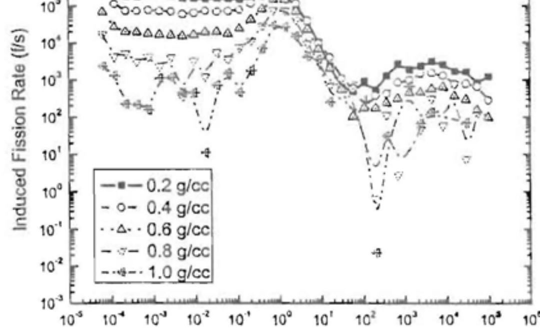

Fig. 1. Time dependences of induced fission rate as a function of water density.

The next calculation was to investigate the time dependence of neutron flux at the detector module. Figure 2 shows the typical time dependence of neutron flux per source neutron at the detector module for the HEU sample in water with a density of 0.2 g/cm^3, which has a hydrogen density that is similar to that of Celotex (0.148×10^{23} atom/cm^3).[3] The neutron flux without HEU was also illustrated in the figure for comparison. In the figure, it can be seen that the background (BG) neutrons are being suppressed effectively by applying a cadmium shield, and the neutrons originating from the prompt induced fission of HEU can be measured in a 1 ms to 10 ms time domain. The signals from induced fission reactions in the time domain can be analyzed using typical DDA techniques to estimate the fraction of fissile material present in the sample.

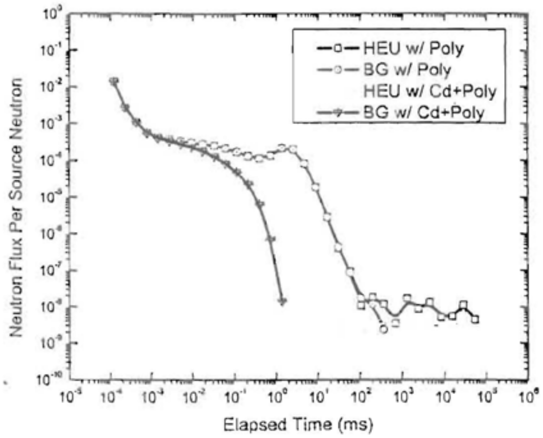

Fig. 2. Time dependences of neutron flux at detector.

The results in Fig. 2 provoked an idea of a simple HEU detection protocol. If the detector is used for screening purposes only, the presence of fissile material could be determined easily by comparing the detector response to the fast and slow neutrons in a certain time domain. The energy-dependent response could be measured by the detector module with the variation in thermal neutron cutoff and the neutron slowing down range. Therefore, calculations were performed to investigate the time distribution of neutron flux at the container surface as a function of neutron energy. Figure 3 shows the ratio of the two-group neutron flux at the container surface. The neutron energy tally was divided into slow neutrons (0.1 eV to 1 keV) and fast neutrons (10 keV to 10 MeV). Because most of the interrogation neutrons would be slowed down as they penetrate the cargo container, the fast neutron portion mainly consists of prompt induced fission neutrons from the HEU. Therefore, as shown in Fig. 3, the fast-to-slow neutron flux ratio begins to increase linearly when the prompt induced fission neutrons aroused from the HEU reach the detector module.

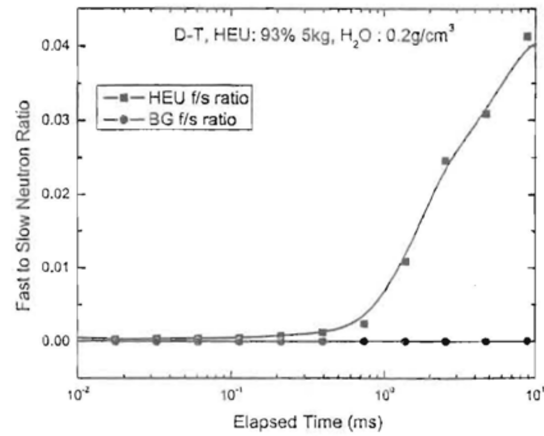

Fig. 3. Time distribution of the fast-to-slow neutron ratio.

III. CONCLUSIONS

A series of MCNPX calculations was performed to investigate the feasibility of using D-T fusion neutron source for the active interrogation of HEU in cargo containers that have hydrogenous shielding material.

The high neutron energy from the D-T fusion reaction showed good penetrating capability and induced fissions at HEU embedded in water with a density up to 0.8 g/cm^3. It was found that a detector design with proper moderators and thermal energy cutoff could provide a reasonable signal-to-noise ratio at the 1 ms to 10 ms time domain. It was also proved that a maximum 100 Hz of pulse repetition rate was possible for the system, which is one of the design requirements for the container inspection system. Further studies will continue in order to confirm the simulation results for various shielding materials and to get an optimum design for the system.

ACKNOWLEDGMENTS

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