Investigations of Active Interrogation Techniques to Detect Special Nuclear Material in Maritime Environments

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INTRODUCTION

The detection and interdiction of special nuclear material (SNM) is still a high-priority focus area for many organizations around the world. One method that is commonly considered a leading candidate in the detection of SNM is active interrogation (AI). AI is different from its close relative, passive interrogation, in that an active source is used to enhance or create a detectable signal (usually fission) from SNM, particularly in shielded scenarios or scenarios where the SNM has a low activity. The use of AI thus makes the detection of SNM easier or, in some scenarios, even enables previously impossible detection. In this work the signal from prompt neutrons and photons as well as delayed neutrons and photons will be combined, as is typically done in AI.

In previous work AI has been evaluated experimentally and computationally. However, for the purposes of this work, past scenarios are considered lightly shielded and tightly coupled spatially. At most, the previous work interrogated the contents of one standard cargo container (2.44 × 2.60 × 6.10 m) and the source and detector were both within a few meters of the object being interrogated. A few examples of this type of previous work can be found in references 1 and 2. Obviously, more heavily shielded AI scenarios will require larger source intensities, larger detector surface areas (larger detectors or more detectors), greater detector efficiencies, longer count times, or some combination of these.

DESCRIPTION OF THE ACTUAL WORK

The purpose of this work is to evaluate several types of AI sources in maritime environments that are heavily shielded and not tightly coupled. This is done by determining the required source strength to successfully detect significant quantities of highly enriched uranium, as defined by the International Atomic Energy Agency, in maritime environments. In this study the maritime environment is limited to one distinct scenario. This scenario involves ships that are between 10 and 200 m in length, and the interrogation is performed by a source and detector that are between 10 and 100 m from the ship being interrogated. This is also referred to as standoff interrogation or detection. In this paper three ships will be evaluated: a luxury yacht, a fishing trawler, and a break-bulk carrier. All the analyses will be performed using the MCNPX [3] Monte Carlo radiation transport code, version 2.6.0. However, weight windows and biased source distributions will be generated using the ADVANTG [4,5,6] code. Examples of the MCNPX geometries for the luxury yacht and break-bulk carrier are shown in Fig. 1. The AI sources will be limited to neutron or photon (via electron bremsstrahlung) isotropic or directional sources, which will fully illuminate the region of the ship containing the SNM. (The analyst knows the location of the SNM a priori.) No specific detectors will be modeled. Instead a 1 m^2 surface crossing tally will represent an idealized 100% efficient detector. The results and conclusions will also give insight into applying AI in other environments that are heavily shielded and not tightly coupled.

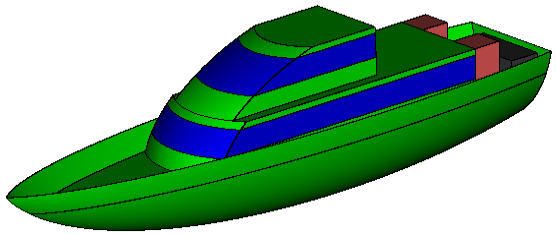

Fig 1a. Luxury yacht MCNPX model.

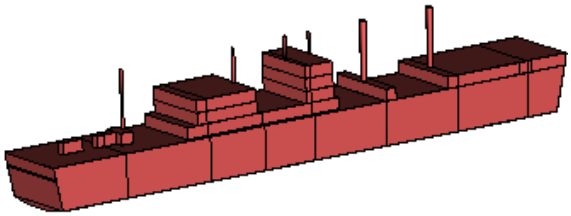

Fig. 1b. Break-bulk carrier MCNPX model.

RESULTS

The analysis of the standoff AI scenarios quickly shows that any sources of an isotropic nature are not as effective as directional sources on a per source particle basis. For example, a 14.1 MeV neutron source, produced by the DT fusion reaction, is not as effective as a bremsstrahlung source created by electrons accelerated to 25 MeV. This results in

isotropic sources needing much larger source intensities than directional sources. The larger sources intensities often are not practical because either sources of the required intensities do not exist or the power requirements to create such sources are not practical.

The results of the interrogation of the luxury yacht with a 25 MeV and 50 MeV bremsstrahlung source are shown in Fig. 2. The results that are plotted are the required *relative* source strength to detect SNM located in three different compartments of the luxury yacht. In each compartment the SNM has been placed at the centerline of the yacht and 1 m inside the hull. The results in Fig. 2 are all relative to the source strength required to detect the SNM when (1) the SNM is 1 m inside the hull of the yacht inside a cabin (bedroom) on the lower deck, (2) the AI source is a 50 MeV bremsstrahlung source, and (3) the AI source and a 1 m^2 100% efficient detector are collocated 10 m from the hull of the ship.

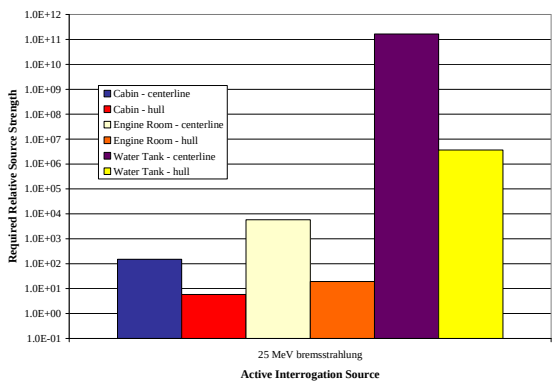

Fig. 2a. Required relative source strengths for luxury yacht active interrogation with a 25 MeV bremsstrahlung source.

An important result that should be learned from this analysis is that the success of AI is not strongly dependent on the method used to cause fission in SNM. Any source, simple or exotic, that can cause fission in SNM can be useful. The particles produced during fission, and more importantly their energies, do not vary significantly based on the type of AI source. Therefore, an exotic AI source that can more easily penetrate to SNM than a simple AI source may not be much more useful because the particles produced by the fission of the SNM will be very similar. If these particles produced by fission cannot reach a detector due to some surrounding shielding, it does not matter if the fissions were induced by a simple or exotic AI source. The only benefit may be that an exotic AI source may cause more fission events.

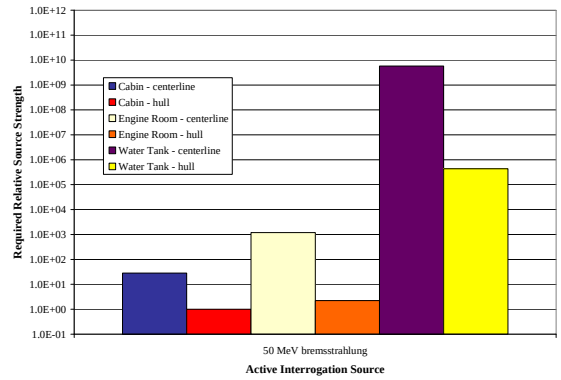

Fig. 2b. Required relative source strengths for luxury yacht active interrogation with a 50 MeV bremsstrahlung source.

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