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Detecting fissionable materials in a variety of shielding matrices via delayed gamma and neutron photofission signatures—Part 2: Experimental results ☆

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ABSTRACT

Successful detection of fissionable material contained in a variety of matrices was demonstrated by photon active interrogation of fissionable and inert target materials. Samples were irradiated with pulsed 15 MeV photons generated by a LINAC and tungsten electron/photon converter, operating at 15 Hz. Matrix materials included air (no matrix), wood, water, and lead. A unique dual mode gamma/neutron detector was used to acquire data from both fission product gamma and fission product neutron emission. Neutron emission was recorded by detecting the 478 keV capture gamma from the ^{10}B (n,α)^{7}Li reaction, generating a photopeak in the recorded gamma spectrum. Two signatures were found to correctly differentiate between the fissionable target (^{238}U) and inert targets (lead, steel, air, and beryllium), with substantial differences in delayed gamma and neutron signatures for fissionable and inert materials in all cases. The signatures are simple to compute and are not significantly affected by system variations or interferences expected during cargo scanning.

1. Introduction

Reliable detection of Special Nuclear Materials (SNM) in various cargos is critically important for homeland security. Unfortunately, the very large variety of items, containers, material, etc. that may contain possible SNM threats along with the requirement of "not impeding commerce" makes detection difficult. Available signatures from SNM do not lead to definitive methods of detection, at least not with the currently available technology. So-called passive signatures are usually significantly attenuated – unintentionally or otherwise – by nearby items or packaging. Because of these limitations, detection is often based on "active interrogation" in which a measureable signature is obtained from SNM by bombarding the suspect materials with photons, neutrons, etc. and observing a characteristic response. Active techniques overcome the minimal "passive" signatures of SNM but the interrogating signal and the returned signal are both subject to the same attenuation that impacts "passive" signatures. In addition, non-threat materials may also respond to the interrogation, leading to possible "false alarms". False SNM alarms are especially bothersome due to the security response to unexpected SNM detections.

While "universal" SNM detection in all situations is still optimistic, we have demonstrated methods based on photon interrogation and delayed fission product emission measurements can unequivocally identify fissionable materials (SNM and others, such as ^{238}U) even when the material is surrounded by a variety of materials that are representative of cargo. SNM detection described here is based on an active interrogation technique in which high energy (5–20 MeV) photon radiation is used to induce fission in "fissionable" (i.e. ^{235}U, ^{238}U, ^{239}Pu) materials. Materials respond to this interrogating radiation by producing various fission products that emit additional gamma radiation and neutrons. Active interrogation with photon (gamma ray) interrogation – "photofission" – with subsequent neutron detection has a long history beginning with waste assay, [1,2] continuing with more recent work of Jones et al. [3]. Several commercial prototypes exist that utilize high energy photons, generated using linear accelerator (LINAC) with neutron detection as the SNM signature measurement. Active interrogation with gamma radiation followed by gamma detection is more difficult as the interrogating and returned signature interfere with each other. Recent work at the Idaho Accelerator Center [4] has investigated use of photon interrogation with detected gamma signatures.

Our decision to use photon interrogation rather than, for example, neutron interrogation, was influenced by both the physics of active interrogation and a plan to use the present demonstration as one component of a future "complete" solution for examining cargo containers. The authors envisioned a

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continuation of this work once successful fissionable material detection was demonstrated: first, the experiments would be repeated on a full-size cargo container (typically 12.2 m × 2.5 m × 2.5 m) to verify the approach of realistic targets of interest. The computational tools described in the Part 1 report [5] would be used to examine scaling issues. Secondly, the photon interrogation source could be used for a cursory transmission X-ray examination of the container, followed by active interrogation of specific locations of interest. Such a transmission X-ray system was commercially available at the time this manuscript was written [6]; this was not the case for active interrogation using neutrons. The LINAC could be used for both X-ray examination and active interrogation. Neutron interrogation has been investigated for cargo container examination [7–9] but did not provide the additional capability of transmission imaging. Also, our observation of neutron interrogation technology has shown that delayed detection of neutrons and/or gamma radiation from neutron interrogation is sensitive to the presence of moderators in the target. Delayed neutron detection "die away" is especially susceptible to matrix variations [10]. Lastly, gamma detectors used for transmission X-ray measurements could also be used for passive gamma scanning with some additional engineering, leading to a complete solution for cargo container scanning.

Our objective here was to demonstrate a "universal" detection for SNM or at least fissionable materials that minimized false positive detections when applied to non-SNM materials and could successfully detect SNM shielded by common materials. We wanted to develop a technique that would minimize "false alarms"—spurious detection of fissionable material when none was present. Discrimination was accomplished by selecting the interrogating beam energy and by measured "delayed" fission signatures. Several key issues became obvious early in the modeling phase of our work [11]: (1) emission from *delayed* fission in target materials is a unique indication of fissionable material. (2) There is a synergistic relationship between neutron and gamma detection. Neutrons penetrate dense material matrices but are scattered and absorbed by lower density hydrogenous material. Gamma rays are absorbed by dense materials but easily penetrate low-density materials, hydrogenous or not. Measurement of both neutrons and gamma ray signatures from fissionable target materials would enhance our capability to detect fissionable materials in many situations that are representative of cargo. Since gamma rays are ubiquitous in nature, an algorithm to discriminate delayed fission signatures from background, scattered, and target-emitted gamma radiation would be needed. (3). High energy photons (~10–20 MeV) would penetrate anticipated cargo materials.

Many materials including lead and iron generate neutrons when bombarded with high energy photons Selecting the appropriate interrogating photon energies would maximize the likelihood of generating delayed signatures in fissionable materials while not causing fission in "inert" targets. Secondly, while many elements fission when bombarded with high energy photon radiation, only 'fissionable' materials generate 'delayed' radiations and particles *after* being interrogated. We exploited well-known fission product decay time constants in detecting fissionable material.

2. Experimental design

Experimental design is based on the simulation results presented in Part 1. Work was carried out at the Idaho Accelerator Center, Idaho State University, Pocatello, Idaho, USA, during January 2008. Large-scale experimental geometry was determined by room dimensions at the Idaho Accelerator Center. The LINAC was located in an 'accelerator room', close to a wall separating the accelerator room and 'experimental room'. The electron beam from the LINAC was bent through 90° and focused by two quadrupole lenses before striking the 2.0 mm tungsten converter target. The converter target was located 58.4 cm from the accelerator room wall. The accelerator room and experimental room were separated by 193 cm of concrete and dirt fill, with a 15 cm diameter pipe through the wall and fill to allow the photon beam to pass through. Room concrete walls were 15.24 cm thick; the remainder was fill material. Collimators were installed in the accelerator room wall 2.5 cm diameter and in the experimental room wall 9.53 cm diameter to limit the beam diameter to 11.8 cm at the target. Fig. 1 shows the experimental arrangement.

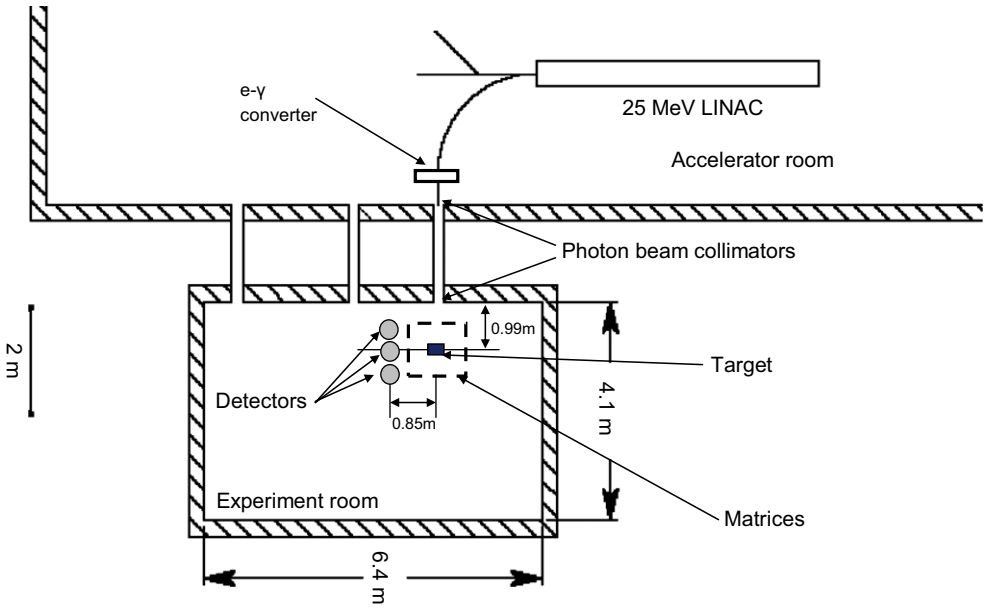

Fig. 1. Accelerator room with LINAC and beam converter, beam tunnel with collimators, and experimental room containing the target, matrices, and detectors. Several different target matrices were examined during the experiments. Wood and water matrix sizes were 0.6 m × 0.6 m or 1.2 m × 1.2 m; lead shields were 25 cm × 25 cm or 30.5 cm × 30.5 cm. Equipment in the accelerator room that was not used for this experiment is not shown.