

OUTDOOR STAND-OFF INTERROGATION OF FISSIONABLE MATERIAL WITH A HYBRID CODED IMAGING SYSTEM *

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Abstract

A hybrid coded imaging and detection system developed at the U.S. Naval Research Laboratory (NRL) was used for active interrogation measurements with pulsed bremsstrahlung at the Hermes-III facility at Sandia National Laboratories, Albuquerque. This work follows previous experiments performed in 2011 [1] and explores different targets and system conditions to the previous work. The techniques used and challenges encountered during this work are described.

I. INTRODUCTION

Passive detection of shielded special nuclear material (SNM) is a difficult problem, particularly at stand-off distances. Even moderate amounts of shielding can be sufficient to successfully mask the naturally occurring gamma rays and/or neutrons emitted by SNM. Alternatively, active interrogation methods can be used to probe materials through shielding and generate a unique and measurable signal in fissionable material; in these methods, a source of interrogating radiation is used to induce fission in the fissionable material, resulting in the increased emission of gamma rays and/or neutrons. This increased emission can be separated into “prompt” (emitted less than 1 μ s after interrogation) and “delayed” (emitted more than 1 μ s after interrogation) signals. However, the use of interrogating radiation can also produce higher background radiation levels due to activation of the shielding or surrounding materials. Both the induced signal from the fissionable target and the active background radiation level change with the type

and energy of the interrogating radiation used. The challenge is therefore to determine the optimal species and energy of interrogating radiation as well as the optimal time window after activation in which to measure the induced signal. Previous investigations into the use of bremsstrahlung interrogating radiation have focused on intense, single bremsstrahlung pulses on indoor targets with standoff distances on the order of a few meters [2] or on investigating prompt emission signatures between repeated pulses of lower-intensity bremsstrahlung radiation [3]. In contrast, the work described herein studies the delayed signals produced by a single intense interrogating pulse in an outdoor setting with standoff distances on the order of tens of meters.

II. EXPERIMENT

In September and October of 2012, measurements were performed at the Hermes-III facility at Sandia National Laboratories, Albuquerque, to study the effects of low- and high-Z shielding on the active interrogation of fissionable materials. The Hermes-III facility is a 16 MV, 500 kA pulsed electron beam accelerator capable of producing 30 ns pulses of bremsstrahlung radiation into an outdoor test cell [4]. The fissionable targets in question included a 30×30×2.5 cm depleted uranium (DU) plate, a 1000 cm³ DU cube, and a 10×10×2 cm low-enriched uranium (LEU) plate. The target was located outdoors approximately 18 m away from the x-ray source. Target shielding materials included lead (5 cm thick), steel (7.5 cm thick), and 2%-borated polyethylene (BPE) (10 and 25 cm thick). The Hermes-III accelerator was run in half-, “medium”-, and full-machine modes to produce

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14. ABSTRACT A hybrid coded imaging and detection system developed at the U.S. Naval Research Laboratory (NRL) was used for active interrogation measurements with pulsed bremsstrahlung at the Hermes-III facility at Sandia National Laboratories, Albuquerque. This work follows previous experiments performed in 2011 [1] and explores different targets and system conditions to the previous work. The techniques used and challenges encountered during this work are described			
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bremsstrahlung pulses with approximate endpoint energies of 8, 12, and 16 MeV, respectively.

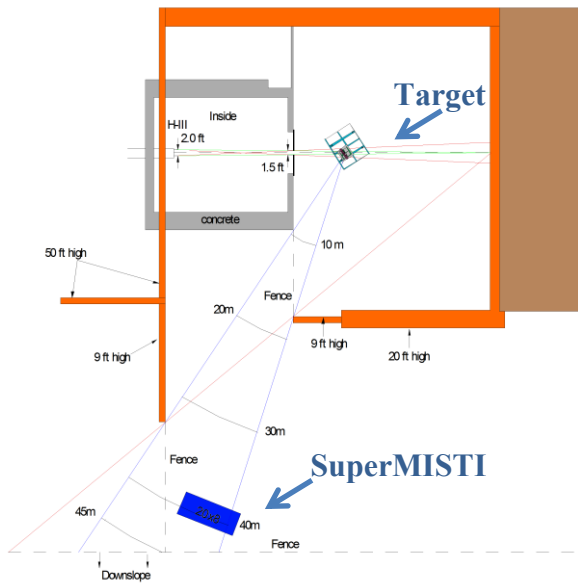


Figure 1. Layout of the Hermes-III test area.

The induced signals from the targets were detected by the imaging/localization subsystem of the SuperMISTI hybrid detection system [5], which was located approximately 40 m from the target location (see Figure 1). The SuperMISTI imaging/localization subsystem consists of 78 NaI detectors ($\text{\O}15\times15$ cm) mounted into a 6×13 array on one side of a 20 ft refrigerated ISO container. The entire array is shielded from above, below, behind, and the sides by 2.5 cm of lead; in addition, lead flooring (2.5 cm thick) provides further shielding from background radiation originating from below. Mounted on the opposite side of the container is a 12×27 pseudorandom mask that comprises 162 lead blocks ($15\times15\times5$ cm). The mask array is 50% open, 50% masked. The pattern of counts in the NaI detectors as a result of the lead mask can be deconvolved to produce a coded image of a gamma-ray source. An optical camera mounted on the exterior of the ISO container provides an image onto which this coded image is then overlaid; such a combined image is shown in Figure 2.

For the active interrogation measurements at Hermes-III, only gamma rays with energies between 3 and 7 MeV were considered. This energy range was chosen for three reasons. First, there is very little natural background gamma radiation above approximately 2.6 MeV. Second, the two dominant sources of activation counts in the NaI detectors result from thermal neutron activation of the aluminum casing of the detectors (resulting in a 1.779 MeV gamma ray) and of the iodine in the detector itself (a continuum ranging from 443 keV to 2.562 MeV due to beta and gamma decay). Third, a unique signature that spans energies greater than 3 MeV is emitted by the beta decay of the short-lived fission products of fissionable

materials [6]; this signature is absent when nonfissionable materials are interrogated. These three features are clearly evident in the spectra shown in Figure 3.



Figure 2. Coded image produced from 3-7 MeV gamma rays emitted from interrogated DU target overlaid on optical camera image. The "hot" pixel denotes the DU target location.

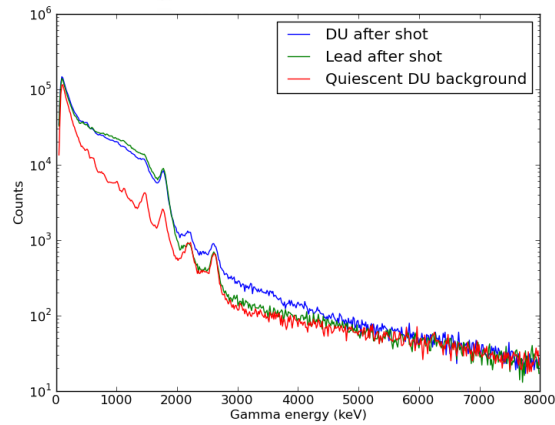


Figure 3. Comparison of gamma spectra measured in NaI detectors for DU and lead targets. Quiescent background denotes spectra for target without interrogating radiation.

In addition to the gamma imaging detectors, a complement of six ^3He detectors ($\text{\O}15\times64$ cm; 2.66 atm) were integrated into the ISO container for neutron detection. The ^3He detectors were each surrounded by an inner layer (2.5 cm) of high-density polyethylene followed by an additional outer layer (2.5 cm) of BPE. The net effect of this two-layer moderation was to lower the detector efficiency for thermal neutron signals while boosting the efficiency for fast neutrons.

III. RESULTS

A. Active gamma background

A rate plot of the 3-7 MeV gamma rays measured by the NaI detectors during 8, 12, and 16 MeV bremsstrahlung pulses with no target is shown in Figure 4. The gamma ray counts in this plot represent the active gamma background associated with these pulses. Note that both the amplitude and the duration of these counts

increase as the endpoint energy of the bremsstrahlung pulse increases. The duration of these active background counts indicate that any prompt gamma-ray measurements must contend with a significant active background; however, for signals more than 0.5 s after the bremsstrahlung pulse, the active background has essentially decayed back to natural background levels.

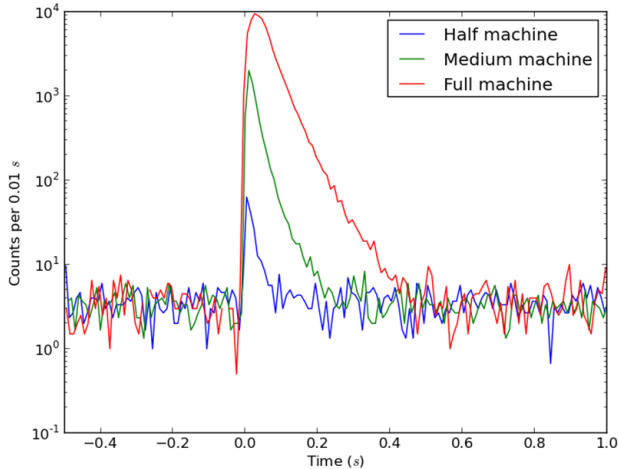


Figure 4. Rate plot of 3-7 MeV gamma rays produced during 8 (half machine), 12 (medium machine), and 16 (full machine) MeV bremsstrahlung pulses with no target.

The associated spectrum for the active background gamma rays is a continuum of counts spanning the entire energy range. The energy spectra for different 100 ms time bins after a full-machine pulse is shown in Figure 5. Note the lack of any discrete peaks and the enhanced continuum of counts that decays over time.

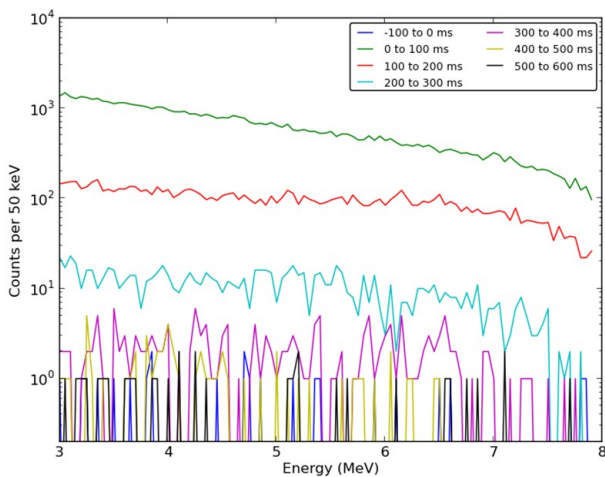


Figure 5. Spectra of high-energy active background gamma rays produced after a 16 MeV bremsstrahlung pulse.

When a coded image of these active background counts is produced, the resulting image indicates that the source of these high-energy gamma rays is localized in the outdoor

test cell. This result indicates that these high-energy gamma rays result from the activation of environmental materials by the interrogating pulse. Further measurements are needed to determine if any particular materials in the environment are responsible for this background signature.

B. Active neutron background

A rate plot of the neutrons measured by the ^3He detectors during 8, 12, and 16 MeV bremsstrahlung pulses with no target is shown in Figure 6. The neutron counts in this plot represent the active neutron background associated with these pulses. Note that, similar to rate plots for the gamma rays, both the amplitude and the duration of the neutron counts increase as the endpoint energy of the bremsstrahlung pulse increases. However, for each bremsstrahlung energy, the duration of the associated neutron active background is shorter than that of the associated gamma active background. Although there is currently no imaging capability for neutrons in the SuperMISTI system, it is assumed that the source of these neutrons, like that of the active gamma background, is located in the outdoor test cell and is associated with photonuclear reactions in environmental materials located therein.

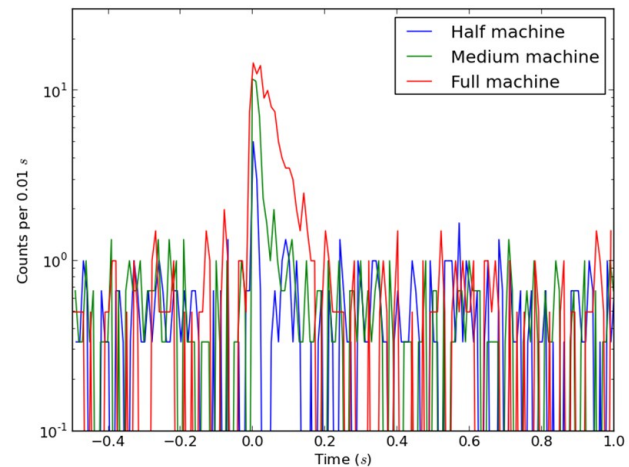


Figure 6. Rate plot of neutrons produced during 8 (half machine), 12 (medium machine), and 16 (full machine) MeV bremsstrahlung pulses with no target.

C. Detection of fissionable materials

Analysis is currently underway to determine the effects of the different shielding configurations used and the endpoint energy of interrogating bremsstrahlung radiation on the detection of fission gamma rays and neutrons. However, early results indicate that the best detections were seen for gammas produced greater than 0.5 seconds after full-machine bremsstrahlung shots. Preliminary gamma detection and imaging results are shown in Figures 7 and 8 for full-machine shots on, respectively, DU and lead targets. Significant full-machine neutron detections were also seen after 0.5 s. For medium-machine shots, gamma detections were possible at earlier

times (0.3 s after the shots) but were weaker. Further analysis is required for half-machine gamma detections and medium- and half-machine neutron detections.

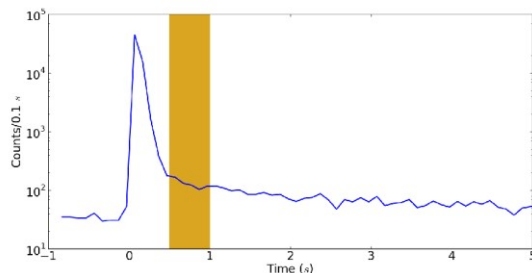
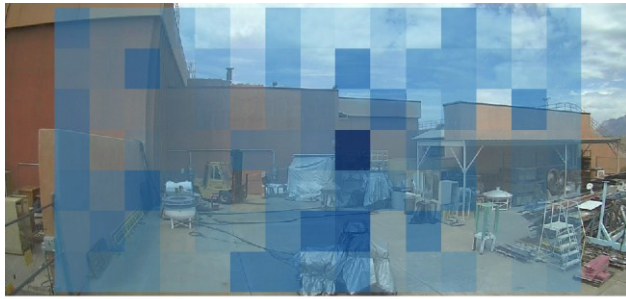


Figure 7. (top) Coded image of 3-7 MeV gammas detected 0.5-1.0 s after a 16 MeV bremsstrahlung pulse on a DU target. (bottom) Rate plot of the 3-7 MeV gammas for this shot. The time window used to produce the above image is highlighted in orange.

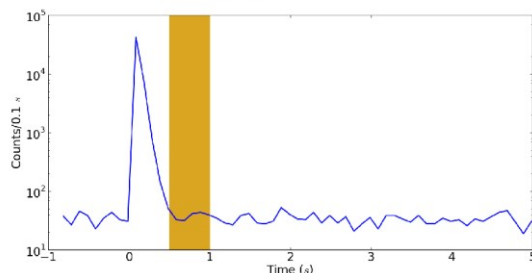


Figure 8. (top) Coded image of 3-7 MeV gammas detected 0.5-1.0 s after a 16 MeV bremsstrahlung pulse on a lead target. (bottom) Rate plot of the 3-7 MeV gammas for this shot. The time window used to produce the above image is highlighted in orange.

IV. SUMMARY

Active interrogation of fissionable materials has been investigated with the SuperMISTI imaging/localization subsystem at the Hermes-III facility at Sandia National Laboratories, Albuquerque. The detection of gamma rays and neutrons emitted from fissionable materials due to bremsstrahlung-induced photofission has been studied at a stand-off distance of 40 m. Gamma and neutron active background signatures with durations of up to 0.5 s have been identified, and unique detection of fissionable materials has been demonstrated. Detection was best for delayed gamma rays induced by an interrogating pulse with a 16 MeV endpoint energy. Analysis is currently underway to determine the effects of different shielding configurations on the detection of fissionable materials in this environment.

IV. ACKNOWLEDGEMENT

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