Active Interrogation of Shielded Fissionable Material using a Pulsed Bremsstrahlung Source

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Abstract—Passive detection of shielded special nuclear material (SNM) is a difficult problem, particularly at standoff distances. The SuperMISTI coded imaging and detection system was used with pulsed bremsstrahlung at the Hermes-III facility at Sandia National Laboratories to study active interrogation techniques as an alternative method of detecting shielded SNM. A combination of high- and low-Z shielding of varying thicknesses was used. Delayed gamma and neutron signatures were measured using NaI and 3He detectors, and signal-to-background ratios were calculated. Experimental setup details and results will be presented.

I. INTRODUCTION

ACTIVE interrogation techniques using pulsed bremsstrahlung are being studied at the U.S. Naval Research Laboratory (NRL) to address the difficulty of detecting shielded special nuclear material (SNM). In this alternative method of detecting shielded SNM, the bremsstrahlung radiation induces photofission in a fissionable target; the resulting induced signal increases the detectability of the target through shielding and/or at standoff distances. Previous investigations at NRL have involved using intense, single bremsstrahlung pulses on indoor targets with standoff distances on the order of a few meters [1]. In the work described herein, targets were interrogated in an outdoor setting with standoff distances on the order of tens of meters. This work builds upon previous efforts in 2011 [2], exploring different targets and system conditions.

II. EXPERIMENT

In September and October of 2012, active interrogation measurements with low- and high-Z shielded fissionable materials were performed at the Hermes-III facility at Sandia National Laboratories, Albuquerque. The experimental setup, techniques used in detection, and challenges faced have been previously described in detail [3] and will only briefly be addressed here.

A. Setup

The Hermes-III facility is a 16 MV, 500 kA pulsed electron beam accelerator capable of producing 30 ns pulses of bremsstrahlung radiation onto targets in an outdoor test cell [4]. The fissionable targets used in these measurements 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 approximately 18 m away from the x-ray source. The target shielding materials included lead (5 cm thick), steel (7.5 cm thick), and borated polyethylene (BPE) (10 and 25 cm thick). The Hermes-III accelerator was run in half-, “medium”-, and full-machine modes to produce bremsstrahlung pulses with approximate endpoint energies of 8, 12, and 16 MeV, respectively.

B. Detection

The induced signals from the targets were detected by the imaging/localization subsystem of the SuperMISTI hybrid detection system [5], which consists of 78 NaI detectors (0.15×0.15 cm) mounted into a 6×13 array on one side of a 20 ft refrigerated ISO container with an associated 12×27 pseudorandom mask of lead elements (15×15×5 cm) located on the opposite side. The SuperMISTI container was located approximately 40 m from the target location. For the active interrogation measurements at Hermes-III, only gamma rays with energies between 3 and 7 MeV were considered. (See [3] for further discussion of this choice of energy range.)

In addition to the gamma imaging detectors, a complement of six 3He detectors (0.15×0.64 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. Fig. 1 shows the relative efficiencies as a function of neutron energy for different moderation configurations as modeled by the SWORD (SoftWare for the Optimization of Radiation Detectors) software package [6].

III. RESULTS

To determine detection of fissionable material at a given time $T$ after a bremsstrahlung pulse, the following signal-to-background ratios were used:

$$ R_{STB}(T) = \frac{\int_{T}^{\infty} (C_S(t) - C_B(t))dt}{\sqrt{\int_{T}^{\infty} C_B(t)dt}} $$

where $C_S$ is the number of counts after a pulse, $T_o$ is the time at which the active background levels return to passive background levels for null target shots, and $C_B$ is the number of counts in the passive background (i.e., with the target and shielding in place but without a bremsstrahlung pulse). The value of $T_o$ was approximately 0.2, 0.3, and 0.5 s for gamma detections for half, “medium”, and full machine shots, respectively. For neutron measurements, $T_o$ was approximately 1 ms, 0.15 s, and 0.2 s for half, “medium”, and full machine shots, respectively. The quantity $R_{STB}$ for a given signal can be considered (more or less) the number of standard deviations above the passive background. For the purposes of these measurements, a signal with an $R_{STB}$ value above 3 was considered a positive detection.

A. Full Machine Detection

The $R_{STB}$ curves for gamma detection are given in Fig. 2 for full machine shots on various target and shielding configurations. Detections of the bare DU plate and of the plate shielded by 10 and 25 cm of BPE are clearly seen. In Fig. 3, the region between with RSTB values between 3 and 10 is...
expanded to more easily examine the curves there. In this figure, detections can be clearly seen for the bare DU cube and the bare LEU plate. Some steel- and lead-shielded DU plate shots result in signals that are sufficient for detection; however, the ratios for these shots are much lower and less consistently rise above the RSTB=3 threshold. Note that no shots on targets lacking fissile material produced signals above this threshold; i.e., there were no false positive detections.

The RSTB curves for neutron detection are given in Fig. 4 for the same shots. Again, clear detections are seen for the bare DU plate shots. By examining the curves in the expanded region shown in Fig. 5, we can see that the bare DU cube and bare LEU plate targets were again detected as was the DU plate shielded by 10 cm of BPE; however, only one shot shielded by 25 cm of BPE was detected, and no lead- or steel-shielded shots produced sufficient signals to cross the detection threshold. The lack of a significant neutron signal for high-Z shielding is less an effect of the shielding on the neutrons as it is an effect of the shielding on the interrogating bremsstrahlung pulse. As before, it is important to note that no false positive detections occurred for the full machine shots with these detectors.

B. "Medium" Machine Detection

The RSTB curves for gamma and neutron detection are given in Figs. 6 and 7, respectively, for “medium” machine shots. For these shots, only three configurations were tested: the bare DU plate, the DU plate with 5 cm of lead shielding, and a null target. As can be seen in Fig. 6, the gamma signal from the bare DU plate is sufficiently large to register as a detection for these lower-endpoint bremsstrahlung pulses; however, detection of the lead-shielded DU plate is borderline at best. The neutron detection curves given in Fig. 7 show no clear detections for these bremsstrahlung pulses. Once again, there

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**Fig. 6.** Signal-to-background ratios (RSTB) for gamma detection as a function of time for different target and shielding configurations with "medium" machine bremsstrahlung shots.

**Fig. 7.** Signal-to-background ratios (RSTB) for neutron detection as a function of time for different target and shielding configurations with "medium" machine bremsstrahlung shots.

**Fig. 8.** Signal-to-background ratios (RSTB) for gamma detection as a function of time for different target and shielding configurations with half machine bremsstrahlung shots.

**Fig. 9.** Signal-to-background ratios (RSTB) for neutron detection as a function of time for different target and shielding configurations with half machine bremsstrahlung shots.
are no false positive detections using either of these detection methods.

C. Half Machine Detection

The $R_{STB}$ curves for gamma and neutron detection are given in Figs. 8 and 9, respectively, for “medium” machine shots. For these shots, the only fissionable material tested was the DU plate; given the relatively smaller signals from the DU cube and the LEU plate with the full machine shots, it was determined that the signals from these targets would be insufficiently large to detect with half machine pulses. Even for the DU plate, however, gamma detections were inconsistent, and no clear neutron detection was seen.

D. Imaging of Fissionable Target

For sufficiently large gamma signals, the SuperMISTI system is able to produce coded images of fissionable targets after activation by bremsstrahlung pulses. For the measurements performed Hermes-III at a 40 m standoff distance, only full machine shots with bare DU or DU shielded by BPE produced sufficiently large signals to be successfully imaged. Figs. 10 and 11 show the coded images produced from the integrated counts from the time window 0.5-1.0 s after a full machine bremsstrahlung pulse for the DU plate and lead targets. Note that a clear hotspot is visible in Fig. 10, indicating the location of the DU plate; in Fig. 11, however, no hotspot is visible for the nonfissionable lead target.

IV. SUMMARY

Detection of fissionable materials using single, intense interrogating pulses of bremsstrahlung radiation has been investigated with the SuperMISTI imaging/localization subsystem at the Hermes-III facility at Sandia National Laboratories, Albuquerque. The delayed signature from both gammas and neutrons emitted from fissionable materials has been studied at standoff distances of 40 m. Despite the increasing active background as the bremsstrahlung endpoint energy increased, the best detections occurred for full machine shots. For all interrogating pulses, delayed gammas provided more consistent detections of fissionable materials than did delayed neutrons. For sufficiently strong full machine detections, coded images were produced indicating the location of the fissionable material; in real-world operations, this additional information could save valuable time and manpower that would otherwise be spent searching suspicious vehicles. Further research into bremsstrahlung pulses with higher endpoint energies, the subsequent trade-offs with increased active backgrounds, and whether these higher energies could permit larger standoff distances would be valuable avenues to pursue in the future.

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REFERENCES


