Intense Pulsed Active Detection of Fissile Materials

J.W. Schumer,[1] R.J. Commisso,[1] J.P. Apruzese,[2]
R.J. Allen,[1] G. Cooperstein,[2] D.D. Hinshelwood,[1]
S.L. Jackson,[1] D. Mosher,[2] D.P. Murphy,[1] P.F. Ottinger,[2]
D.G. Phipps,[1] S.B. Swanekamp,[1] B.V. Weber,[1]
F.C. Young,[2] and J.C. Zier[1]
[1]*Plasma Physics Division*
[2]*Engility Corp.*

Introduction: Passive and active detection of hidden fissile material are subjects of intense interest. In active detection, the naturally emitted characteristic radiations associated with radioactive decay are externally enhanced by inducing fission, thus increasing the strength of these radiations compared with what could be measured passively. One approach to active detection uses the bremsstrahlung produced when an energetic electron beam strikes a high-atomic-number material. Bremsstrahlung photons of energy greater than about 6 mega-electron-volts (MeV) can induce photo-fission in fissionable material, the products of which are detected.

Bremsstrahlung-based interrogation using linear accelerators (LINACs) is typically used for active detection, but the LINAC approach requires minutes of exposure to produce a detectable signal above background. The Pulsed Power Physics Branch of NRL's Plasma Physics Division has pioneered and demonstrated an intense pulsed active detection (or IPAD) approach[1–3] using single-pulse, terawatt-level, pulsed-power technology to achieve an inspection time of a few seconds. We have focused on the use of single intense pulses of bremsstrahlung (x-rays) to induce photo-fission, and have also effectively applied the IPAD approach using both neutrons and characteristic gamma rays generated using energetic ion-beam interactions with appropriate targets as the interrogation sources.[2]

The use of a single, very intense interrogating pulse of either high-energy photons or neutrons has several unique advantages over lower-power systems that repetitively pulse over hundreds of seconds.

(1) The short irradiation time leads to a detection time of order seconds (vs minutes for the LINAC-based approach), minimizing the passive background, which is proportional to the detection time.[1] Also, the short irradiation time-window (~100 ns) allows for the possibility to measure radiations associated with prompt, short-, and long-lived fission products.

(2) Pulsed accelerators driving high-power diodes, when used with a ruggedized commercial off-the-shelf detection system, can rapidly scan moving targets of interest within seconds.

(3) Bremsstrahlung can efficiently generate both high-energy photons and neutrons (via photo-neutron processes). This can be useful in scenarios where low- or high-atomic-number shielding is placed around the fissile material.

(4) Unique alternative signatures (such as neutron-based activation analyses and delayed-prompt neutron emissions for differentiation of ^{235}U and ^{238}U) may be accessible following a single, intense pulse.

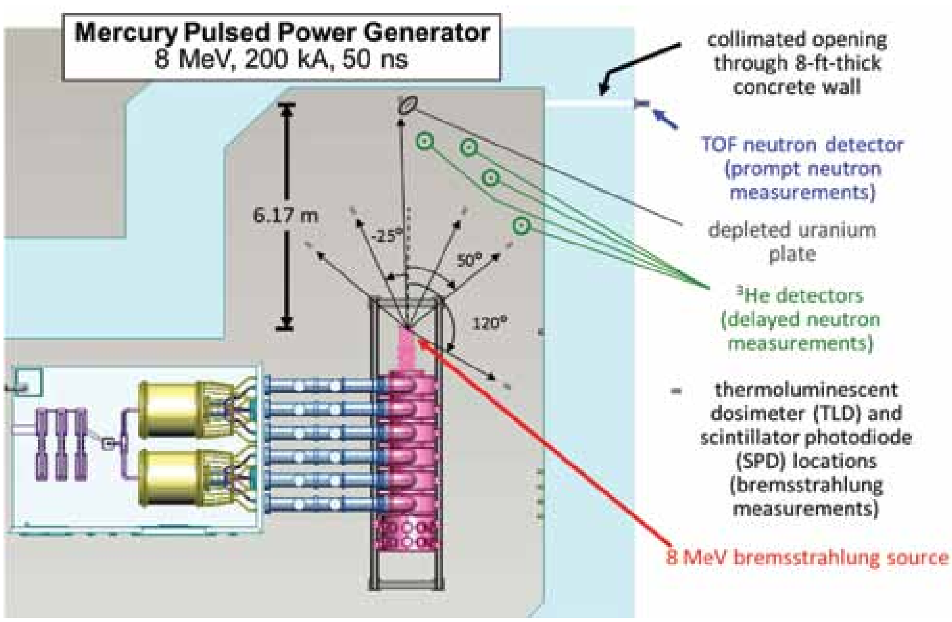

FIGURE 1
Top view of the NRL Mercury facility, showing a small sample of the detectors fielded around the depleted uranium (DU) plate.

(5) Higher signal-to-background and alternative signatures afforded by intense pulsed techniques permit tradeoffs between signal and personnel dose (and collateral activation). The systematic study of these tradeoffs for IPAD is one of the main objectives of our work.

Accomplishments: In the past two years, work has focused on using single intense pulses of bremsstrahlung as a laboratory test bed. A 50 nanosecond (ns) long, 200 kiloampere (kA), 8 MeV pulse from the NRL Mercury pulsed-power generator produces a pulse of intense bremsstrahlung that induces photo-fission in a 45 kg depleted uranium (DU) plate. The DU plate, located several meters from the bremsstrahlung source, is used as a surrogate for fissile material (see Fig. 1).

Exciting experiments with large arrays of various gamma and neutron detectors have been fielded at Mercury. Fission signatures have been measured and independently validated by collaborating teams of scientists from the NRL Space Science Division, the Atomic Weapons Establishment (UK), the Idaho Accelerator Center (IAC), the University of Missouri–Kansas City (UMKC), Brookhaven National Laboratory, and Rapiscan Systems of Sunnyvale, California.

As shown in Fig. 2, delayed neutron signatures well above background were measured with specially filtered ^{3}He proportional tubes and ^{6}Li-doped scintillators within a second or less following a single intense bremsstrahlung pulse. Delayed gammas in the 3 to 7 MeV range from induced fission have been measured using a bismuth germinate oxide (BGO) scintillator and clearly show the presence of the DU plate. Other delayed gamma detectors that have been successfully fielded include a large-area NaI(Tl) array, LaBr(Ce), high-purity germanium, and plastic and liquid scintillators. Prompt neutrons, which are 100 times more abundant and up to 10^{9} times more intense than delayed neutrons, were recorded within 200 ns after the interrogating pulse using a well-shielded, fast-time-response plastic scintillator (see Fig. 3).[3] When the DU is present, all these measurements give unambiguously larger signals than both active and passive background, even in the noise environment of a terawatt-level pulsed-power generator. Computational models using a pulsed-power circuit code, a 2D particle-in-cell charged-particle simulation code, and a neutron particle transport code were accurately chained together to reproduce electrical signals, the interrogating radiation, and the detection results, respectively.

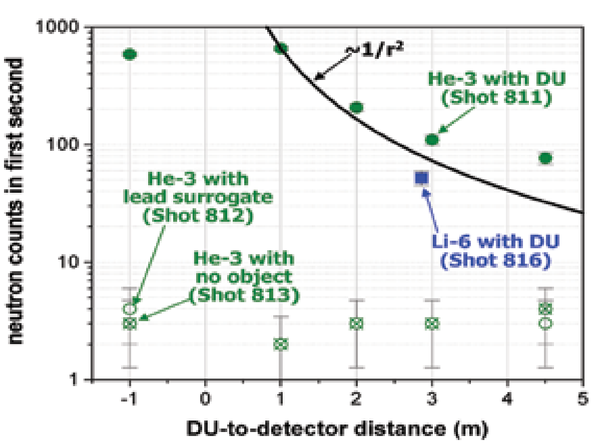

FIGURE 2
The number of delayed neutron counts on the ^{3}He detectors in the first second after the pulse is plotted as a function of distance from the DU; ^{6}Li scintillator detector results are also shown. Comparison of counts with DU vs without DU (or a lead surrogate) shows a clear difference.

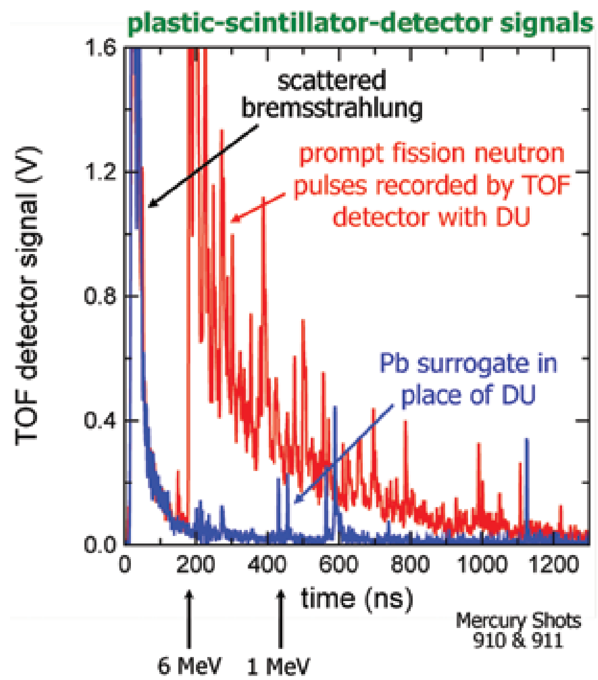

FIGURE 3
Prompt neutron detection data from a plastic scintillator placed 6 m from the DU, which was 6 m from the Mercury bremsstrahlung source. The signal was apertured by a 15 cm diameter hole in a 2.4 m thick concrete wall (see Fig. 1). The scattered-radiation signals from the bremsstrahlung pulse decay rapidly enough (~150 ns) that the prompt-neutron signal is clearly evident. (TOF = time of flight.)

Future: The development of an optimized pulsed-power generator with integrated radiation detection system is the eventual goal. Optimization of the bremsstrahlung source will lead to smaller pulsed-power generators, deployable collimators, and more manageable personnel shielding. As operational scenarios develop, there could be a need for a repetitively operated pulsed-power generator, requiring serious consideration of available generator architectures, thermal management, size, weight, maintainability, and cost. Detector systems need to integrate fast-gating high-voltage electronics to quickly access the best portion of the fission signature (early time) with detector materials that can recover quickly, have a long life in the harsh radiation environment associated with the generator, and, if possible, be commercially available in large volumes. With an optimized IPAD system, a new tool is available to decision makers, enhancing their ability to prevent a nuclear threat from entering our borders.

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Missile Tracking and Range Safety

D.J. Dowgiallo,[1] S. Rauen,[2] M.A. Davis,[2] W.M. Peters,[1] E.J. Polisensky,[1] E.M. Twarog,[1] and R.W. Harry[3]
[1] *Remote Sensing Division*
[2] *Space Systems Development Department*
[3] *Spacecraft Engineering Department*

Introduction: The tracking of missiles at close range proximity has been an ongoing challenge for many launch environments. The ability to provide accurate missile trajectory information is imperative for range safety and early termination of flight. In an effort to provide a potential solution to tracking issues that have plagued many traditional techniques, the Tracking Interferometer Pathfinder System (TIPS) was developed at the Naval Research Laboratory through the joint cooperation of the Space Systems Development Department's Advanced Systems Technology and C4I branches and the Remote Sensing Division's Radio/IR/Optical Sensors and Remote Sensing Physics branches. This partnership provides a unique solution for missile tracking.

In the past, radar and optical techniques have been used for short-range tracking with mixed results. Radar systems have experienced issues with multipathing, clutter, and range gating. Expended rocket stages contribute additional problems in tracking by disguising the primary target. Optical systems have had difficulty with varying cloud cover and nonoptimal viewing conditions. An alternative to the previous methods is a passive interferometer, offering several benefits over other tracking techniques: all-weather operation, constant day/night imaging, no moving parts, and no radio frequency emissions.

System Overview: A traditional interferometer is a passive system in which multiple receivers "listen" to a signal at a particular frequency, in this case, at the S-band microwave spectrum. Each receiver uses an antenna that is arranged into an array consisting of many antennas. The arrangement of the antennas in the array affects the resolution and features of how the interferometer interprets received signals into a processed image. By varying the positions of antennas in relation to each other (Fig. 4), both constructive and interfering responses are produced. By overlaying interference patterns produced by unique antenna pairings, an image can be formed (Fig. 5). The raw images produced can be cleaned by the use of thresholds that filter the data in a noise reduction process.

Interferometric techniques make use of sparse arrays by employing multiple antennas to encompass a limited area of a large, equivalent diameter dish antenna. Essentially, smaller antennas (7.5 cm in diameter) fill in the region of what would be a much larger antenna (3 m diameter in the case of TIPS, which is the largest spacing of antenna pairs). Additional receiver channels will reduce the noise of the imaged scene by providing more antenna pairings that fill in the array, canceling sidelobe noise to provide positive reinforcement of the interference patterns.

TIPS consists of 16 receiver channels packaged into a single box. Spiral horns are used for their inherently broad beamwidth (60 degrees, half power beamwidth for TIPS), allowing a large field of view. A custom data acquisition system, developed by a vendor for an aircraft-platform interferometer, was leveraged for the analog-to-digital data capture of the 16 channels. In addition to the phase alignment of all channels to a master reference, an important aspect of the data capture is the time synchronization of the channels for simultaneous triggering at specific data collection intervals. The data are oversampled at a continuous rate of 200 MHz to minimize target motion in the tracking process. The relatively fast sampling provides a dataset that can then be evaluated for future missions so as to determine the optimal sample rate, thus streamlining data in practice.

Typically, interferometers have relied on hardware correlators to process phase and magnitude information received by the antenna pairs. In the system

FIGURE 4
Tracking Interferometer Pathfinder System (TIPS) deployed at the Kauai Test Facility. Inset: A spiral antenna.

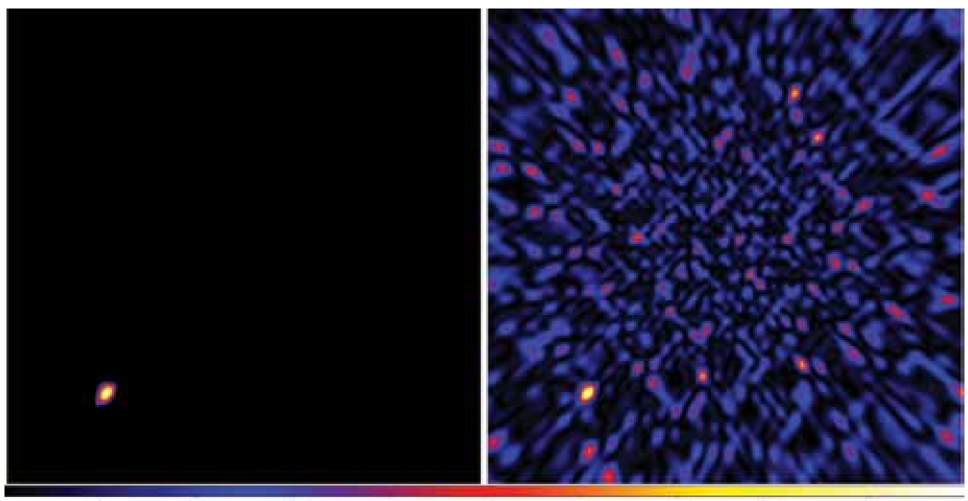

FIGURE 5
Snapshot of images from August 30, 2011, prior to missile launch. Left, image of telemetry transmitter aboard missile on launch pad with noise reduction applied. Right, raw image of transmitter. Color bar indicates normalized signal intensity values.

implemented for tracking purposes, NRL developed a software correlator that uses digital processing techniques to rapidly determine phase relationships of the antenna pairs. The software correlator greatly reduces the size, weight, power, and complex tuning that would otherwise be required of a hardware correlator.

Test Deployment: A pathfinder system was requested by the program sponsor with the goal of a field experiment to test the viability and accuracy of the conceived design. The Pacific Missile Range Facility (PMRF), in conjunction with the Kauai Test Facility (KTF), located in Kauai, Hawaii, was chosen as the test site. The test missile to be used included a telemetry transmitter for standard operation. It was recognized in the design proposal that this internal transmitter would also provide a signal for system keying and allow phase information to be derived.

TIPS was designed and built within 6 months at NRL and installed during August 2011 at KTF. The array was attached to an antenna positioner to allow the boresight of the array to be aligned in a manner that would capture T–0 to T+10 seconds of flight, basically allowing the target to streak across the imaging field of the system (Fig. 6).

On August 30, 2011, TIPS tracked a vehicle launched from KTF (Fig. 7). The immediate 10 seconds after launch was the critical window of interest to program sponsors, as this is the time during which crucial termination protocol measures are implemented. The threshold requirement for a fully developed solution is a total track accuracy of 25 m. The pathfinder sensor was able to achieve tracking accuracies of better than 5 m in T+3 seconds of launch, and better than 25 m across the extended tracking window when compared against best estimate trajectories.

Summary: TIPS successfully demonstrated a missile tracking ability using interferometric techniques. The ability of the interferometer to be unperturbed by factors in the launch environment provides a needed requirement for early missile tracking. The TIPS pathfinder has shown that it can be used as an integral part of a potential range safety program. A follow-on sensor is currently being designed that will extend the accuracy and overall response time for future missions.

[Sponsored by the Missile Defense Agency]

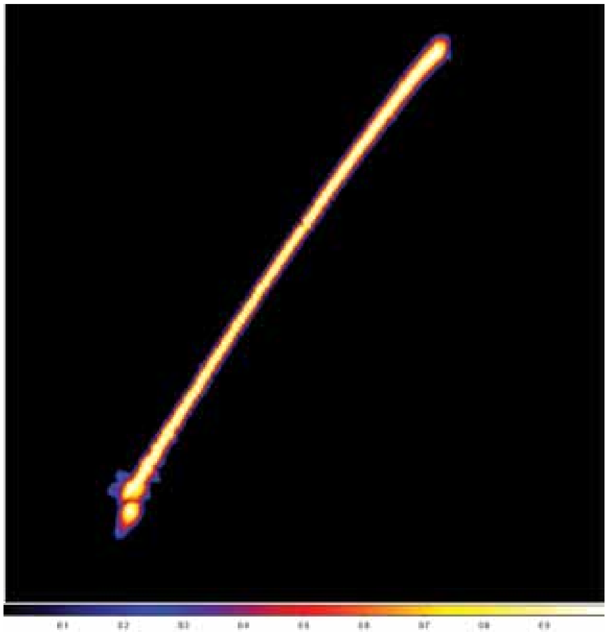

FIGURE 6
Tiling of the interferometric images to produce a 10-second track.

FIGURE 7
The launch platform at KTF shown with a target similar to that used for the TIPS mission.