5.3 SHARING SCIENCE AND TECHNOLOGY WITHIN THE INTERAGENCY

Jonathan Medalia

INTRODUCTION

There are multiple paths to a terrorist nuclear weapon, and as if to emphasize and confirm the point, a recent edition of *The Washington Post* [1] quoted David Kilcullen, one of the world's leading terrorist experts. He said, "We're now reaching the point where within one to six months we could see the collapse of the Pakistani state." If terrorists were to acquire a bomb, the main and last line of defense would be nuclear detection technologies.

I will explain how detection works, give a few examples of detection technology, and discuss several lessons and thoughts for interagency and other forms of coordination. I should emphasize that this talk represents my personal views and not necessarily those of my employer, the Congressional Research Service.

THE SCIENCE

One must learn a bit of science to understand nuclear detection. Nuclear weapons use fissile material. What is important

Dr. Jonathan Medalia is a Specialist in National Defense at the Congressional Research Service, where he has worked for many years on nuclear weapon policy issues for Congress. These issues include MX, Trident, nuclear testing, nuclear weapon laboratory demographics, the Comprehensive Test Ban Treaty, stockpile stewardship, nuclear and radiological terrorism, and most recently the Robust Nuclear Earth Penetrator, Advanced Concepts Initiative. He received a bachelor's degree from Cornell University and a master's degree and Ph.D. from Stanford University. He received a Doctoral Research Fellowship from the Brookings Institution and a Postdoctoral Fellowship from MIT.

about fissile material is that it can be fissioned or split by neutrons traveling at any speed, fast or slow.

In a large enough piece of fissile material, fission releases neutrons that release more neutrons, resulting in a runaway chain reaction that releases vast amounts of energy. The two main types of fissile material are uranium highly enriched in the isotope 235, which is called highly enriched uranium (HEU), and plutonium, especially isotope 239. Collectively, they are called special nuclear material (SNM).

Nuclear weapons and SNM have various signatures by which they can be detected. As we will see, detection is difficult but not impossible. I will discuss five of these signatures.

Gamma Rays

Gamma rays are high-energy photons emitted when an atomic nucleus decays to a lower energy state. The energies of gammas from a particular isotope may be depicted in a spectrum, which is a plot of energy versus number of counts at each energy level (Figure 1). The bottom axis is the energy and the vertical axis represents the counts. There are different peaks at different energy levels. This spectrum is unique to an isotope; if you can identify the spectrum, you can identify the isotope that caused the spectrum.

However, there are several detection problems. A cargo container may hold items containing nonthreatening radioactive material, and dirt may generate background gamma rays. As a result, spectra of several radioactive isotopes may be commingled so that the threat signature must be distinguished from the others. Another difficulty is that HEU is hard to detect because its main gamma ray—as we see on the far left in Figure 1—is a relatively low energy. If terrorists were to build a bomb, they would prefer to use HEU because, unlike plutonium, it can be used to make a gun-assembly bomb, the simplest design. Plutonium is easier to detect. Yet another problem is that dense material can be used to shield gamma rays.

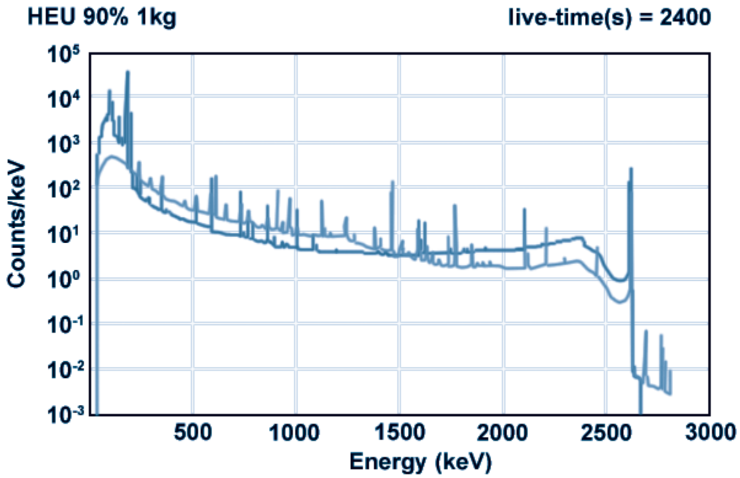

Figure 1 Gamma Ray Spectrum of HEU Taken with Geranium Crystal

Neutrons

Neutrons offer a second signature. Plutonium and uranium to a much lesser extent emit neutrons spontaneously, but few other materials do, so detection of neutrons is suspicious.

Size and Density

Third, a bomb may be detected by its size and density. High-energy photons can be beamed through a cargo container to produce a radiograph, just like a medical x-ray. A nuclear weapon would show up on a radiograph because it is dense, as would lead shielding.

Muons

A fourth signature comes from muons, which are heavy, subatomic particles that are caused when cosmic rays strike the Earth's upper atmosphere. They travel at nearly the speed of light. Their mass and velocity make them very penetrating. When they strike matter, they are deflected in proportion to its density. The high densities of uranium and plutonium would result in a different deflection pattern than plastic.

Flourescence

Fifth, ultraviolet light causes certain materials to emit light in a process called fluorescence. The ultraviolet raises the electrons to a higher energy state, and they emit light when they drop back to a lower energy state. Similarly, when a nucleus is struck by photons of precisely the right energy, it will emit gamma rays in a spectrum unique to that isotope.

This science that I have just discussed forms the basis for technology projects. A detector system has building blocks. Detector material captures photons or neutrons and converts their energy into measurable electrical pulses, algorithms process data, and computers to run the algorithms and provide a usable output, such as a display on a computer monitor.

TECHNOLOGY UNDER DEVELOPMENT

Nanocomposite Scintillator

One technology under development is a nanocomposite scintillator. Many detector materials are plastics or crystals. Certain plastics like polyvinyl toluene (PVT) are rugged and cheap, and they can be made in large sheets. However, they have poor resolution of gamma ray spectra, so they cannot identify the source of radiation. As a result, they are prone to produce nuisance alarms.

Figure 2 is a spectrum taken with a PVT detector. It shows negligible detail. Contrast that with the spectrum from the germanium detector in Figure 1. Certain crystals, like high-purity germanium, have high resolution and can identify a substance emitting gamma rays, but they are small, delicate, and expensive. Los Alamos is currently mixing nanometer-size crystals in a plastic matrix to develop a detector material with the best features of both; the Domestic Nuclear Detection Office (DNDO), the Defense Threat Reduction Agency (DTRA), and Los Alamos jointly fund this project.

GADRAS

The second technology I want to discuss is called Gamma Detector Response and Analysis Software (GADRAS), the gold standard of algorithms for analyzing a spectrum to determine what material(s) generated it. GADRAS originated in 1985 at Sandia and has continually been updated, especially after 9/11. While many spectrum analysis programs examine spectral peaks, GADRAS analyzes the entire spectrum, which is important because most data are outside the peaks, and shielding and multiple radioactive sources may subtract from or add to the spectrum.

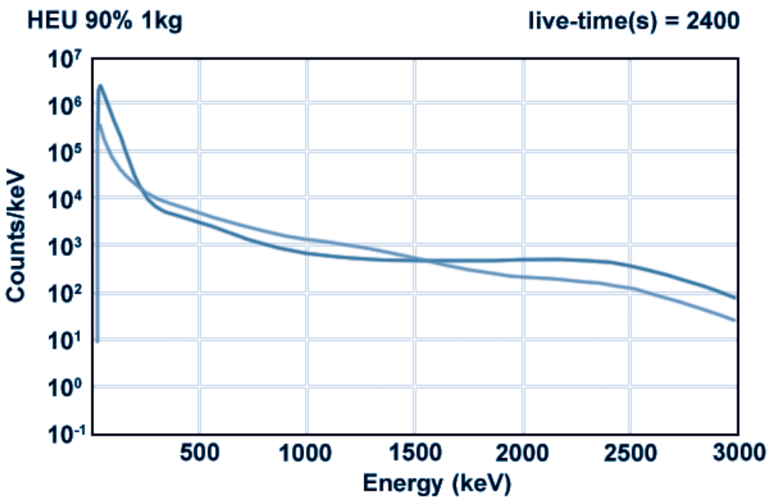

Figure 2 Gamma Ray Spectrum of HEU Taken with PVC

CAARS

A third technology is Cargo Advanced Automated Radiography Systems (CAARS). DNDO started CAARS to develop next-generation radiography equipment for Customs and Border Protection (CBP) to screen cargo at ports of entry. The goal is to detect dense material like uranium, plutonium, or lead. Dense materials are more opaque to high energy x-rays than less dense materials, and both materials have similar opacity to lower energy x-rays. The pixel-by-pixel ratio of the two radiographs of a container taken with x-rays of higher and lower energy permits differentiation between dense and less dense material.

One approach is to use two x-ray generators, one for each energy level. That requires a larger system, which is a problem where available space is at a premium, such as seaports. In another approach, Science Applications International Corporation (SAIC) and Accuracy Corporation developed a single so-called interlaced accelerator that generates x-rays at both energy levels. This accelerator is expected to permit a much smaller system.

Muon Tomography

The fourth technology is muon tomography. Recall that muons are highly penetrating subatomic particles. Los Alamos, through a cooperative research and development (R&D) agreement with Decision Sciences Corporation, has developed an algorithm to calculate the track of individual muons entering and exiting a cargo container. Calculating the deflection of each track is used to determine density of each volume element and locate dense material. This equipment is large but does not generate radiation because it uses naturally-occurring muons, potentially making the equipment of particular value for inspecting cars with passengers inside, such as at border crossings.

Nuclear Resonance Fluorescence

A fifth technology is nuclear resonance fluorescence (NRF). Bombarding an isotope with x-rays of the right energy level can cause the nucleus to emit gamma rays. The gamma rays are emitted in all directions, so by placing a detector behind the object to be detected relative to the x-ray beam, it is possible to detect only those gamma rays that are scattered backwards, minimizing interference from the x-ray beam. Because the gamma spectrum is unique to each isotope, this technique indicates which isotopes are present; for example, it can differentiate between U235, which can be used in a gun-assembly bomb, and U238, which cannot. Note that the gamma spectrum produced by NRF is different than the spectrum emitted through radioactive decay. Passport Systems is developing this system under contract to DNDO.

INTERAGENCY COORDINATION

Coordination might be improved in various ways. Here are two possible forms of international coordination:

1. Foreign governments, corporations, and universities are conducting nuclear detection R&D. Is there a way to coordinate U.S. and foreign R&D and acquisition to reduce overlap with work in the U.S. and take advantage of complementary efforts?

2. Terrorists might be deterred by fear that their attempts to conduct a nuclear strike would fail. Is there a way to coordinate a campaign to communicate to terrorists—indirectly, of course—that the large and growing global portfolio of detection technologies will increase their risk of failure?

Within the U.S., three agencies fund most nuclear detection work: DNDO, a part of the Department of Homeland Security (DHS); DTRA, a part of DoD; and the National Nuclear Security Administration (NNSA), a part of the Department of Energy. Dr. William Hagan, Acting Deputy Director of DNDO, told me that these agencies do coordinate in various ways. They evaluate each other's proposals and participate in each other's program reviews. If a laboratory submits a proposal to NNSA, DNDO and DTRA also know about it, they can decide on a case-by-case basis which agency conducts the work on a project. Sometimes, as we have seen, two or three agencies jointly fund a project. Could coordination be improved?

Improved intra-agency coordination may also be of value. CBP and DNDO are two components of DHS. DNDO funds development of nuclear and other detection technologies that CBP uses to inspect cargo. Some interactions between them have been well coordinated. For example, so-called contextually aware systems for inspecting cargo containers combine data from radiation detectors with data from a container's manifest and other sources to help CBP operators determine which containers merit additional attention. This determination is important to CBP because much of its work involves detecting traditional contraband like guns and drugs.

At the same time, CBP's agents operate the equipment to carry out DNDO's mission of detecting nuclear weapons and materials. Any technology that DNDO can devise to support both missions benefits both agencies.

Other interactions have not been well coordinated. DNDO misunderstood CBP's needs when defining the requirement for CAARS. CBP had a detection facility with an area of 160 by 60 feet, and DNDO thought that was an acceptable size for CAARS. Two of the three CAARS candidates used enclosures that size. However, the CBP system was experimental and much too large for use at seaports, where space is at a premium.

DNDO and CBP have learned from this experience. For example, they established the Joint Integrated Non-Intrusive Inspection Working Group to coordinate work on both CAARS and non-CAARS detection programs. A more general lesson learned is the importance of coordination between technology developers and users.

CONOPS

The success of a detection system requires a concept of operations (CONOPS), one aspect of which is the response if a threat is detected. Think of the detector material as the eyes and ears of a system, the algorithm as its brains, and the CONOPS as its hands. A system needs all three. If a CBP operator detects HEU but cannot use that information, the system is valueless. Thus, it is imperative to develop plans for various scenarios.

What happens if CBP detects something that looks like a terrorist nuclear bomb? Who determines if it is a bomb? Who attempts to defuse it? Who orders an evacuation? CONOPS requires coordination between CBP operators, weapons laboratories, response teams, state and local responders, and many others. Improved coordination or information sharing might also facilitate and increase productivity at the working level.

In preparing my report on nuclear detection, I found that hundreds of detection projects are underway, and work on one project might benefit other projects. However, in speaking with dozens of scientists and engineers, I found that they were often unaware of such work. How can information on these advances be distributed among projects that are funded by different agencies or carried out by competing laboratories, companies, or universities?

Brian Reese, a technical staff member at Los Alamos National Laboratory (LANL), believes that the root of this problem is that there is not a classified forum for disseminating this information outside the intelligence community. He says, "I am reluctant to publish things that skirt a classified topic. There is not even an appropriate forum for publishing For Official Use Only material."

To conclude, the U.S. is working on many nuclear detection projects. Understanding them requires a basic understanding of the science on which they are based, but that science is comprehendable. Improved coordination at various levels should promote more efficient development of nuclear detection capability.

REFERENCE

1. *The Washington Post*, "A Conversation With David Kilcullen," Interview by Carlos Lozada, Sunday, 22 March 2009; Page B02.