Screening Cargo Containers

Livermore scientists are developing a system to search for weapons and fissile materials that terrorists might hide in cargo shipped to U.S. seaports.

EACH year, some 48 million cargo containers move between the world's ports. More than 6 million of these enter the U.S., but only about 2 percent are opened and inspected when they arrive at U.S. seaports. The West Coast ports of Los Angeles–Long Beach, Oakland, and Seattle alone process 11,000 containers per day, or about 8 containers per minute.

Because of this high traffic volume, U.S. seaports are especially vulnerable to a terrorist attack. Illicit radioactive materials could be hidden in any one of the cargo-filled containers that arrive at U.S. ports. Yet, searching every shipment would bring legitimate commercial activities to a halt. Improving security at U.S. ports is thus one of the nation's most difficult technical and practical challenges because the systems developed for screening cargo must operate in concert with ongoing seaport activities.

Working at this intersection of commerce and national security, Lawrence Livermore researchers are applying their expertise in radiation science and detection to develop improved technologies for detecting hidden radioactive materials. One new technology being designed and tested at the Laboratory is a neutron interrogation system for cargo containers. This system will quickly screen incoming shipments to ensure that nuclear materials such as plutonium and highly enriched uranium (HEU) are not smuggled into the U.S.

Balancing Security and Commerce

The Livermore system would bathe suspicious containers in neutrons to actively search for nuclear materials. A truck carrying a container laden with suspicious cargo would be towed over a generator that would bombard the container with neutrons. It would then be towed through an array of detectors, much like driving through a car wash. If the

to Remove a Terrorist Threat

neutrons encountered any fissile material shielded and hidden among the container's contents—whether produce, clothing, electronics, lumber, automotive parts, or other consumer goods—the interaction would induce tiny fission reactions. These reactions would produce the telltale delayed gamma rays of nuclear materials, which would be picked up by the detectors.

The Livermore system is not intended to screen every container entering a U.S. seaport. Instead, it will be used on the suspect cargo identified by screening procedures, such as radiography or passive radiation inspection, that show some of a container's contents.

The 19-member project team draws on the talents of personnel from Livermore's Engineering Directorate as well as the Physics and Advanced Technologies; Chemistry and Materials Science; Safety and Environmental Protection; Nonproliferation, Arms Control, and International Security (NAI); and Computation directorates. "To some approximation, we work like a soccer team of 8-year-olds," says project leader Dennis Slaughter, technical director of Livermore's 100-megaelectronvolt (MeV) electron linear accelerator (linac). "By that, I mean we all follow the ball. There are no established positions. Everyone 'turns to' the urgent task, and we all help each other without disciplinary distinctions."

Originally funded by Livermore's Laboratory Directed Research and Development effort, the detection project was picked up by the Department of Energy (DOE) in 2003 and is now supported by the Department of Homeland Security (DHS). The Livermore team is focused on developing a system that is not only reliable but also commerce-friendly.

"We want a system that can detect small targets of nuclear material—about 5 kilograms of HEU and 1 kilogram of plutonium—with low error rates of about 1 percent false positive and false negative," Slaughter says. "This system would permit rapid scanning so it wouldn't disrupt commerce. Our goal is to complete the scan and report in about a minute."

An Active Interrogation System

Slaughter and his colleagues consider active interrogation to be the most promising option for detecting HEU in containers. Even moderate amounts of shielding make it difficult to passively detect radiation emanating from hidden sources. The high-energy, gamma-ray signature produced when neutrons interact with nuclear material is unique, so the liquid scintillation detectors can readily distinguish it from the signature for normal background radiation.

The neutron scan would pose few risks to cargo. Most residual radioactivity would dissipate within seconds after the scan. In the team's experiments, radiation dose rates were low.

The team is also working to minimize potential risks to the people who will operate the equipment. The project goal is to limit radiation exposure to the normal allowable doses specified in federal standards for the general public. "Because people might be inside a container during irradiation," says Slaughter, "we want the radiation dose to be too small to cause harm."

Slaughter hopes to see such a system as a regular part of cargo container security at U.S. ports. Eventually, it might also be used at foreign ports to scan containers before they are loaded aboard U.S.-bound ships. Since 2002, the Livermore team has done considerable work related to basic science and engineering of the system, developing the detector and establishing requirements for the neutron generator. Research has been conducted at Livermore and at the 88-inch cyclotron at Lawrence Berkeley National Laboratory (LBNL). The team's timetable is to build a research prototype and evaluate it in a laboratory setting during 2005 and field a vendor prototype at a container port in 2006.

Detecting the Gamma-Ray Signature

Use of a high-energy, gamma-ray signature to detect nuclear materials in containers was proposed by Stanley Prussin, a professor of nuclear engineering at the University of California (UC) at Berkeley, and Eric Norman of LBNL. Prussin, now the chief scientist for the cargo container project, has long consulted with the Laboratory's NAI Directorate. He became involved with the cargo container effort in the summer of 2002 while on sabbatical at Livermore to work on an unrelated project.

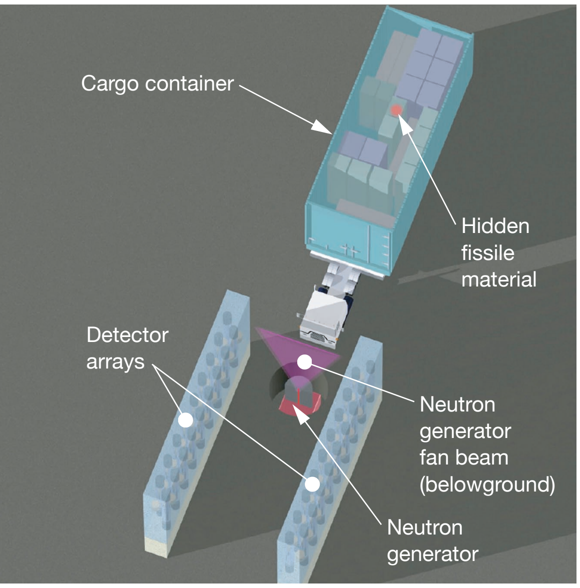
Prussin was familiar with Slaughter's work and attended a meeting at which modelers discussed the container effort. He says, "It didn't take too long for me to become convinced that, under their defined worse-case condition, we ought to take another look at the technique they were modeling."

Rather than high-energy gamma rays, the Livermore team originally considered a system that counted delayed neutrons emitted by neutron-induced fission. Delayed neutrons are emitted from a fraction of a second to a few minutes after fission and have lower energies than the fast prompt fission neutrons. Although delayed neutrons can be a reliable indication of nuclear materials, their yield is low.

Prussin noted a difficulty with using delayed neutrons: Hydrogenous cargo—fruits and vegetables, canned meats, wood, plastics—can absorb the short-lived neutrons and thus might interfere with the delayed neutron count.

"Any system we develop must look for fissionable materials that will be well shielded," says Prussin. "If the material is shielded by hydrogenous material, the probability for the delayed neutrons to actually escape from the container into an external detector is very small. In the U.S., we import almost everything under the sun, and many of those imports are hydrogenous."

Instead of the delayed neutron count, Prussin suggested the team measure the gamma rays emitted. Fission products make numerous gamma rays that have comparable decay characteristics of delayed neutrons. Yet, says Prussin, the probability of the neutron-induced gamma rays escaping from the container through hydrogenous material is about 1,000 times greater than it is for delayed neutrons.



The design for the detector system calls for a belowground neutron generator that would bathe containerized cargo with neutrons. Interaction of the neutrons with fissile material inside the container would produce fission, followed by delayed gamma rays detected by an array of liquid scintillators as the container moves through the system.

In 2003, Prussin and Slaughter worked with Norman to arrange for a series of experiments, funded by DOE's Office of Science, at LBNL's 88-inch cyclotron. The first experiment was conducted using a deuteron beam on a beryllium target. The researchers also bombarded well-shielded sample targets of uranium-235 and plutonium-239, irradiating each sample for 30 seconds, going back and forth to get enough statistics for a relevant evaluation.

"The high-energy gamma rays essentially represent a unique signature that fission has occurred," says Prussin, "both because of their energies, which are above 3 MeV, and because of their temporal behaviors."

Researchers followed up the LBNL measurements with signature verification experiments at a new laboratory commissioned at Livermore for scanning cargo containers. The laboratory houses a 6-meter container provided by APL, one of the world's largest container transportation companies, and gives the researchers a realistic testing environment. In these experiments, they irradiated a 22-kilogram target of natural uranium with a beam from a 14-MeV neutron source. Their results confirmed the intensity of the signature in a realistic cargo-scanning configuration using 150 grams of HEU and a low-intensity source.

Good Results with Simulated Cargo

In studies using simulated cargo stacked around the target, the gamma rays produced were very intense, between 2.5 and 4 MeV. The neutron beam energy must be high enough to penetrate the cargo but low enough to avoid interfering activation. (The research indicates the neutron source should be between 5 and 8 MeV.) Although gamma radiation is 10 times stronger than delayed neutrons, it is weak but detectable, and high-resolution detectors are not required to measure it. Large arrays of low-resolution detectors, such as liquid scintillators, can be cheaply produced and easily deployed.

One question the team must resolve is what accelerator characteristics are required for practical field applications. "Accelerators that can give the appropriate deuteron beam energy intensity on the appropriate target can, in principle, be manufactured commercially and for a reasonable amount of funding," Prussin says. "We don't know that one has been constructed for the exact conditions we'll specify, and we may have some technical issues to address. But our requirement is not for a scientific system. What we will want is a much simpler device."

Meanwhile, the team wants to resolve some problems found when using Monte Carlo codes to mock up experiments and test them on the computer. "We are developing a method that seems likely to serve our purpose," says Prussin. Experiments on irradiation of uranium, which will be conducted at LBNL, are being designed to help the researchers understand how well the computational procedures represent the experimental data.

Simultaneously, efforts are moving forward to develop a large array of liquid scintillators that are sensitive to both neutron and gamma rays. As currently envisioned, the design includes a bank of 20 liquid scintillator–filled tubes spanning each side of the car wash.

Benefits of Liquid Scintillator

Liquid scintillator is a good candidate material for the cargo interrogation problem. It has a fast response time, and it can be inexpensively instrumented to scan a large volume of material, which helps to ensure that a large fraction of the particle flux emitted by the neutron-irradiated nuclear material will be detected. Livermore physicist Adam Bernstein, who leads the detector design team, says, "Neutrons and gamma rays create a 20-nanosecond pulse of blue light when they scatter in the medium, and this fluorescent pulse can be detected in photomultiplier tubes.” Such detectors can be used in various cargo detection and interrogation scenarios. For example, even with the neutron source off, the detector array may still be sensitive enough to scan cargo for some types of radioactive materials of concern.

The segmented array, which has a response time of about 100 nanoseconds or better, would indicate the location or spatial extent of radioactive material hidden in the cargo. “By establishing the geometric extent of the radioactive material,” says Slaughter, “we can better differentiate cargo with small amounts of uranium distributed throughout from normal cargo with a small component of nuclear material hidden in it.”

“The liquid scintillator project dovetails nicely with the Laboratory’s mission,” says Bernstein. “Livermore in general is a center for radiation detection because of nuclear weapons and other nuclear physics research.” He adds that the liquid scintillator work is building on a detection technology that has been used for years in high-energy physics. “These types of detectors are often used in fundamental physics research, where we engage in neutrino physics and dark-matter searches, but not for practical applications such as fissile material detection. In this project, we’re taking a technology that’s a workhorse in high-energy physics and applying it in the real world.”

Using liquid scintillators in such applications brings its own challenges for detector designers. “We have a lot of work to do in developing the algorithms for the gamma-ray signal that comes out of cargo containers,” says Bernstein. “We want to process the signal in a different way than we do in a physics experiment where we don’t have any time constraints and we can wait to obtain data. In this application, we have about a minute to decide whether the cargo container is suspicious or not.”

APL, one of the world’s largest container transportation companies, provided Livermore researchers with a 6-meter container, which gives them a realistic test environment in the container laboratory.

Keeping the false-positive and false-negative rates low is another technical issue facing the designers. “We want to optimize the signal-to-background ratio as best we can,” says Bernstein, “and we’ll have to establish the number of false positives that are acceptable. For example, if a few hundred cargo containers go through the car wash each day, a false-positive rate of 1 percent might be unacceptable because that could mean you stop the chain once a day to remove a container for closer inspection.”

Another challenge is to develop a robust system, one that can work continually for months or years and that can be operated by people who are not experts in radiation detection. “People frequently underestimate that aspect of the development process,” Bernstein says.

Members of the team built a small prototype of a 0.6-meter-tall detector, which they successfully tested. This spring, they are working with an array of four detectors, each 2 meters tall and 20 centimeters in diameter, and according to Bernstein, the team expects this testing to result in some iterations of the design. By the end of 2004, the team hopes to be working on a larger array that would cover one side of the car wash.

“By January or February 2005, we should have the full array,” says Bernstein. “We most likely will build it at Livermore. While we’re designing the prototype, we’ll also try to make the system portable, so we can take it into the field—and possibly test it at a port.”

Slaughter is hopeful that by 2005 the Laboratory team will add a commercial partner to develop a system that could eventually be deployed in the fight against global terrorism.

—Dale Sprouse

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