Imaging Cargo's Inner Secrets

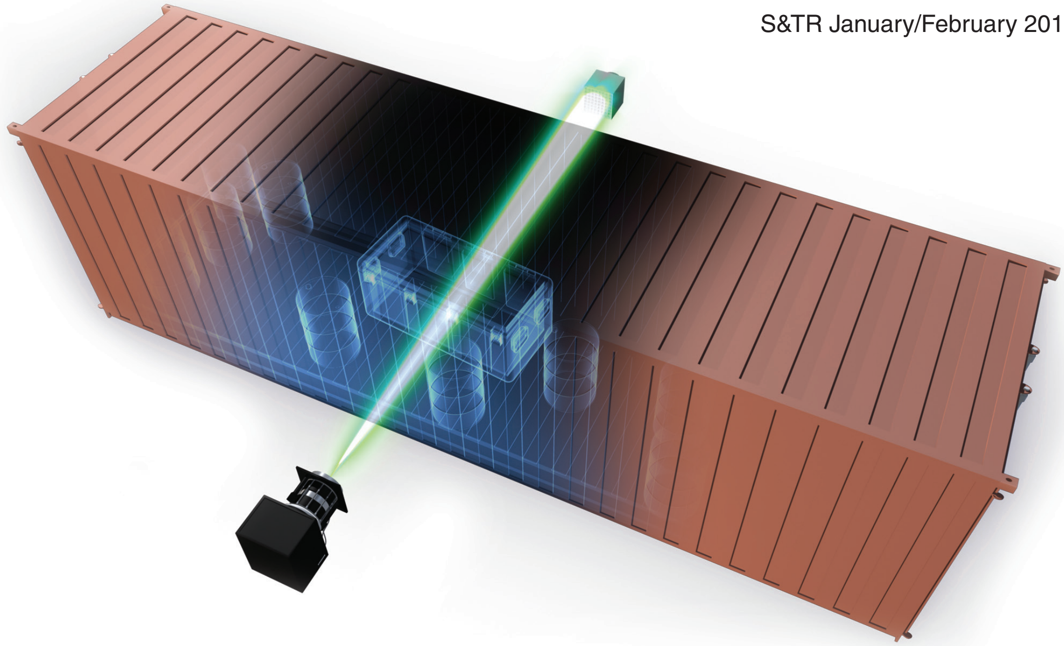
EACH year, millions of cargo containers from around the world are shipped to U.S. ports, holding in their metal "bellies" a variety of essential goods such as food and textiles. While this method of importing freight is necessary for the nation's livelihood, monitoring the contents in such a vast volume of containers poses a challenge to homeland security experts. The events of September 11, 2001, brought transportation security issues into the limelight, including the need to ensure that cargo containers coming into U.S. ports are not carrying clandestine fissile materials.

One of the difficulties scientists face in developing detection technologies for homeland security is how to accurately and efficiently identify hidden nuclear materials without significantly slowing commerce or, worse, bringing it to a halt. With funding from a grant through the University of California (UC) Office of the President, Livermore physicist Marie-Anne Descalle and UC Berkeley collaborators are studying the effectiveness of a radiographic imaging technique for use as a primary screening tool to rapidly scan cargo shipments. "To be effective," says Descalle, "the technology must be able to identify high-atomic-number elements [high-*Z*, where *Z* is greater than 72] within a minute or less."

In previous modeling studies performed by the UC Berkeley collaborators, Monte Carlo simulations showed that the proposed radiographic method has the potential to identify small quantities—0.1 kilograms—of uranium and plutonium within containers filled with homogeneous cargo. The method, which measures high-energy photons transmitted through a material, could potentially detect other high-*Z* materials used as shielding for particular objects. Screening authorities applying the technique could greatly minimize the number of suspect containers, identify possible materials of interest, and then permit definitive searches as warranted.

Narrowing Down the Suspects

Current cargo screening methods typically take one of two forms. In the first method, a truck carrying radiographic equipment scans a row of containers using gamma or x rays. Similar to the way medical x-ray machines capture internal images of people's teeth and bones, this process produces a two-dimensional image of the insides of a container. Inspectors then compare these radiographs to information in the shipping manifests to determine whether additional searches are necessary. Another screening method involves reviewing the manifest, opening the container, and performing a visual inspection. In either case, the process can be quite time-consuming and is not practical for checking millions of containers.



A Livermore–University of California team is studying a more efficient approach to rapidly scan cargo containers for illicit materials. On one side, a light source directs a photon beam through a container. On the opposite side, a detector with an array of pixelated scintillators measures the photon energy spectra emerging from the container to generate a radiographic image of the contents. (Rendering by Kwei-Yu Chu.)

A more efficient approach for identifying illicit materials is being studied by the Livermore–UC Berkeley team. This method uses a new photon-based radiographic technique to rapidly scan each container, which would allow port authorities to narrow the number of suspect containers in a short time and thus facilitate the flow of commerce. Stanley Prussin, a professor of nuclear engineering who leads the UC Berkeley work, says, "Our proposed primary screening process has the potential to rapidly scan containers with a high probability that 99.9 percent of the containers will not require further inspection." Containers that warrant closer examination would undergo a secondary screening during which authorities would either physically inspect the container or use other radiation detection techniques to definitively analyze the contents.

The team's research builds on a previous Livermore–UC Berkeley collaborative project known as the "nuclear car wash." (See *S&TR,* May 2004, pp. 12–15.) In this detection scheme, a container-laden truck passes over an underground generator that propagates neutrons through the cargo. Similar to driving through a car wash, the truck then proceeds through an array of large plastic scintillators that detect high-energy delayed gamma rays emitted when neutrons interact with fissile material. One concern surrounding this method is that the neutron irradiation would induce some radioactivity. According to Prussin, "Our new approach uses photons that are unlikely to produce radioactivity or would induce such low-intensity radioactivity that it would be negligible."

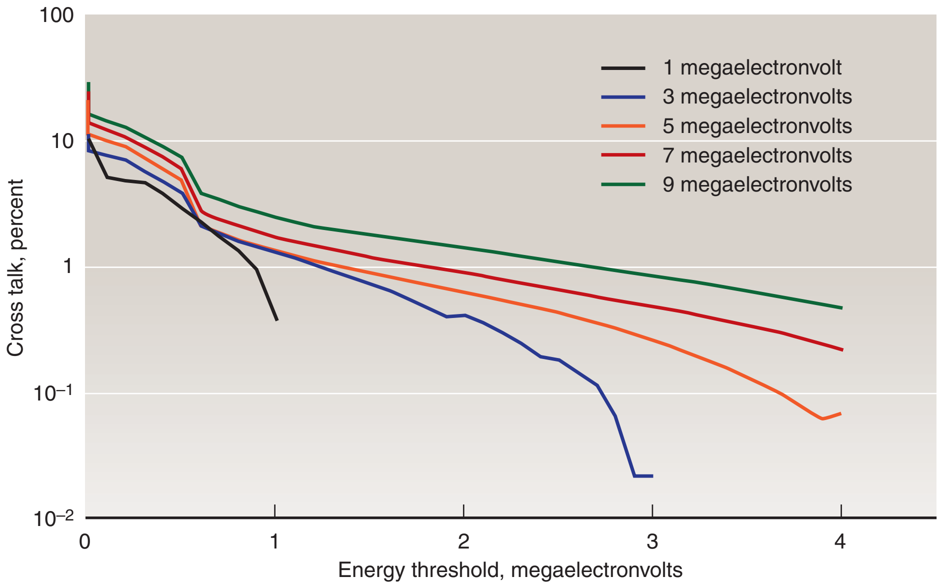
Small Target, Big Container

Intermodal cargo containers are typically 2.5 meters in height and width, 6 or 12 meters in length, and carry up to 27 metric tons of freight. Thus, finding a small amount (less than 1 kilogram) of hidden fissile material among a container's contents is akin to finding the proverbial needle in a haystack. Prussin says, "Our method is unique because we can in principle detect very small amounts of material, exceeding the Department of Homeland Security's sensitivity requirement for the Cargo Advanced Automated Radiography System." This system is currently being developed as a general screening method for all cargo containers entering U.S. ports.

The team's detection method uses a photon source to direct a beam of high-energy bremsstrahlung photons (x rays) through the side of a container. Depending on the cargo, the photons will either pass through the container relatively unchanged, be completely absorbed by the material inside, or undergo Compton scattering. In the last scenario, lower energy photons are produced when high-energy photons collide with atoms and then lose energy as they "bounce" off the atoms in various directions from their original trajectory.

On the opposite side of the container is a detector with an array of pixelated scintillators that measure all photons emerging from the container. "The intensity, and to some extent the energy spectrum, of the detected photons will be quite different if a material of interest is present in a container," says Prussin. "Those measurements will show us whether a container holds something of concern."

Each photon that reaches the detector produces a signal on an individual pixel. The spatial distribution of the material inside the container as well as the energies of the photons are determined from these signals. Ultimately, researchers plan to place two pixelated detectors at different angles to the container, one at the side and the other at the top, to create a more detailed radiograph that will allow them to see an object of interest and determine its dimensions. They will then use the dimensions and the estimated intensity of the source photons that have passed through the container without any interaction to derive the object's linear attenuation coefficient (a function of material density and atomic number). "The challenge is how to distinguish these photons from photons of the same energy that arrive at the detector after having been scattered one or more times," says Prussin.



Monte Carlo simulations help the team to determine the amount of photon signal that scatters from one pixel to another (cross talk). Colored lines indicate the amount of cross talk in one adjacent pixel as a function of the energy threshold when individual monoenergetic beams of varying energies are focused on the center pixel. These data are necessary for determining the effectiveness of the shielding used in the detector. This simulation used 1-millimeter-thick tungsten between each pixel.

Proving the Theory

Descalle, a Monte Carlo simulation expert, leads the modeling effort. The simulations support the experimental campaign and allow the team to explore spaces with larger parameters than would be possible experimentally. Initial simulations determined the requirements for the detector and proved the overall efficacy of the method. Descalle began by modeling various well-characterized materials that could be used for building the detector to establish which ones would provide the best spatial resolution and highest efficiency. Perhaps one day soon, new materials (see the article beginning on p. 4) will provide even greater resolution and efficiency.

Simulations helped the team troubleshoot issues related to detector design. For example, they assessed the effectiveness of materials that could be used to shield each pixel within the detector array. Without shielding, photons coming into the detector would bounce between pixels, which would affect the team's ability to distinguish where the photons originated. "The simulations helped us identify which materials would provide the best shielding and how much shielding would be necessary," says Descalle. "We determined 1 millimeter of tungsten between each pixel would provide the most effective shielding." A prototype detector is now being built that consists of 64 pixels with individual pixel sizes of 0.6 square centimeters.

With the detector design complete, the team is focused on simulating how the method will perform under less than ideal conditions. "We are now modeling the physics of the photons interacting with the cargo and the detector material," says Descalle. "Using simulations, we can model spectra that resemble the energy spectra we expect to see in an actual detector." Additional simulations will verify whether obtaining more images of the container at different angles would improve accuracy. The set of images could be combined using reconstruction algorithms to better identify high-*Z* materials in three dimensions and approximate linear attenuation coefficients.

The Best of Both Worlds

The Livermore–UC Berkeley team, which also includes professor of nuclear engineering Kai Vetter and two student researchers, began the project in May and will continue perfecting its method over the next three years. Once the researchers demonstrate through simulations that the detection scheme can work under a variety of conditions, they will focus on building a second prototype. "Ultimately, we want to test the detector with surrogate and real materials to assess if it will perform as expected," says Prussin.

The success of the project thus far is very much a team effort. "We are making the best use of the expertise inside the Laboratory and the flexibility of academia to pursue an idea that is important to the public interest," says Prussin. With a little time, hard work, and high-performance computing power, the nation may soon have a more effective mechanism for revealing what is hidden inside the dark recesses of cargo containers.

—Caryn Meissner

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For further information contact Marie-Anne Descalle (925) 423-9660 (descalle1@llnl.gov).