SEEKING OUT HIDDEN RADIOACTIVE MATERIALS

New technology and improved training help first responders to better locate and characterize radioactive materials in the field.

THE specter of terrorists setting off a homemade device containing radiological or special nuclear materials in a densely populated urban area is a harrowing prospect. In such a scenario, finding the device before it explodes would prevent a catastrophe. But should the worst occur, the ability of first responders to accurately locate and effectively identify radioactive contamination would save many lives.

Two groups in Livermore's Global Security Principal Directorate are working on different yet complementary approaches to more efficiently and expertly locate and characterize radioactive materials. The first project, supported through internal Laboratory funding, aims to make training exercises vastly more realistic for first responders who would be called upon in the aftermath of a radiological or nuclear incident. The second, funded by the National Nuclear Security Administration (NNSA), is designed to enhance the effectiveness of searches for radioactive materials in urban areas.

Creating a Realistic Situation

Steven Kreek, leader of Livermore's Nuclear Detection and Countermeasures Research and Development Program, is heading the effort to dramatically improve radiation-detection training. The challenging goal is to provide realistic radiation signals for high-hazard sources that first responders may encounter in an actual incident without such sources being present. Training exercises do not generally use high-hazard radiation sources for reasons of cost, logistics, safety, and security. As a result, training scenarios that would involve highly radioactive radionuclides, such as a post-explosion contamination zone with varying concentrations and compositions of these materials, are unfeasible to construct and execute.

"An important role of government is to ensure we have emergency responders adequately trained to deal with true radiation hazards, such as high-intensity sources that are present either through accidents or acts of terrorism," says Kreek. "Current training and exercises for first responders are inadequate and artificial because trainees cannot practice with their own equipment and exercise with sources of health concern."

Current training with high-hazard sources requires an on-site health physicist federal license and security guards to ensure the source is controlled. Development team leader and computer scientist Greg White says, "Training is not effective if the hidden source is inevitably located close to the person wearing a yellow vest who is trying to act casual."

Alternatively, pinhead-sized point sources can be used, but these materials do not represent real threats because of their nonhazardous strength and inability to be widely distributed in a mock contamination zone. Kreek says, "We need to train responders to find both high-hazard point sources and to work in extensively contaminated areas."

In an effort to enhance realism, some training managers have turned to virtual reality. "Virtual exercises can only go so far," says Kreek. "They don't allow operators to train with actual instruments or fully experience the environments first responders are most likely to face."

Kreek's team has been working to make possible far more realistic training without radioactive sources using a Livermore-developed instrument called the Spectroscopic Injection Pulser (SIP). The early prototype device, a 10-square-centimeter black box with a small liquid crystal display, attaches to a radiation detector's exterior.

SIP injects preprogrammed high-fidelity signals for any isotope or mixtures of isotopes at a given location into the detector's amplifier. "To the detector and the trainee, the signals appear to be generated by a true source," says White. SIP mimics in detail not only the preselected source's spectral shape but also the statistical randomness of radioactive signals and the variation of signal strength with distance.

Depending on the goals for a particular exercise, instructors decide on what and how many radiation sources are included as well as their respective strengths, distribution, and global positioning system (GPS) locations. The SIP then generates the radiation spectra and associated signal strength for any location within the training exercise area. Based on their location, trainees see the same count rate, spectrum, and dose rate on their instruments as they would if the point source or distributed sources (within a contamination zone) were actually present. Trainees can also see background radiation rates that are common to a given area. After training, the SIP is simply detached from the detector, returning the instrument to normal function.

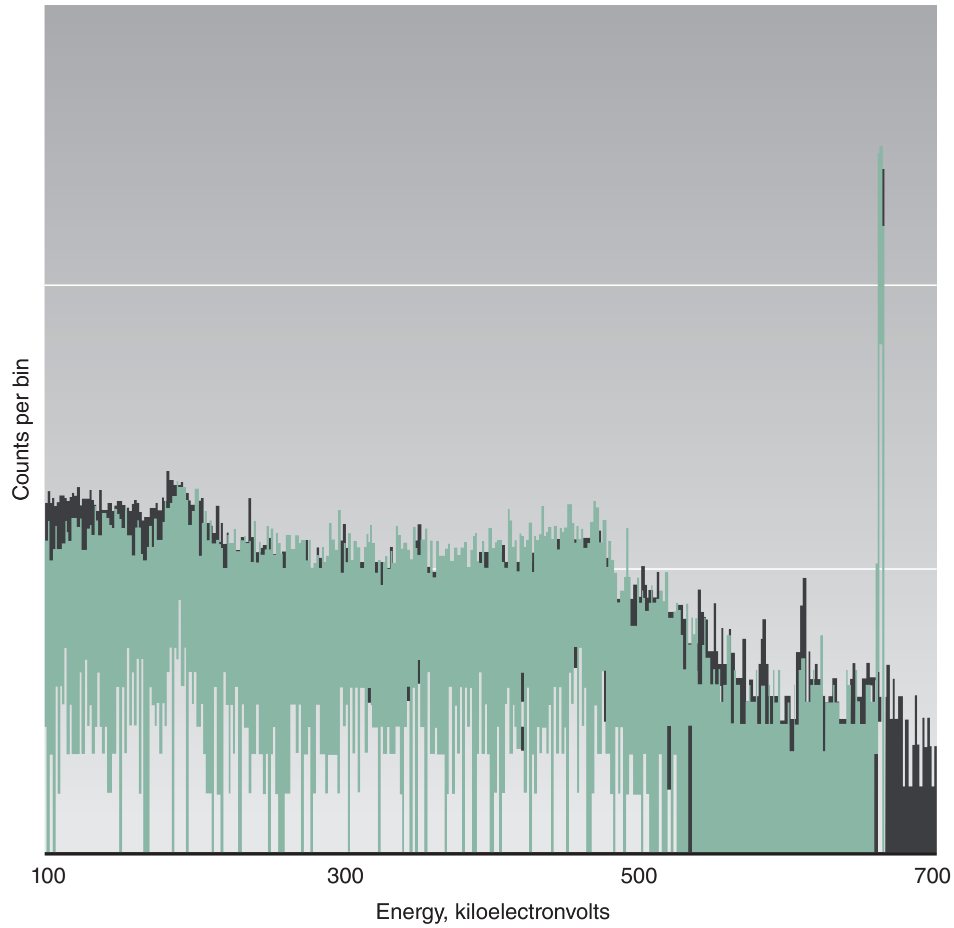
Training exercises, such as the one shown here wherein unsuited Livermore scientists monitor suited first responders, cannot include high-hazard radiation sources. Livermore researchers are developing the Spectroscopic Injection Pulser (SIP) to make radiation-detection training more realistic.

Technology Evolution

The SIP concept was first proposed by Livermore physicist S. John Luke as part of a nonproliferation project. Luke conceived of a device that mimics the pulses generated by a high-purity germanium detector as a way of gaining confidence in laboratory results. The original device was a laboratory instrument plugged into a wall outlet and tied to a desktop computer. Over several years, each generation of prototypes became significantly less expensive and smaller than its predecessor. Kreek and the development team recognized the pulser technology's potential as a training tool if it could be combined with modern capabilities found in a mobile phone, including GPS.

"We reasoned that if we could base the radiation signal on a trainee's location, the unit could keep track of that person's location and generate the appropriate signal," explains Kreek. "The unit generates weaker or stronger responses depending on the person's distance to the virtual source." The unit would also take into account short-lived isotopes—examining an area immediately after a simulated spill of medical isotopes would yield much different detector readings one day later. In addition, a command mode for the exercise leaders would indicate the location of sources or an entire contamination zone, track trainees' locations and responses, and monitor the synthetic count rate, dose rate, and spectra of trainees' instruments. These data would improve exercise execution and inform future detection exercises and response scenarios.

The current development effort is focused on embedding GPS, wireless, and field-programmable gate arrays into a battery-powered, credit-card-size Raspberry Pi computer. The team plans to have a prototype capable of injecting GPS location-dependent signals into a detector and to perform a demonstration by October 2016. The long-term goal is for a similarly miniaturized device to include a variety of network options, share signals across the network, and seamlessly operate with multiple detector types.



Actual (black) and SIP-generated (green) spectra for cesium-137 are essentially indistinguishable.

Tablet Showcases Capabilities

To demonstrate SIP's potential, Livermore researchers in 2012 developed software for a tablet computer that approximated a miniaturized SIP device attached to two different detector types. Coming soon to iOS and Android, the tablet showed how multiple instruments could work in unison in a realistic scenario, including a personal radiation dosimeter that sounds an alarm when a strong source is close by and sophisticated units that reveal the spectra of radioactive isotopes. The team has conducted demonstrations of the technology emulating both synthesized point sources and distributed contamination for representatives from U.S. federal agencies, as well as the International Atomic Energy Agency and the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), both in Vienna, Austria.

People using the tablet saw their location on a GPS map and watched the count rate and spectral information change as they moved closer to or farther away from the virtual sources. Simultaneously, the SIP's wireless communication capabilities permitted instructors to observe trainees' movements, provide guidance, and communicate information to a command center. Instructors could also visualize the extent of the virtual contamination area, something the trainees can only experience from their instrument readings. The SIP's simulated signals currently match those generated by an ORTEC Detective high-resolution gamma-ray detector. In fact, the SIP development team can easily simulate the signals of various instruments. The team is currently seeking to interface the technology with instrument manufacturers through partnership opportunities.

Kreek points out that the Laboratory has a long history of solving radiation detection challenges. For example, the ORTEC Detective has licensed technology from Livermore and is used around the world to identify and quantify radiation sources. The device, which features Livermore's electromechanical cooling system and easy-to-use analysis interface, was used in CTBTO's Integrated

Field Exercise 2014 in Jordan. Kreek was one of several Laboratory scientists and engineers who took part in the exercise. (See *S&TR,* June 2015, pp. 12–15.)

The group has been working with Livermore's Industrial Partnerships Office to encourage manufacturers of radiation detectors to produce equipment that can easily interface with SIP. One company has already modified its instruments to accommodate the technology, and others are considering doing the same. White is leading efforts to port the tablet application from Windows to iPad and Android tablets to demonstrate SIP capabilities on a wider range of platforms—an effort that incorporates work being done by students from the University of the Pacific and Washington State University.

"The SIP technology dramatically improves responder preparedness against the most realistic scenarios," says Kreek. His goal is to have a wide range of civilian and military first-response teams routinely use SIPs in training within a few years, as instrument producers plan upgrades to existing devices and new equipment makes its way into the first-response community. Kreek has demonstrated the technology to representatives from the Departments of Energy (DOE), Defense (DOD), and Homeland Security (DHS); U.S. Coast Guard; U.S. Customs and Border Protection; and to the International Atomic Energy Agency and CTBTO.

The capabilities of the SIP technology are easily expandable to accommodate improvements. For example, a neutron-detection component would be useful to some inspectors. What's more, with appropriate engineering, the SIP concept could work with any scientific instrument that measures physical quantities, such as detectors for chemical and biological weapons, high explosives, and even seismic signals (such as for CTBTO exercises).

Optimizing Searches

Richard Wheeler, Livermore's associate program leader for systems analysis and studies, leads a multilaboratory project to develop, demonstrate, and transition the Optimization Planning Tool for Urban Search (OPTUS) to routine operations. The OPTUS software program is designed to help search teams cover an urban area (up to several square kilometers) more efficiently, given a limited amount of search time. The goal is to either find a stationary radioactive source or declare the area free of potential threat sources with a quantitative estimate of confidence.

By exploiting knowledge of the urban area under investigation, estimates of background radiation, potential threat source materials and locations, and available human and technological resources, OPTUS calculates optimum search vehicle routes. In addition, for high-interest locations that are

SIP mimics radiation sources using the first responders' location and by injecting high-fidelity signals of any isotope or mixtures of isotopes into the amplifiers of their radiation detectors.

searched by pedestrian teams, OPTUS can compute optimal "dwell" times at positions around the location to maximize the probability of detection given the total search time and the area.

Given the same search assets and search time, OPTUS increases the probability of clearing an area compared to conventional methods. Alternatively, an OPTUS plan can be as effective as a conventional search method but takes much less time. The software tool is intended for use on a laptop computer by teams from the NNSA, DHS, local and state law-enforcement agencies, and potentially by teams for international search operations.

Searches Often Necessary

Law enforcement and homeland security agencies typically need to ensure that an area is clear of radiological or nuclear threats prior to special events. Such searches are conducted when credible reason exists that a device could be planted in a given area or as part of a general sweep in advance of a special event that represents a potential target. For example, sweeps are routinely conducted for major sporting events, parades, political speeches, or a presidential inauguration. Personnel from DOE (including a team from Lawrence Livermore) and the Federal Bureau of Investigation are available to support these sweeps.

Wheeler notes that urban searches for radioactive materials often result in inefficient use of the limited number of trained personnel and vehicle-mounted and human-portable detectors available. Search teams typically divide an area and do their best to search their assigned portion under severe time constraints. The teams are left with uncertain confidence about the effectiveness of their searches. "We needed to be able to optimize a search quickly, without a large computational effort, so we turned to developing smart algorithms that calculate how to best route multiple vehicles in a limited amount of time," says Wheeler. The team focused on developing a family of computationally efficient algorithms that optimize search assets within time restrictions. OPTUS can, for example, direct a vehicle to make multiple passes by a suspicious address to increase confidence that a radioactive source is not present.

OPTUS uses a detailed description of the physical characteristics of the urban search environment. Map data are read into OPTUS along with historical background radiation readings. The software assembles a model of the search area to define potential source and detector locations. This model includes the road network; metadata associated with individual road segments, such as road class or number of lanes; turn restrictions at intersections; building locations and footprint; and other urban features.

The software assumes the radioactive source is stationary and can be located anywhere in the outside search area. For example, a source can be in a parked car on the street. OPTUS shows how to most efficiently search the prescribed area, given the number of available vehicles with radiation detectors and pedestrians equipped with handheld detectors. For vehicle-based searches, the software

Livermore's tablet prototype illustrates how multiple detectors would work in unison during a realistic training scenario using SIP. (left) A Google Earth map of the United Nations building in Vienna, Austria, shows two radioactive sources (red dots) of virtual cobalt-60 and cesium-137 and a person (yellow dot) operating two detection instruments. The gamma-radiation detector shows the synthetic spectra (upper right) of cobalt-60, while the personal radiation dosimeter readings (bottom right) indicate the person is close to the source.

calculates turn-by-turn instructions that users upload to a navigation device such as a cell phone or laptop computer equipped with GPS.

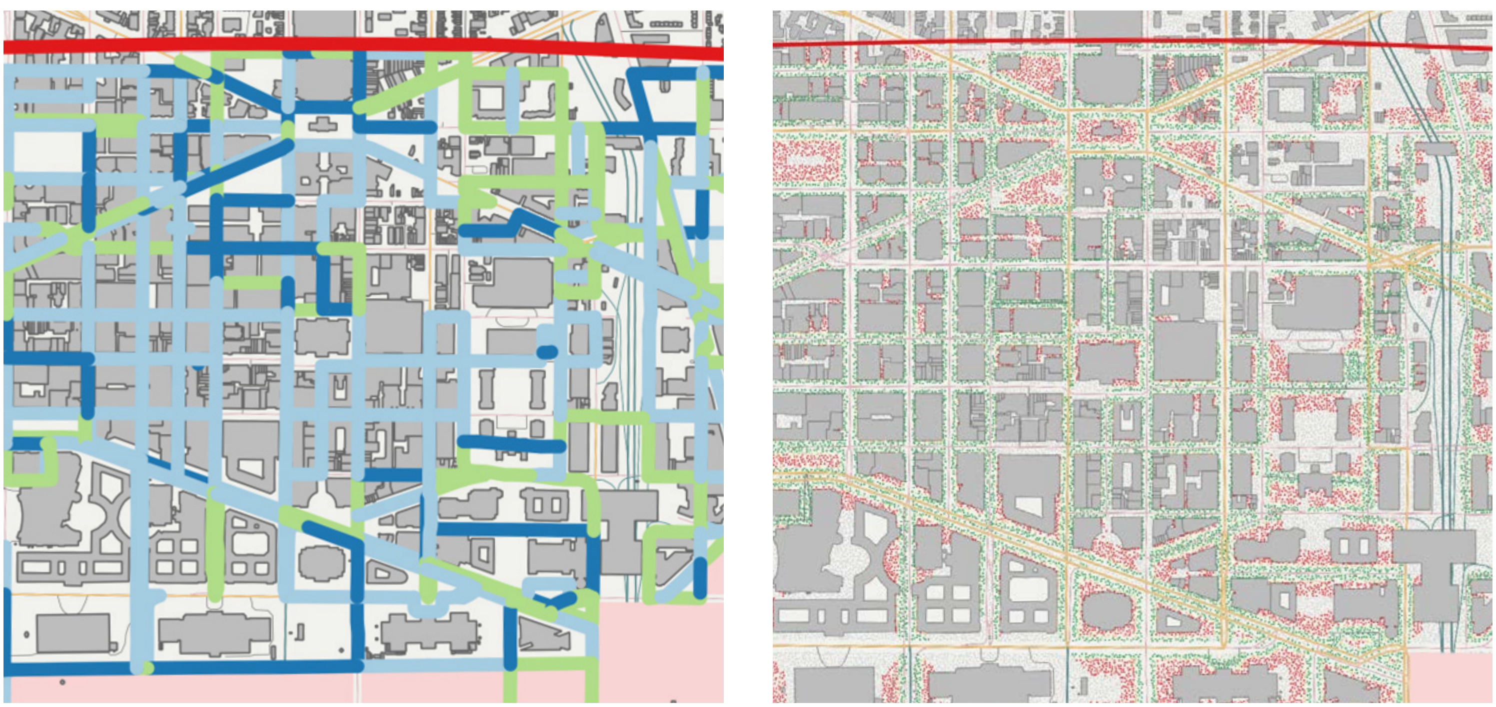
OPTUS also provides a confidence level as to how effectively the search effort clears the designated area. A “coverage estimator” is computed and the results displayed by color-coding each possible source location corresponding to the confidence the source is not there. Initially, this calculation will be done in advance of the search to explore optimal performance under various conditions and assumptions. During an actual search, OPTUS can estimate at any time the degree of clearing that has been achieved up to that point. The color-coded “heat map” would be updated to allow personnel to see the extent of the cleared area as the search proceeds. The result is a search conducted in as little as half the usual time, or a more thorough search (hence greater confidence) in the same amount of time.

Two Different Searches

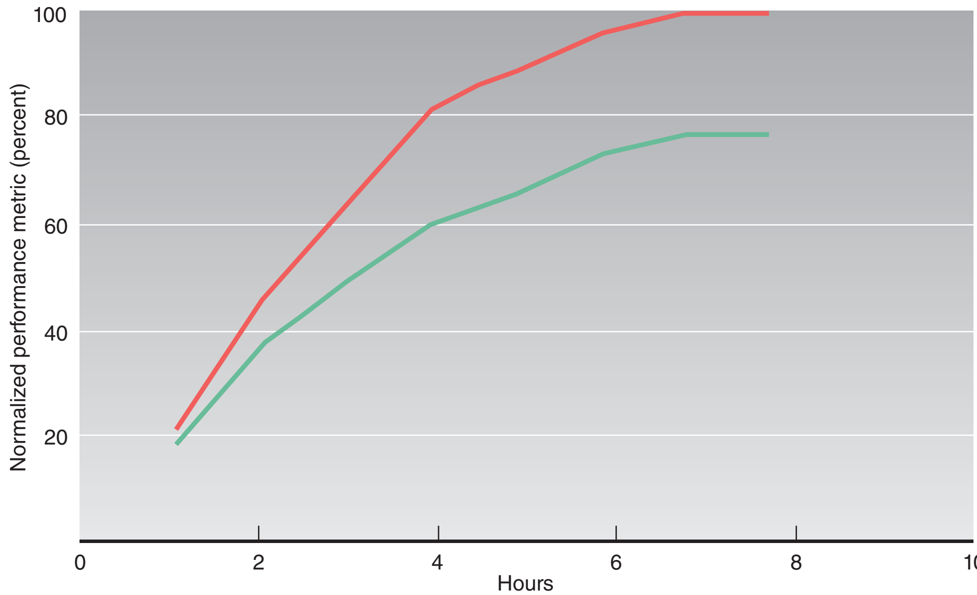
When complete, OPTUS will calculate optimal plans for both wide-area exterior searches and those for high-interest locations. The first is done with vehicle-mounted detectors whose movement is constrained by the road network. Dan Faissol, operations research expert and principal Livermore OPTUS researcher, notes, “The vehicles must perform the search while following the flow of traffic, so OPTUS optimizes both the number of times to traverse each road segment as well as the driving route to achieve those traversals. For example, a good route may revisit the hardest-to-clear road segments multiple times while avoiding time-consuming left- and U-turns.”

The second search approach involves a closer pass of high-interest locations by an individual carrying a detector on foot or in an all-terrain vehicle. A high-interest location could be a place frequented by individuals of interest, a possible hiding spot for a weapon, or a good place to detonate a device so that it causes significant damage or casualties.

Complicating urban search efforts are common building materials such as concrete, granite, and brick that contain naturally occurring, long-lived radioactive isotopes. As a result, the background radiation of the search area needs to be taken into account to estimate the performance of the detection algorithms. Possible approaches to estimating background radiation include taking baseline readings in advance by driving through the area, using data collected



The Optimization Planning Tool for Urban Search (OPTUS) helps search teams sweep a selected urban area more efficiently in a limited amount of time. (left) OPTUS-optimized driving routes indicate the areas that will be passed one (green), two (light blue), or three (dark blue) times. (right) When a search is complete, OPTUS provides an estimate of the search effectiveness. In this hypothetical example, green areas are considered cleared while red areas are not.



Searches with OPTUS (red line) are more effective over the allotted time interval or perform as well as conventional searches (green line) in about half of the time.

from previous searches, or using physics models together with building construction information gathered from city databases.

Each assigned detector location has an associated background radiation estimate as well as a signal attenuation factor from all potential source locations. Faissol points out that radiation from a source decreases as the square of the distance. For example, a detector located 8 meters away from a radioactive source produces a signal one-fourth as strong as a detector located 4 meters away. Intervening materials between the source and detector, such as building walls, further attenuate signals.

A Multilaboratory Effort

Livermore is the lead OPTUS development institution, with contributions from Lawrence Berkeley and Oak Ridge national laboratories, the Remote Sensing Laboratory (RSL) at the Nevada National Security Site, and graduate students from Carnegie Mellon University-Silicon Valley. The Livermore technical team, led by Faissol, includes researchers Claudio Santiago, Thomas Baginski, Pedro Sotorrio, Tom Edmunds, and Karl Nelson, and is responsible for developing and writing the software to implement the optimization algorithms. In addition, Livermore has overall responsibility for the software and data integration, including a user interface. To produce the current OPTUS prototype, the Livermore team developed simplified versions of all the required models.

In March, the team completed a prototype tool that is currently being tested and evaluated by search teams and planners from Lawrence Livermore and RSL. After incorporating suggestions from these early users, a refined version of the software will be available for additional field testing. Wheeler expects that a true “version 1.0” (scheduled for 2017) will be adopted for evaluation by both civilian and military agencies for planning large national and regional events.

The project has a user advisory board that provides additional feedback from NNSA’s Office of Defense Nuclear Nonproliferation Research and Development and Office of Nuclear Incident Response, DHS’s Domestic Nuclear Detection Office, and DOD’s Defense Threat Reduction Agency. Wheeler has also been in discussion with the police department of a major U.S. city that is interested in OPTUS because of the large number of high-visibility events it hosts.

The increased adoption of OPTUS and the improved training that SIP provides are certain to make searches for radioactive materials more efficient and cost effective. Both SIP and OPTUS showcase Livermore’s ongoing efforts to strengthen capabilities and training for guarding against the use of weapons of mass destruction by either terrorists or a rogue nation. The new technologies are examples of understanding customer needs, applying relevant technologies, and partnering with other institutions to meet the demands of national security.

—Arnie Heller

Key Words: first responder, gamma-ray detector, Optimization Planning Tool for Urban Search (OPTUS), ORTEC Detective, Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), radioactive material, Spectroscopic Injection Pulser (SIP).

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