Lawrence Livermore National Laboratory

Science & Technology Review

January/February 2010

Breakthrough Materials: Radiation Can't Hide

Also in this issue:

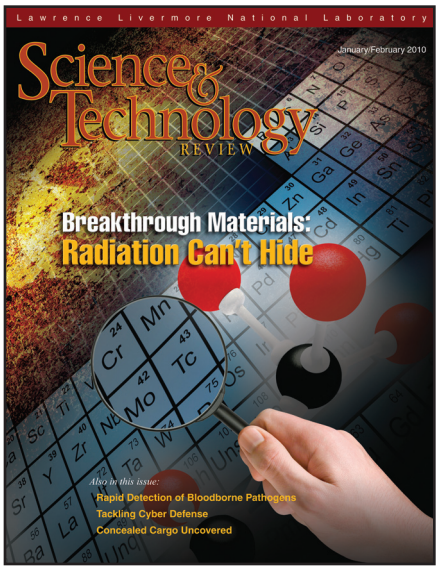
Rapid Detection of Bloodborne Pathogens

Tackling Cyber Defense

Concealed Cargo Uncovered

About the Cover

As the article beginning on p. 4 describes, the elements of the periodic table were the starting point for a search by three Livermore teams to find new materials for radiation detectors. Each team is seeking to find the optimal material for identifying gamma rays, fast neutrons, or thermal neutrons. Their work involves evaluating many elements and dozens of compounds. A radiation detector materials campaign that started several years ago at Livermore has grown into a collaboration that includes Pacific Northwest, Lawrence Berkeley, Oak Ridge, Brookhaven, and Sandia national laboratories; Fisk, Stanford, and Washington State universities; the University of Nebraska; and numerous private firms.



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About the Review

At Lawrence Livermore National Laboratory, we focus science and technology on ensuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published eight times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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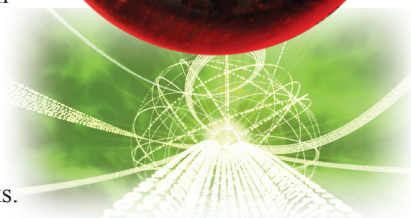

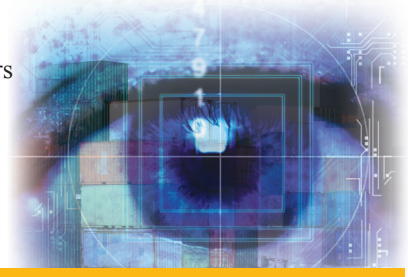

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Nanotube Technology Flows to Marketplace

The Laboratory's Industrial Partnerships Office has exclusively licensed to Porifera, Inc., in Hayward, California, a carbon nanotube technology that can be used to desalinate water and can be applied to other liquid-based separation processes as well. Carbon nanotubes—molecules made of carbon atoms in a unique tubular arrangement—allow liquids and gases to rapidly flow through, while the tiny pore size blocks larger molecules, offering a cheaper way to remove salt from water.

"The technology is very exciting," says Olgica Bakajin (shown in the photo), who serves as Porifera's chief technology officer and is one of the Livermore researchers who created the carbon nanotubes. Bakajin worked at the Laboratory, where she was recruited in 2000 as a Lawrence Fellow and then became chief scientist on the carbon nanotube project. She is currently on a two-year entrepreneurial leave from the Laboratory. Porifera is developing carbon nanotube membranes with very high permeability, durability, and selectivity for water purification and other applications.

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Bright Future for New X-Ray Laser

The brightest x-ray laser in the world has awakened with a series of experiments to characterize its beams and interactions with materials. The Linac Coherent Light Source (LCLS) at the Stanford Linear Accelerator Center (SLAC) is the first large-scale x-ray free-electron laser user facility. Scientists, such as Livermore's Stefan Hau-Riege, expect to validate the physics of materials simulations they have conducted using the bright light source, which has to date produced up to 8 kiloelectronvolts of light.

In October 2009, a team of scientists from Lawrence Livermore, LCLS, and European institutions characterized several significant properties of the beam including the wavefront (the pattern of incoming x rays of various energies and intensities), the intensity distribution across space, and the total beam energy. Hau-Riege's first user experiment, scheduled for spring 2010, will use the laser to explore the properties of a graphite lattice. "Once we heat the material, we will be able to see the scattering and measure the temperature, density, and distortion before the sample is destroyed."

At the heart of LCLS is a free-electron laser that produces beams of coherent, high-energy x rays. Coherence—the phenomenon of all photons in a beam acting together in perfect unison—makes laser light far brighter than ordinary light. Because x-ray photons at LCLS are coherent, the resulting beam of light will be as much as a billion times brighter than any other x-ray light source available today. LCLS also contains a femtocamera that can stitch together images of ultrasmall materials taken with the light source's ultrafast pulses (from 10 to 100 femtoseconds). Scientists are for the first time creating molecular movies, revealing the frenetic action of the atomic world.

Lawrence Livermore was part of a SLAC-led consortium to plan, design, and build LCLS. Other partners include the University of California at Los Angeles and Los Alamos, Brookhaven, and Argonne national laboratories.

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Commentary by Bruce Warner

Innovative Materials Rise to the Radiation Challenge

THE events of September 11, 2001, and subsequent terrorist activities around the world focused attention on terrorism in all its forms. At the Department of Homeland Security, a particular emphasis is the issue of nuclear terrorism. Scientists and politicians have come to recognize the importance of detecting nuclear and radiological materials at our borders and, if possible, even earlier at foreign seaports and airports. Livermore has responded to this challenge with a number of technological innovations.

The article beginning on p. 4 reports on our efforts to find new materials that improve the detection of weapons-grade plutonium and highly enriched uranium. Our largest concern is the introduction of an improvised nuclear device, but we are also looking for small amounts of these materials not yet incorporated into a device. Such materials could form the basis of a radiological "dirty bomb" that could do local damage and instill widespread fear into the population. The ability to detect radiation of all types—particularly the penetrating radiation of neutrons and gamma rays—is critical for identifying illicit nuclear and radiological materials before they cross U.S. borders.

Our research in new materials for radiation detectors focuses on improved efficiency and energy resolution. Efficiency is important because not all radiation that passes through a detector will register on the instrument. It is particularly important if the detector must be small and portable. Higher efficiency increases the probability that the detector will "pick up" the presence of a radiation source. At the same time, higher resolution increases a detector's ability to pick up the specific energy spectrum of the radiation in question. Detector materials with the highest possible resolution and efficiency make possible the unambiguous identification of small amounts of plutonium and highly enriched uranium, even when these radioactive materials are shielded by lead or other materials to avoid detection. Scientists in the Global Security and Science and Technology principal directorates have partnered with collaborators at universities and other national laboratories to develop improved diagnostic tools for rapidly evaluating the effectiveness of an array of new detector materials.

We are researching three kinds of materials: inorganic crystal and transparent ceramic scintillators to detect gamma radiation, organic crystals to detect the weak signals from fast neutrons, and semiconductor devices to detect slower, thermal neutrons. This latter effort is particularly important because the standard method for thermal neutron detection relies on tubes filled with helium-3, which is in short supply. Our work has produced some exciting results.

For some homeland security applications—for example, cargo inspection at ports—active means of identifying hidden nuclear materials such as radiography can be used, rather than passive radiation detection. The highlight on p. 17 describes a new photon-based radiographic technique we are developing with collaborators from the University of California at Berkeley. It offers the possibility of rapidly screening cargo and identifying suspect containers with high reliability and a low false-alarm rate.

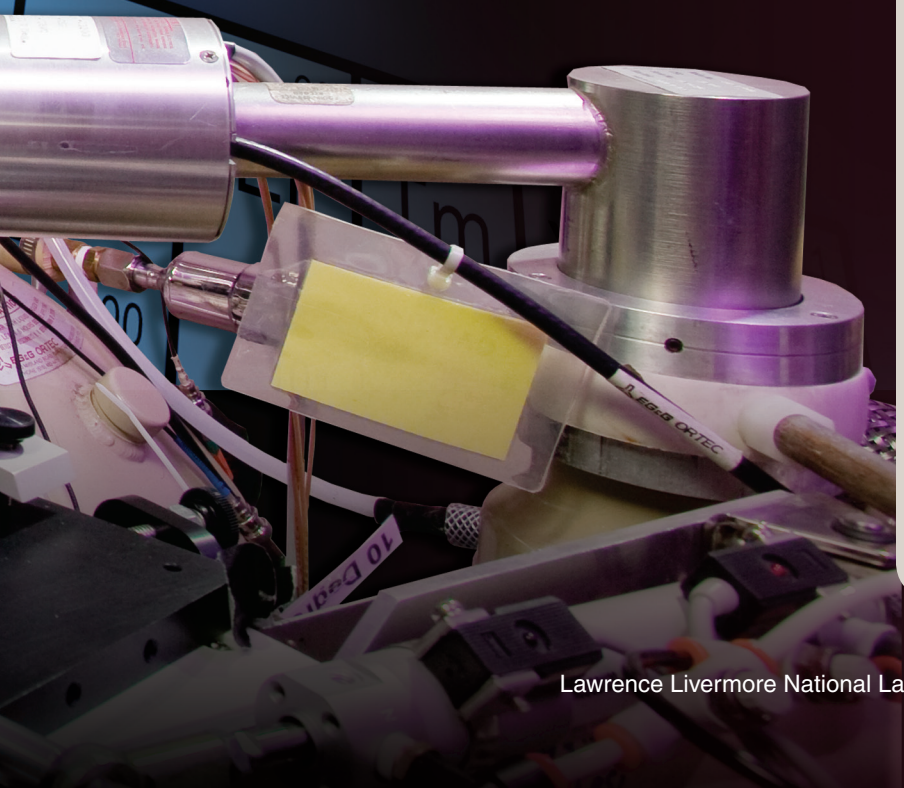
As we look toward the future, we expect Laboratory research in the area of radiation detection to remain constant and perhaps expand. For example, in an April 2009 speech in Prague, Czech Republic, President Barack Obama outlined broad initiatives in nonproliferation and arms control that could require innovation in radiation detection materials as well as detection techniques. We look forward to bringing the Laboratory's multidisciplinary expertise to bear on finding technical solutions for these important national problems.

■ Bruce Warner is acting principal associate director for Global Security.

The Hunt for Better

Radiation Detection

Laboratory researchers are working to stay ahead of terrorists who might try to bring weapons-grade materials into the country.



Three Livermore teams are evaluating many elements and compounds in their search for new radiation detection materials. (Pictured Steve Payne and Nerine Cherepy.)

DETECTING illicit sources of plutonium and highly enriched uranium is a tricky business for first responders, airport security personnel, and U.S. port and border inspectors. Both plutonium and highly enriched uranium are typically identified using a combination of devices, working together, to detect their invisible gamma and neutron radiation emissions. For many years, the existing detection technologies were deemed adequate, but the world became a far more dangerous place after September 11, 2001. Since then, concerns of radioactive materials falling into the wrong hands have been rife. Ensuring that the country remains safe from a nuclear or radiological attack is driving the search for more definitive radiation detection and identification technologies.

The Department of Energy (DOE) has for decades been building the science and engineering basis for the detection of radiological materials, and the Laboratory has made a significant contribution to this ongoing effort. Livermore researchers have worked on improving the efficiency and energy resolution of radiation detectors. They have also developed systems that illuminate objects such as cargo containers and use these radiographic techniques to find hidden nuclear materials. (See *S&TR*, May 2004, pp. 12–15, and the highlight beginning on p. 17.) In 2005, the Department of Homeland Security (DHS) made a bold request for developing significantly more effective materials to detect gamma and neutron radiation emissions. New materials for smaller, faster, and more accurate sensors could improve the nation's ability to unambiguously identify radiation from illicit sources.

The development of new detector materials used to be a time-consuming, trial-and-error, often decades-long process. Today, greatly improved diagnostic tools for measuring material properties combined with faster, more accurate computer simulations allow researchers to rapidly evaluate materials for performance and ease of fabrication.

Physicist Steve Payne leads three teams in a radiation detector materials campaign at Livermore, in a collaboration that includes Pacific Northwest, Lawrence Berkeley, Oak Ridge, Brookhaven, and Sandia national laboratories; Fisk, Stanford, and Washington State universities; the University of Nebraska; and numerous private firms including, Radiation Monitoring Devices, Inc. "With so many partners working together, we can avoid duplication of facilities, which is more cost-effective," says Payne.

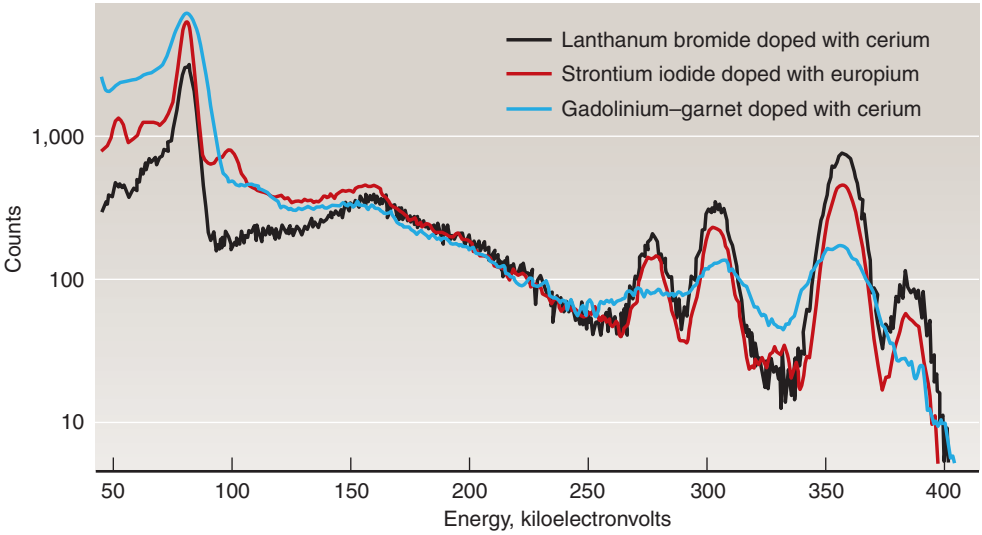
Getting It Right the First Time

For many field applications, radiation detectors must be inexpensive and robust, operate at ambient temperature, provide high efficiency, and be small enough for use in covert operations. They must also provide unambiguous identification of a material. For example, the tiny amount of thorium in cat litter is radioactive, but thorium is not a security threat. Additionally, detectors must be able to pick up very weak signals, such as from plutonium heavily shielded with lead to avoid detection.

Current detector technology is limited in its ability to meet the requirements of people on the front lines who are responsible for ensuring the nation's safety. Some of today's best gamma-ray detectors are those that use germanium as the sensor material. The Laboratory has been at the forefront of efforts to make germanium detectors as small and field-portable as possible, and a challenge has been that to achieve the best resolution, the germanium must be cooled to below room temperature. (See *S&TR*, October/November 2009, pp. 8–9.) Detectors for low-energy neutrons, known as thermal neutrons, are typically tubes filled with helium gas, but these instruments are large, require high voltage to operate, and are sensitive to vibration. The best material for detecting high-energy, or fast, neutrons is a crystal called stilbene, but the crystal is difficult to grow, expensive, and available from just one company in Ukraine.

The Livermore teams of chemists, physicists, and engineers, along with their collaborators, set out to find new, better materials for all three types of detectors—materials that meet the needs of as many users as possible. Payne says, "In our search for novel materials with the necessary properties, we began with the entire periodic table." Each team used a different process of elimination because the requirements for detecting the various forms of radiation are different.

Earlier work at Livermore on new detector materials for thermal neutrons was funded by the Laboratory Directed Research and Development Program. As that project and others demonstrated success, outside funding for new detector materials followed, first from DOE's National Nuclear Security Administration (NNSA) and later from DHS and the Defense Threat Reduction Agency.



Gamma-ray spectra from a barium-133 radioactive source were acquired using three different scintillator materials. In the energy ranges most important for identifying plutonium, the Livermore-developed strontium iodide, with the narrowest pulse widths, offers the best resolution.

Locating Gamma Rays

Gamma rays, produced through radioactive decay, have the highest energy in the electromagnetic spectrum and thus can penetrate most materials. Because of this extreme penetrability, gamma rays can be detected even when the radiation source is shielded by concrete, dirt, or a few centimeters of lead. However, gamma rays can only be viewed indirectly by observing their interactions with detector materials.

High-purity germanium, a semiconductor, has been the standard for detecting gamma rays for years. An alternative method is scintillation, in which radiation interacts with a material to produce a brief but measurable flash of light. Livermore chemist Nerine Cherepy and her team are on the hunt for a material that will produce the brightest flash of light when exposed to plutonium or highly enriched uranium. The precision of the scintillator material's response, or energy resolution, defines the material's ability to distinguish between gamma rays that have similar energies. Such discrimination is needed because not all gamma rays are indicative of a source that poses a threat.

Scintillators of lanthanum bromide doped with cerium, $LaBr_3(Ce)$,

offer the highest energy resolution among commercial devices. However, $LaBr_3$(Ce) is difficult to grow, is radioactive because of the presence of lanthanum-138, and is expensive. The goal for Cherepy's team is to find a high-resolution material that is not radioactive, operates at room temperature, is inexpensive, and can be manufactured in large volumes. After much analysis and elimination—with an array of crystals grown from various compounds by national laboratory, industrial, and university partners—Cherepy and her team narrowed their search to two materials: transparent ceramic gadolinium-based garnets and strontium iodide crystals.

Transparent ceramics have already been used in Livermore's solid-state heat-capacity laser, a system that is setting the stage for "directed energy" laser weapons. (See *S&TR*, April 2006, pp. 10–17.) "Livermore has established expertise in transparent ceramics," notes Cherepy. For scintillators, transparent ceramic garnet is relatively inexpensive, strong, and can be fabricated into large, uniform, robust devices. The team has developed a novel fabrication technique for transparent ceramics starting from nanoparticles, for which they earned a Nano 50 Award in 2008.

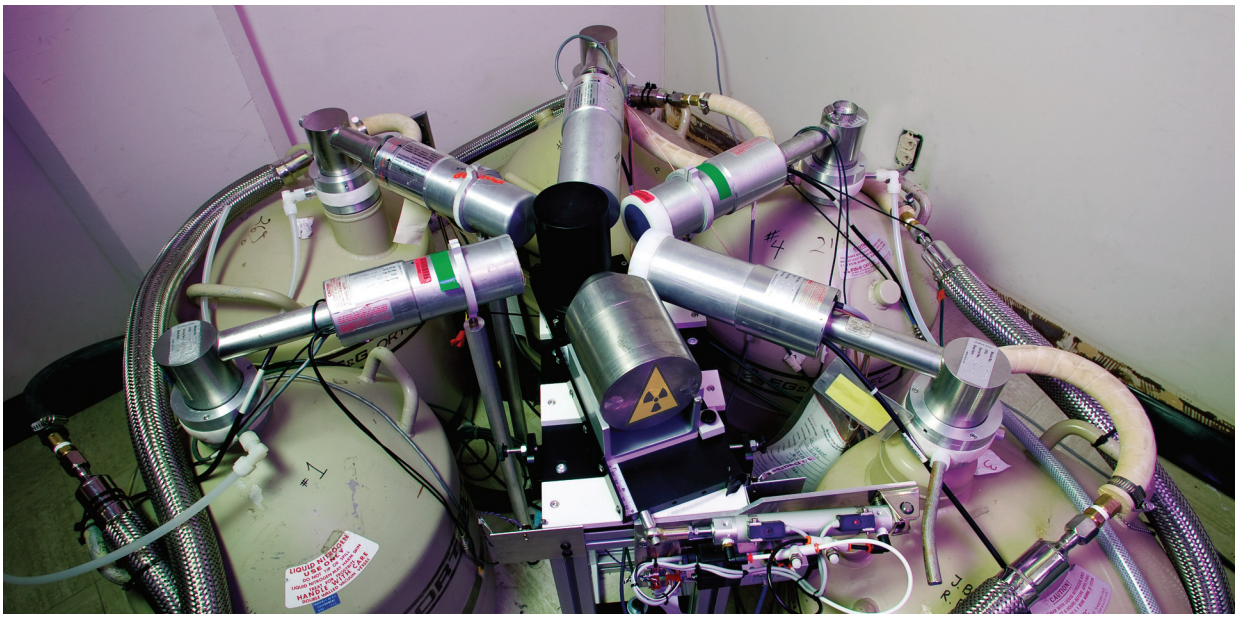
The best energy resolution for any of the various garnet compounds is about 4 percent, when exposed to gamma energy of 662 kiloelectronvolts. (This energy, from a cesium-137 source, is the standard used in experiments for measuring the resolution of a gamma-ray scintillator.) The energy resolution of $LaBr_3$(Ce) is 2.6 percent, and for gamma detection, smaller is better. The team's goal is to find a material with a resolution of 2 percent.

Strontium iodide doped with europium, SrI_2(Eu), has proved to be the best scintillator material yet. "It is an easily grown crystal with excellent energy resolution," says Cherepy. It produces more photons—more light—than $LaBr_3$(Ce) and is not radioactive. Small crystals have demonstrated 2.5-percent energy resolution, slightly better than $LaBr_3$(Ce). "The resolution degrades a bit with larger crystals," says Cherepy. "However, we expect to achieve 2-percent resolution by improving the purity of crystals as they grow in size and by optimizing the detector's optics and digital electronics."

An array of tools and computer codes is used to characterize and analyze the materials being studied. A particularly interesting new tool is the scintillator light-yield nonproportionality instrument, or SLYNCI, which was developed by Payne and collaborators at Lawrence Berkeley. Nonproportionality—an inconsistency between the energy deposited in a scintillator and the number of visible photons produced—has been a problem with scintillators for decades. If too much exists, scintillator pulses are not precise, degrading energy resolution. Doping is one way to improve proportionality. SLYNCI has been crucial in evaluating the physics of nonproportionality in various scintillators.

Identifying High-Energy Neutrons

While working on a Ph.D. at Moscow State University in Russia, Livermore physicist Natalia Zaitseva developed a method for growing extremely large crystals faster than ever before. Zaitseva perfected the process after coming to the Laboratory and won a 1994 R&D 100 Award with her team. At the time, the researchers were focused on producing

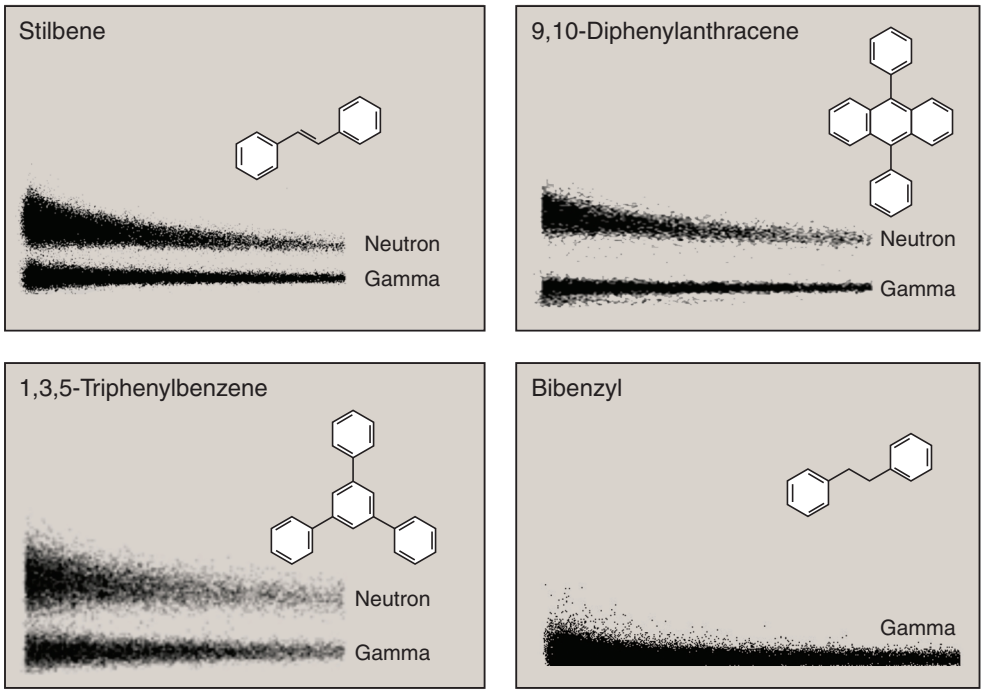


SLYNCI, the scintillator light-yield nonproportionality instrument, measures the difference between the energy deposited in a scintillator and the number of protons produced.

large crystals of high-quality potassium dihydrogen phosphate (KDP) for Livermore lasers such as the National Ignition Facility (NIF). In 1996, the team produced in just 27 days a KDP crystal measuring 44 centimeters across. Growing a crystal that size under standard growing conditions would have taken 15 months. The NIF laser design required a huge amount of KDP—about 600 large slices—for conversion of the laser's infrared light to shorter wavelengths as the beams travel to the target chamber. In 1997, the Livermore team produced the world's largest single-crystal optical element—a pyramid-shaped KDP crystal measuring more than a half-meter tall and weighing about 250 kilograms—in just six weeks. Today, Zaitseva's team is applying everything learned with KDP—an inorganic substance—to organic substances for neutron detection.

In examining possible compounds, Zaitseva's aim was to find a material that would most effectively separate out a signature for neutrons from the strong background of gamma radiation, a process known as pulse-shape discrimination (PSD). Decades ago, researchers found that the organic crystal stilbene could quickly discriminate neutrons from gamma radiation. Today, liquid organic scintillators are more commonly used for PSD because of stilbene's limited availability and high

In the 1990s, Natalia Zaitseva developed a rapid-growth technique for producing very large crystals in record-shattering time. She now leads a team that grows organic crystals for use in fast-neutron detectors.



Gamma rays and fast neutrons are distinguished from one another by pulse-shape discrimination. The signatures differ depending on the compound being used as the scintillator. Although stilbene is the best commercial scintillator available, some compounds, such as 9,10-diphenylanthracene and 1,3,5-triphenylbenzene, show as good as or better discrimination and can be grown more easily. Other compounds, such as bibenzyl, reveal no discrimination.

cost. However, because of flammability, toxicity, and environmental concerns, NNSA and others are now searching for alternative materials.

"We surveyed 140 organic compounds," says Zaitseva, "all of which were prepared with characteristics known to be important for fast-neutron detection." A few such characteristics include the presence of benzene rings for efficient scintillation; high hydrogen content for interactions with neutrons; only low-atomic-number (low-*Z)* constituents, such as hydrogen or carbon, to avoid excessive interaction with gamma radiation; and a delayed emission to better show PSD.

"We bought the compounds as powders, purified them, and prepared the solutions," says Zaitseva. "Some had never before been used to grow crystals." Most of the materials have been well known for their scintillation properties since the 1950s. However, because of the limitations of electrical circuits available then for evaluating PSD, many of the compounds had never been evaluated for their neutron–gamma discrimination properties.

Experiments revealed that some molecules were close to or even better than stilbene at separating the neutron and gamma signals. Other materials produced plenty of light but did not exhibit PSD. When Zaitseva's team could not find an obvious correlation between PSD and molecular structure, they turned to Livermore experts in quantum molecular simulations. Computational modeling of organic molecules and their properties revealed how PSD is tied to the migration of certain excitations in the crystal. "Impurities in the crystals may also decrease PSD," notes Zaitseva.

For this initial survey, Zaitseva's team grew crystals to 1 centimeter using a simple evaporation technique, with growth rates of 1 to 2 millimeters per day. They also grew larger crystals (5 to 10 centimeters) in a custom-built, temperature-reduction device similar to the one used for KDP. Whereas many of the small crystals showed defects, the larger crystals were of high optical quality.

The first organic material grown in the custom device was 1,3,5-triphenylbenzene, which grew to 8 centimeters high and 5 centimeters across in just a week. This experiment proved that the rapid-growth technique is as effective for growing large single-crystal organic scintillators as it is for KDP. Since then, stilbene crystals have also been grown in the new crystallizer.

Rebecca Nikolić and her team are developing a detector made of silicon pillars and boron for capturing neutrons.

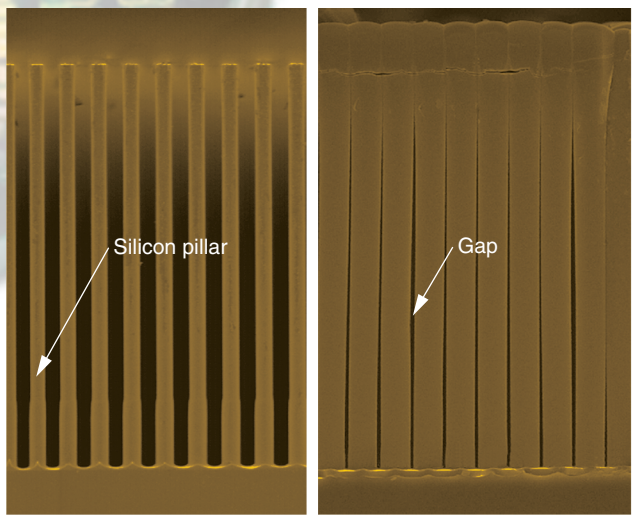
A Substitute for Helium

An attempt to hide a plutonium source might include not only shielding the material's gamma rays with heavy metal but also shielding its fast neutrons with plastic. Even if those two shields are effective, thermal neutrons may still be detectable. Fortunately, thermal neutron radiation is fairly rare compared to gamma radiation, and detecting its presence makes identifying the material in question that much easier.

In instruments for neutron detection, helium-3 has for years served as the neutron-absorbing material. However, finding a substitute for this material has become essential for the development of improved detectors. One disadvantage of helium-3 detectors is their size—the tube containing the helium can be up to 1 meter long. In addition, the device requires about 1,000 volts for operation. "Perhaps most importantly," says Payne, "helium-3 is much less available now than it was when the country was building nuclear weapons. Current supplies of helium-3 come, in part, from the dismantling of nuclear weapons where it accumulates as tritium decays." Supplies of this material are fast declining.

A solid-state material substitute for helium-3 has some advantages. Moving from a gas medium to a solid increases the density of the neutron-absorbing material, reducing the size of the detector. Previous researchers developed a two-dimensional detector, but its efficiency was low, only about 5 percent. (Note that with scintillation, as described above for gamma radiation and fast neutrons, the goal is high resolution, which is a low percentage. In contrast, the measure for effectiveness of thermal neutron detectors is efficiency, or the highest possible percentage.)

At Livermore's Center for Micro- and Nanotechnology, engineer Rebecca Nikolić and her team trekked through the periodic table and landed on a combination of silicon and boron, from which they have



The sensor developed by Nikolić's team uses a wafer with 50-micrometer-tall silicon pillars interspersed with boron to detect thermal neutrons. The left image shows the pillars before boron is added, and the right image shows boron-coated pillars with tiny gaps between each.

created a three-dimensional, pillar-shaped sensor. Incoming neutrons interact with boron to produce particles that, in turn, interact with the silicon semiconductor and create a current for an electronic signal. The silicon–boron pillar detector is expected to offer efficiency of more than 50 percent and require less power than the helium-3 tube. Because the silicon wafers can be cut to any size, detectors can be designed to meet the needs of many end users. For example, the wafer can be cut in smaller pieces for covert applications or tiled to cover large areas for portal monitors.

Initially, Nikolić's team etched a silicon wafer with pillars 20 micrometers high, and university collaborators used chemical vapor deposition to fill in the spaces between the pillars with boron. The prototype device had an efficiency of 20 percent, the highest efficiency reported for such a detector. And, it turns out that size matters. "We have found that taller pillars, which provide a thicker boron layer, are more efficient at capturing neutrons," says Nikolić. The team has recently completed a design with 50-micrometer-tall pillars to increase efficiency.

In almost every way, the three-dimensional silicon–boron wafer is superior to the helium-3 tube. The wafer device requires less than 3 volts for operation, and newer designs may require even less. In addition, this highly effective detector will have less than 5 percent the physical volume of the standard helium-3 detector for the same efficiency.

Going Forward

All three research teams are looking at several more years of research. Cherepy's team is continuing efforts to improve the performance of both garnets and strontium iodide. They are also exploring the possibility of engineering high-*Z* nanocomposite polymer scintillators, which could be highly efficient, inexpensive, and provide high resolution. While Zaitseva has shown that large organic crystals can be produced very quickly, her team has yet to determine the final optimal alternative to stilbene. An unexpected discovery was a compound with triple PSD that can discriminate among the three types of radiation—fast neutron versus gamma and thermal neutron versus gamma. This compound may even prove to be an effective material for detecting antineutrinos.

For materials being considered by all three teams, quantum simulations are used to identify and rank detrimental defects. Simulations also help guide optimal characterization experiments, whose results are fed back into future simulations.

"We have just begun to examine yet another possible technique for detecting neutrons," says Payne. "This method uses acoustic detection. Boron captures a neutron, which interacts with other materials, ultimately generating an acoustic wave. Livermore has the right mix of experts for meeting this research challenge."

—Katie Walter

Key Words: crystal growth, gamma radiation, garnet, helium-3, lanthanum bromide (cerium), neutron, radiation detection, scintillation detector, stilbene, strontium iodide, transparent ceramics.

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Time-Critical Technology Identifies Deadly Bloodborne Pathogens

CONSIDER this scenario—an elderly man is brought to an emergency room confused, disoriented, and shaking severely with chills and fever. His heart is beating rapidly, and his blood pressure is dangerously low. The patient appears to be in a state of shock. What doctors suspect, but can't immediately confirm, is that he is suffering from extreme sepsis, a serious medical condition characterized by a whole-body inflammation and the presence of a bloodstream infection. Sepsis is the second-leading cause of death in noncoronary intensive-care-unit patients and the tenth-most-common cause of death overall in the U.S., according to the Centers for Disease Control and Prevention. If the patient does not receive swift medical intervention, death is imminent.

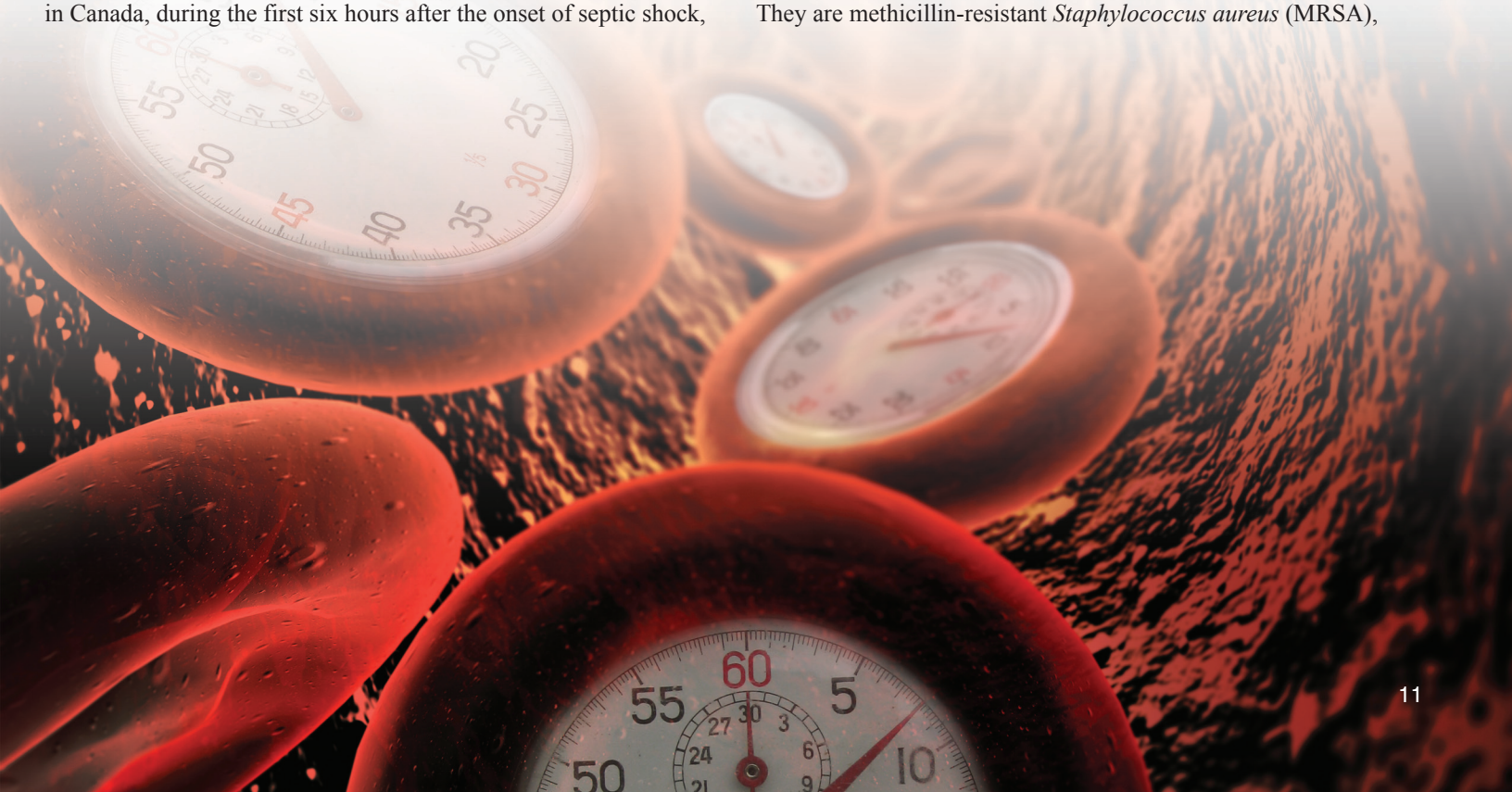
A new bloodborne-pathogen detection technology may in the near future allow doctors to diagnose serious bloodstream infections within an hour. Conventional lab tests typically take several days. Furthermore, instead of transporting a blood sample to a hospital, trained medical personnel could make a diagnosis at an emergency shelter or at the scene of a disaster. These and other advances are expected to result from a five-year, $8.5 million grant to a team of scientists, engineers, and physicians from Lawrence Livermore and the University of California (UC) at Davis that focuses on point-of-care testing (POCT). POCT is defined as diagnostic testing at or near the site of patient care.

"According to a recent study from the University of Manitoba in Canada, during the first six hours after the onset of septic shock, the mortality rate increases 7 percent for every hour that a patient doesn't receive effective antimicrobial treatment," says Livermore chemist Brian Baker, who works in the Laboratory's Physical and Life Sciences Directorate. "For treatment to begin without delay, health care workers need to quickly identify which bloodborne pathogen has infected the patient."

The National Institute of Biomedical Imaging and Bioengineering (NIBIB) awarded the grant in October 2007. The collaboration was funded as part of NIBIB's Point-of-Care Technologies Research Network, which includes three other medical research centers that are part of a larger cooperative research effort. The grant provides funds for developing and testing two single-channel prototype instruments, each of which can simultaneously detect five bacterial and fungal bloodborne pathogens. The first-generation POCT device measures about 40 by 50 by 50 centimeters and is designed for hospital settings, while a smaller, second-generation device will be designed for deployment to remote disaster sites.

Quick Detection Saves Lives

Five pathogens were selected based on their clinical significance, occurrence in hospitalized patients, threat to the community, and frequency of being found in wounds on victims of severe floods and other weather-related natural disasters. They are methicillin-resistant *Staphylococcus aureus* (MRSA),



a bacterium long associated with catheter-related infections and now being found in community settings such as schools; *Pseudomonas aeruginosa*, a bacterium often linked to hospital-acquired bloodstream infections and associated with pulmonary complications such as respiratory distress syndrome; *Escherichia coli*, one of the more common organisms found among patients who contract hospital-acquired infections; *Streptococcus pneumonia*, the most common cause of severe community-acquired pneumonia; and *Candida* yeast, which can affect people with weakened immune systems. Infections with any one of these five pathogens can lead to sepsis.

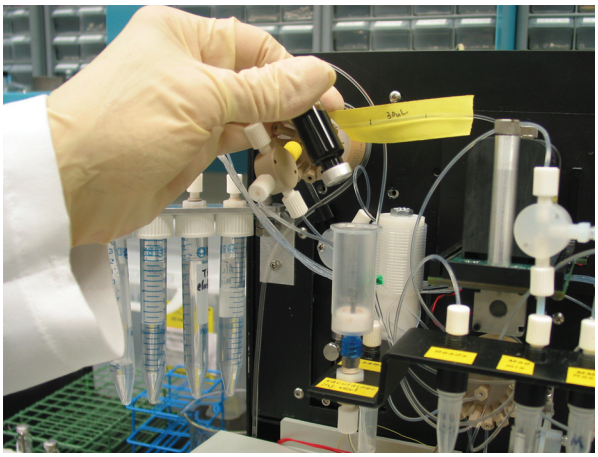
The detection process begins with loading a blood sample in the POCT instrument. The device then automatically handles all the remaining processing steps. Instead of relying on the polymerase chain reaction (PCR) technique used today—a time-intensive process that requires multiple cycles of heating and cooling blood samples—the compact instrument uses a new DNA amplification method called loop-mediated isothermal amplification (LAMP). The LAMP method uses a portion of *Bacillus stearothermophilus* DNA polymerase protein, an enzyme that splits the double strand of DNA and allows it to be copied at a single temperature (63°C, 145°F), saving precious time. The multichannel prototype can run a synchronized test for all five pathogens in the blood sample within one hour.

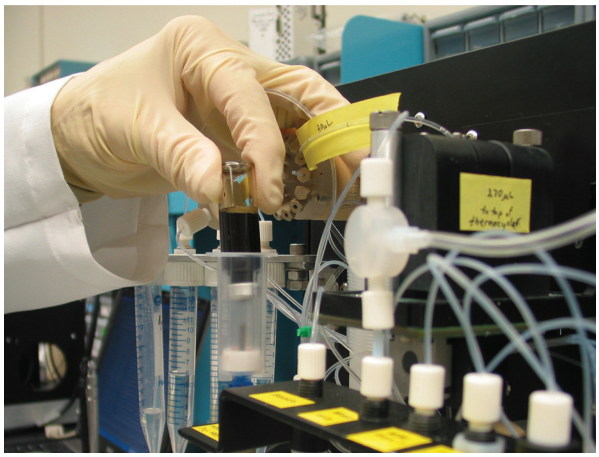
In 2005, emergency response efforts in New Orleans following Hurricane Katrina demonstrated the basic feasibility of POCT. However, according to Nam Tran, associate director of the Center for POC Technologies at the UC Davis Medical Center, follow-up laboratory experiments showed that current testing equipment is not adequate for field use by first responders. Rescues were impeded during the Katrina response because hospitals were out of commission and doctors did not have adequate tools for making fast diagnoses. Consequently, treatment was delayed. “Our preliminary survey work following Hurricane Katrina found disaster responders lacked evidence-based methods to diagnose and treat bloodstream infections,” says Tran. “Bringing rapid pathogen nucleic-acid recognition technologies to the point of care will accelerate treatment decisions and potentially improve outcomes.”

A Network of Solutions

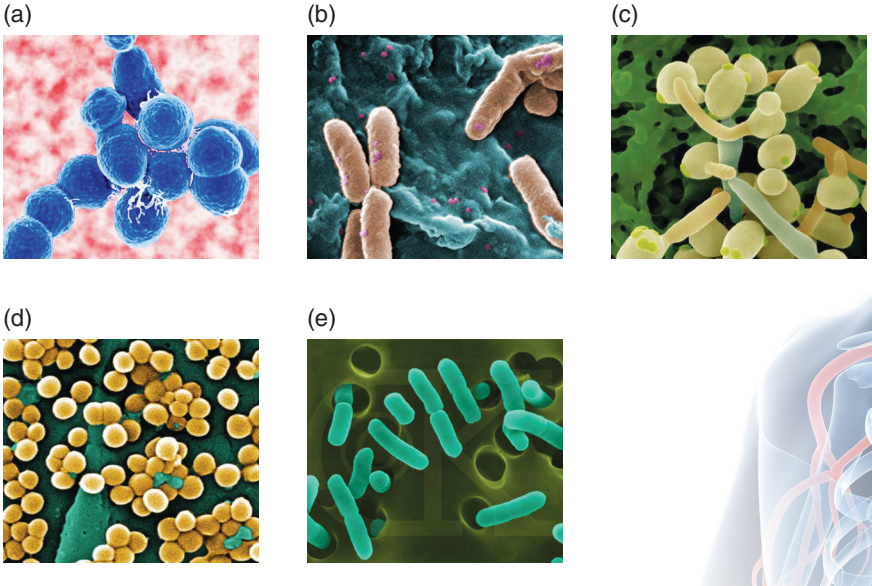
Previous Livermore-developed biodetection technologies—including the Autonomous Pathogen Detection System for protection against bioterrorism—will provide some of the foundational technologies for the new POCT instruments, according to chemical engineer John Dzenitis, who is leading the effort at Livermore. “Many of the techniques we use to detect bioterrorism can be adapted to detect bloodborne pathogens,” says Dzenitis. “Before beginning this project, we had a good starting point in bioinformatics research, including tools for designing DNA tests, procedures for screening and optimizing the tests, and instrumentation to automate the process.”

In addition to the center at UC Davis–Livermore, NIBIB has established three other centers that are part of the larger cooperative research effort. One center is at the University of Cincinnati and focuses on emerging neurotechnologies. Another center at Johns Hopkins University in Baltimore, Maryland, focuses on research involving sexually transmitted diseases. PATH Seattle partners with the University of Washington at the fourth center, which focuses on diagnostics for global health. Brenda Korte, program manager of NIBIB’s Division of Discovery Science and Technology, oversees all four NIBIB centers.

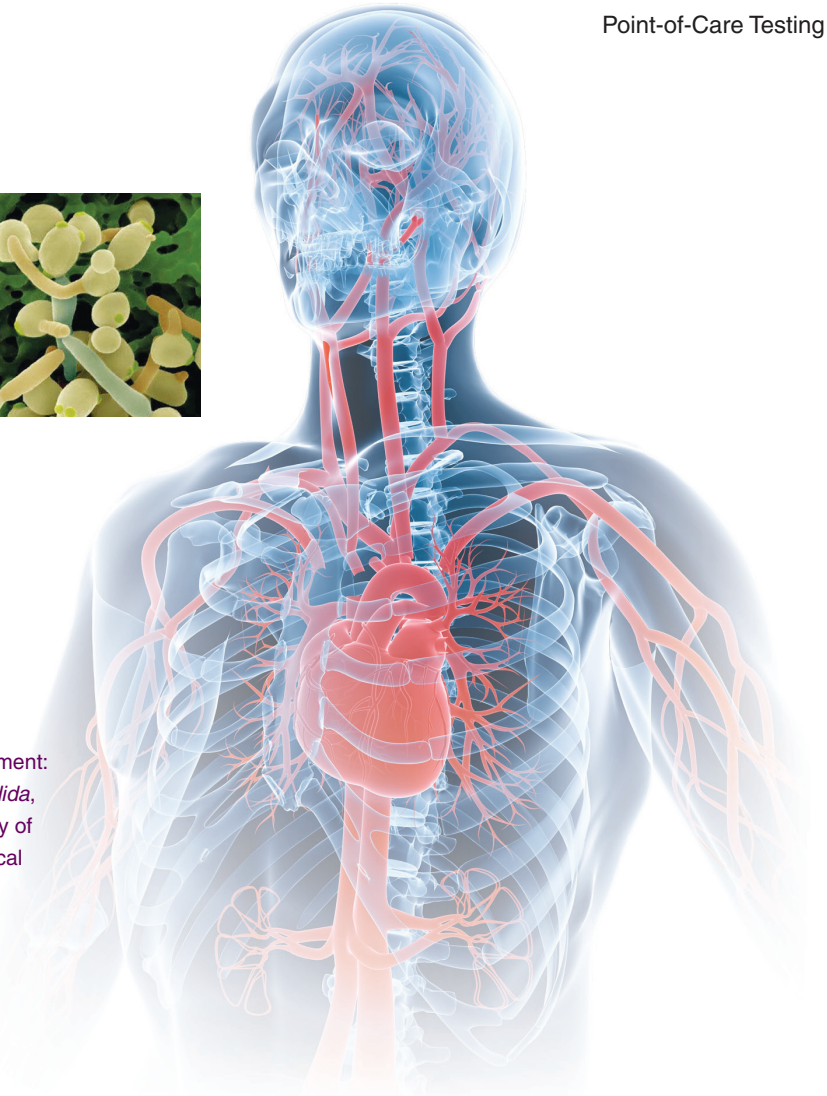




A blood sample is loaded in a prototype point-of-care testing (POCT) instrument designed for fast detection of high-priority bloodborne pathogens. The portable device uses a new DNA amplification method called loop-mediated isothermal amplification to detect multiple targeted pathogens at once.



Five pathogens were selected for testing in the prototype POCT instrument: (a) *Streptococcus pneumonia*, (b) *Pseudomonas aeruginosa*, (c) *Candida*, (d) *Staphylococcus aureus,* and (e) *Escherichia coli.* Infections with any of these pathogens can lead to sepsis. If a patient does not receive medical intervention within hours, death is imminent.



"The goal of the Point-of-Care Technologies Research Network is to drive the development of appropriate point-of-care diagnostic technologies through collaborative efforts that simultaneously merge scientific and technological capabilities with clinical need," says Korte. In the field, the need for rapid and accurate diagnosis of infectious disease is critical, given the dependence of therapeutic choices on pathogen identification and the time-consuming nature of alternate approaches. Korte notes, "The disaster setting presents specific environmental challenges that the team is addressing through ongoing needs assessments and through its expertise in both technology development and clinical applications."

A Healthy Future

The team plans to eventually develop an instrument capable of testing several blood samples at once. Initial tests have already begun at Livermore on bovine whole blood spiked with bacterial DNA and live bacterial cells. Future plans include testing similarly spiked human whole-blood samples on the POCT instruments at UC Davis Medical Center. These tests, expected to commence this year, will use whole blood from patient volunteers who are suspected of having a blood infection.

POCT devices also could be adapted to test for other types of pathogens, according to Dzenitis. "With a tweak in design, our device could be used to detect influenza viruses, or it could be used to test for certain types of DNA to determine if someone is predisposed to conditions such as Parkinson's or diabetes," he says. Whatever its purpose, one thing is certain—the POCT device has the potential to better prepare the nation for future disasters and enhance patient survival outcomes through rapid decision making at both hospital bedsides and in emergency field operations.

—Kristen Light

Key Words: bloodborne-pathogen detection, loop-mediated isothermal amplification (LAMP), point-of-care testing (POCT), sepsis.

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Defending Computer Networks against Attack

ASSAULTS on stand-alone and networked computers, called cyber attacks, are escalating in frequency and severity as the world relies increasingly on World Wide Web applications for commerce, defense, research, education, and health care. In particular, government operations have come to depend on the Internet and are, therefore, vulnerable to a variety of attacks. As a result, cyber security has become a top national priority requiring the best computer experts in government, academia, and business. Some of these experts are working on a Lawrence Livermore project whose goal is to develop a fundamentally new approach for cyber defense.

"A large-scale computer network is the most complicated thing humans have ever developed," says Livermore engineer Jim Brase, who helps oversee several Laboratory efforts in cyber defense. Brase notes that commercial products such as antivirus software are useful at thwarting cyber attacks for stand-alone computers. However, they are inadequate for defending a network of thousands of computers from attacks orchestrated by groups of expert programmers as well as solitary hackers.

Forms of attack vary but most are attempts to read, alter, or destroy data or to compromise a computer's operating system to take control of the machine. Most computer users are aware of the possible danger from computer viruses, worms, and "phishing," in which an attacker sends an e-mail purporting to come from a valid bank or credit card company and requests personal information. They are also aware that simply surfing the Web can result in "drive-by downloads," in which malicious software (malware) is unknowingly installed on the user's computer.

Some cyber attacks are the work of solitary hackers simply yearning for notoriety. However, far more sophisticated threats exist, in particular from overseas groups, designed to steal important military and business data as well as personal banking information. U.S. computer experts estimate that more than 60,000 machines per day are co-opted into loose networks of computers, called botnets, some of which are operated by foreign professionals.

Cyber Attacks Are Unrelenting

Lawrence Livermore's unclassified computer network, which includes about 40,000 machines, is under continuous siege from cyber attacks. Detecting these attacks is a daunting challenge for Laboratory cyber security experts because the volume (several trillion bytes, or terabytes, of data per day) and diversity of legitimate traffic make it difficult to identify the relatively small amount of malicious activity. "Furthermore, the increasingly

sophisticated attacks are designed to be undetectable," says computer scientist Celeste Matarazzo.

Matarazzo is leading a Laboratory Directed Research and Development–funded project called the Supercomputing Enabled Transformational Analytics Capability (SETAC). The project's goal is to dramatically increase the ability to detect, characterize, and combat malicious attacks on large computer networks. The three-year effort focuses on establishing situational awareness—that is, a state of continual awareness—of network behavior to better detect malicious intrusions in real time (or nearly real time), while being respectful of individuals' privacy. In this way, human analysts will have the opportunity to respond to threats immediately.

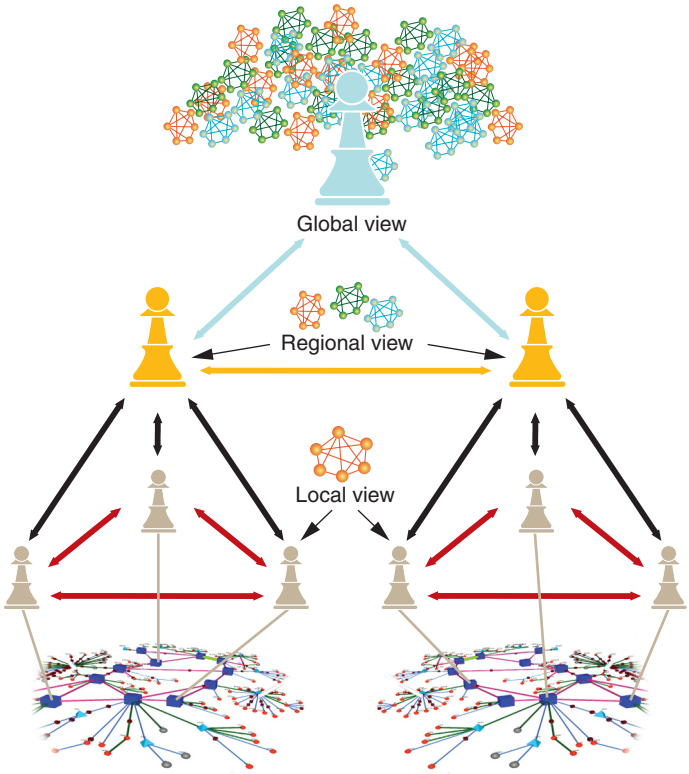
Matarazzo says that, to date, effective situational awareness of computer networks has been challenging because of the problem's scale and complexity. For example, at the perimeter of Livermore's unclassified computer network, terabytes of traffic data are collected each day, containing hundreds of millions of connection records. Furthermore, the cyber threat is extremely dynamic as adversaries can continually change the Internet Protocol (IP) addresses from which they conduct their operations, making detection difficult. Another challenge is malware that changes its behavior over time. Finally, the Web is always evolving, and computing environments blur the lines between personal computers and applications that reside on networks.

As part of the situational awareness effort, SETAC researchers are using complex algorithms distributed throughout the network together with novel hardware architectures derived from supercomputers. The researchers plan to deploy the algorithms (also called software sensor agents) to collect, analyze, and share data across the unclassified Livermore network. These distributed software sensor agents will also access data provided by commercial tools such as antivirus software and "learn" to quickly recognize suspicious behavior and take any necessary protective actions.

The sensors are designed for use at specific locations: firewalls (the part of a network that attempts to block unauthorized access), intermediate routers (devices that join smaller networks), and individual computers. Basic sensors report data to manager sensors that have more sophisticated analysis capabilities and a regional view of the network. In turn, manager sensors report to director sensors that have full analytic capabilities and a global view of the network. Currently, for testing purposes, about 50 sensor agents have been deployed on host machines of development team members and interested parties. Thousands of sensor agents will be deployed by the project's completion in September 2011.

Searching for Anomalies

Sensor agents look for anomalous scenarios such as multiple machines simultaneously performing the same action or an unauthorized action, a large amount of data suddenly being sent outside the Laboratory, a computer accessing a supercomputer that

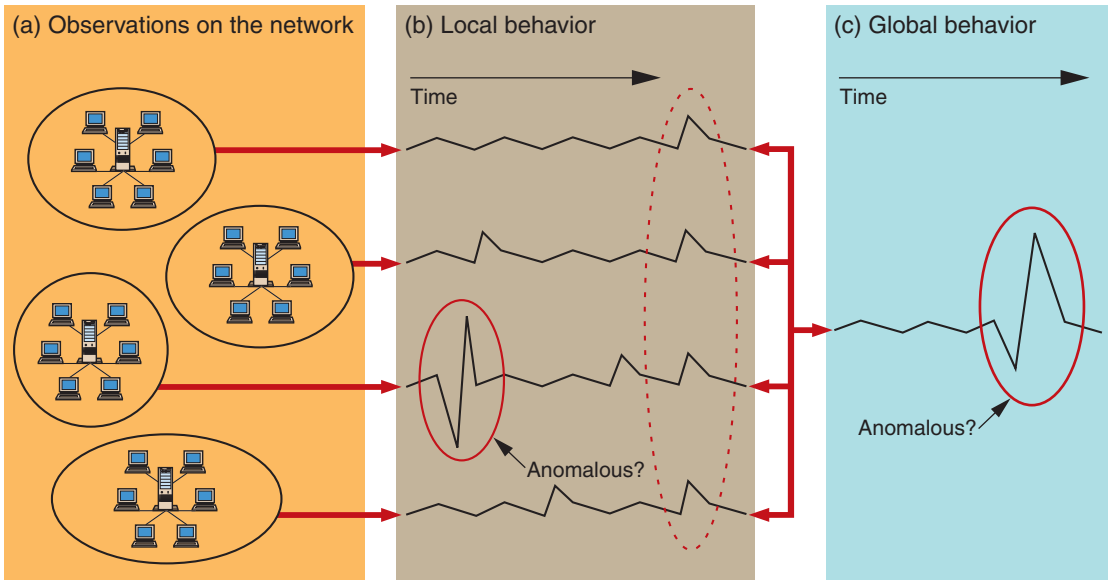


The Supercomputing Enabled Transformational Analytics Capability (SETAC) will deploy thousands of software sensor agents (algorithms) that collect, analyze, and share data across the unclassified Lawrence Livermore network. Basic sensors (gray) report data to manager sensors (gold) that have a regional view of the network. In turn, manager sensors report to director sensors (blue) that have a global view of the network. In addition, information is shared among all levels for decentralized control.

it has never previously accessed, or a computer communicating with an outside server that frequently changes its IP address. Should a sensor detect an anomalous scenario, it shares this information with other sensors to determine if similar behavior is occurring elsewhere on the network; if so, a security analyst would be alerted.

Matarazzo emphasizes that SETAC does not displace human cyber security personnel. Rather, "SETAC enhances an analyst's ability to make timely decisions," she says. By gathering network data and performing analyses in real time, the sensors permit human analysts to respond to threats as they unfold, thereby preventing identity theft, data collection, and installation of malware.

The three primary characteristics of SETAC—distributed decision making, an emphasis on behavior modeling using machine learning approaches, and real-time analysis and detection—are novel features of cyber defense. SETAC's situational awareness emphasis is preferable to today's typical cyber defense, which relies on commercial software at the organization's network perimeter and analysis after an attack



SETAC is designed to detect both local and global patterns of behavior. (a) In this example, sensors continuously observe the behavior of four computers. (b) A spike in activity of one computer indicates a possible anomalous local behavior. (c) A simultaneous spike in activity of all four computers indicates a possible anomalous global behavior. The information collected is then shared with other sensors, and a security analyst is alerted for further investigation.

has occurred and damage has been done. "Current cyber defense has limitations," says Matarazzo. For example, once an internal machine is breached, the entire network is at risk, because of the difficulty in preventing the spread of malware from within the organization. Also, intrusion detection typically means searching for known attack signatures, such as IP addresses previously identified as belonging to hackers. Intrusions are temporal in nature and are often identified only through analyses that cannot be performed in real time. These limitations frequently make contemporary cyber defense a job of cleanup and repair following an attack. Matarazzo adds, "Commercial tools are moving in directions similar to SETAC, although they deploy proprietary algorithms geared toward solving specific problems at limited scale."

SETAC's continual monitoring is analogous to credit card companies monitoring their clients' credit card use, with deviations from typical activity triggering a warning of possible unauthorized use. To detect anomalies of computer usage, however, SETAC developers must better understand what Livermore network activity looks like on a "normal" workday and weekend. "There are many dimensions of 'normal,'" says Matarazzo. For example, different departments and groups, and even occupations, may have different normal patterns of behavior.

Cyber Defense Taps Many Specialties

Livermore's research team includes computer scientists, statisticians, mathematicians, and engineers. Academic partners include the University of California at Riverside and Davis and Carnegie Mellon University. "Some interesting cyber defense research is under way in academia," says Matarazzo. "Partnering with academia allows us to access that knowledge." The SETAC team is also collaborating with experts at Sandia National Laboratories, Pacific Northwest National Laboratory, and Cisco, Inc.

SETAC is developing new approaches that contribute to national efforts such as the Comprehensive National Cyber Security Initiative, one of the largest single national security research and development investments in the U.S. today. "Livermore and the other national labs have much to offer the nation," says Brase. "We're expert at developing large-scale systems and monitoring how information flows."

In the meantime, researchers have instituted a test bed for sensor and system evaluation using controlled experiments with real cyber security data. "We don't have to make up a dangerous environment to test our system," says Matarazzo.

Because Livermore's network is not unusual in size or structure, a broad range of businesses and government agencies could soon benefit from SETAC cyber defense innovations. Within a few years, many large networks in the U.S. may well be armed with defenses pioneered at Livermore and aimed at thwarting a world full of clever "bad guys."

—Arnie Heller

Key Words: Comprehensive National Cyber Security Initiative, cyber security, hacker, Internet, malware, Supercomputing Enabled Transformational Analytics Capability (SETAC).

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Imaging Cargo's Inner Secrets

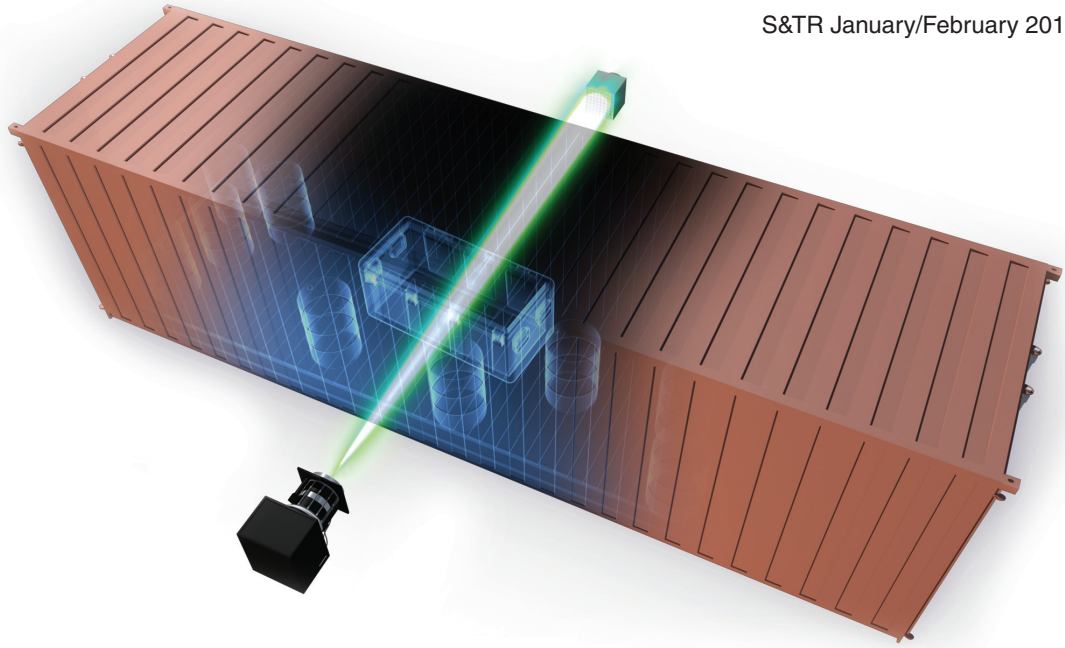
EACH year, millions of cargo containers from around the world are shipped to U.S. ports, holding in their metal "bellies" a variety of essential goods such as food and textiles. While this method of importing freight is necessary for the nation's livelihood, monitoring the contents in such a vast volume 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."

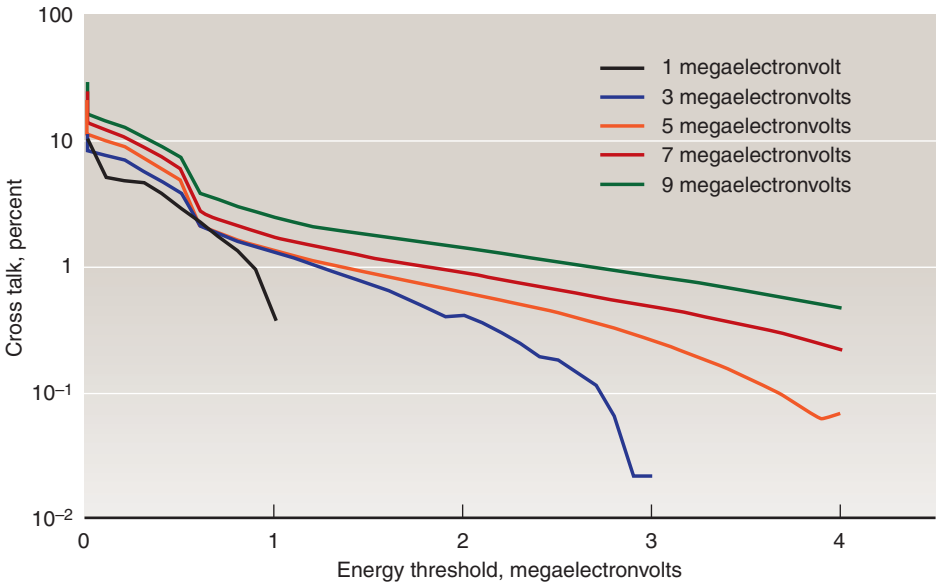
Small Target, Big Container

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

Key Words: Cargo Advanced Automated Radiography System, cargo screening, fissile material, fission, Monte Carlo modeling, photon, radiation detection, scintillator.

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

In this section, we list recent patents issued to and awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Guide Wire Extension for Shape Memory Polymer Occlusion Removal Devices

Duncan J. Maitland, Ward Small IV, Jonathan Hartman
U.S. Patent 7,611,524 B1
November 3, 2009
This flexible extension enhances a shape-memory polymer occlusion removal device. A shape-memory polymer instrument is transported through a vessel via a catheter. A flexible elongated unit is connected to the distal end of the shape-memory polymer instrument to enhance maneuverability through tortuous paths en route to the occlusion.

System for Trapping and Storing Gases for Subsequent Chemical Reduction to Solids

John S. Vogel, Ted J. Ognibene, Graham S. Bench, Graham F. Peaslee
U.S. Patent 7,611,903 B2
November 3, 2009
This system for trapping and storing gases can be used for quantitatively reducing oxide gases. A preselected amount of zinc is placed in a vial with a tube. The zinc and tube are separated. A preselected amount of a catalyst is placed in the tube. Oxide gases are injected into the vial. The vial, tube, zinc, catalyst, and oxide gases are cryogenically cooled. At least a portion of the vial, tube, zinc, catalyst, and oxide gases are heated.

Optically Measuring Interior Cavities

Gary Franklin Stone
U.S. Patent 7,612,896 B2
November 3, 2009
This method can be used to measure the three-dimensional volume or perimeter shape of an interior cavity. First, an optical slice of data is collected that represents a partial volume or perimeter shape of the interior cavity. Next, additional optical slices of data are collected that represent a partial volume or perimeter shape of the interior cavity. Finally, the first optical slice of data and the additional slices are combined to calculate the three-dimensional volume or perimeter shape of the interior cavity.

Awards

Laboratory chemical engineer **William Smith** has garnered the top award of the **American Institute of Chemical Engineers** (AIChE) Northern California section. Smith, who was honored with the 2009 **Professional Progress Award**, received a plaque and gave an invited lecture entitled "Improving the Environment We Share."

Smith has been instrumental in developing and commercializing a personal decontamination system that helps remove chemicals from human skin. He has worked in the Global Security Principal Directorate and the Environmental Restoration Division.

The Professional Progress Award was created in 1982 as the premier means for AIChE's Northern California section to honor one of its members. The award is given in consideration of sustained and substantial service to the section, recognized professional career achievement, and significant contributions to the chemical engineering profession.

The Laboratory's **Program for Climate Model Diagnostics and Intercomparison** is being recognized by the **American Meteorological Society** with a **special group award** for "leadership in implementing, maintaining, and facilitating access to the Climate Research Program CMIP3 multimodel data set archive, which led to a new era in climate system analysis and understanding."

The award cites **David Bader** (formerly of Livermore), **Karl Taylor**, and **Curt Covey** of the Physical and Life Sciences Directorate and **Jennifer Aquilino**, **Robert Drach**, and **Dean Williams** of the Computation Directorate. The award will be presented at the January 20, 2010, American Meteorological Society Meeting.

In November 2009, at the R&D 100 Awards ceremony sponsored by ***R&D Magazine***, a Livermore team and its partners received an **Editors' Award**, signifying the utmost achievement in developing new technology. **Satinderpall Pannu**, the team lead of the Laboratory's artificial retina program, accepted the plaque on behalf of the four other national laboratories, four universities, and one industrial partner working on an implant that may one day restore sight to patients with impaired vision.

Livermore also received eight R&D 100 Awards—more than the Laboratory has ever before won in the annual competition for the top 100 industrial, high-technology inventions. (See *S&TR*, October/November 2009.) Although winning awards serves to recognize excellence, the next step is just as important. Erik Stenehjem, director of the Laboratory's Industrial Partnerships Office, says, "These R&D 100 Awards are an invaluable aid in spreading the word about Livermore's expertise in advancing our nation's leadership in technology. Looking ahead, we hope to transfer many of these award-winning projects to industrial partners."

Abstract

The Hunt for Better Radiation Detection

Ensuring that the U.S. remains safe from a nuclear or radiological attack is driving a search for more definitive detection and identification technologies. A radiation detector materials campaign started several years ago at Livermore has grown into a collaboration that includes Pacific Northwest, Lawrence Berkeley, Oak Ridge, Brookhaven, and Sandia national laboratories; Fisk, Stanford, and Washington State universities; the University of Nebraska; and numerous private firms, including Radiation Monitoring Devices, Inc. Three Livermore teams are working with collaborators to find new and better detector materials to provide unambiguous identification of gamma radiation, fast neutrons, and slower, or thermal, neutrons emitted from plutonium and highly enriched uranium. Each team is aiming for the highest possible resolution or efficiency to quickly identify signals from weak sources (for example, lead-lined cargo containers that block most gamma rays or plastic-coated containers that hide fast neutrons). Researchers include not only chemists, physicists, and engineers but also computational modeling experts whose quantum molecular simulations help guide researchers in selecting materials.

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Responding to a Chemical Weapons Attack

Livermore researchers are helping strengthen federal and state response capabilities to an incident involving chemical weapons.

Also in March

- *Simulations reveal for the first time how blast waves may cause traumatic brain injuries.*
- *Laboratory researchers are developing solar thermal technology to supply residential electric power at nearly half of the current retail price.*
- *A Livermore-developed system is helping scientists better understand how plague cells infect healthy host cells.*

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