September 2004

Science & Technology REVIEW

National Nuclear
Security Administration's
Lawrence Livermore
National Laboratory

Improving Radiation Detection

Also in this issue:

- **Ultrawideband Revolutionizes Radar and Communication Devices**
- **Simulated Terrorist Attack**
- **Solid-State Modulators Increase Collider Efficiency**

About the Cover

As the article on p. 4 describes, the Laboratory's Radiation Detection Center (RDC) helps initiate and support projects to develop novel radiation technology for national security and basic science programs. Nuclear threats can be detected, identified, and analyzed using a multitude of radiation detection devices, such as those shown on the cover (clockwise from top): ultrahigh-resolution neutron spectrometer; coaxial germanium Compton imager; combination handheld radiation sensor, cellular phone, and Global Positioning System; planer germanium imaging spectrometer; and scintillator-based gamma-ray imaging spectrometer. The multidisciplinary RDC centralizes the Laboratory's radiation detection efforts and offers national workshops, seminars, and student internships through its outreach program.

Cover design: Kitty Madison

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, 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 10 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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September 2004

Lawrence Livermore National Laboratory

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Lab garners five R&D 100 awards

Livermore researchers turned in another strong showing in the annual R&D 100 awards competition for top industrial inventions, winning five awards. Each year, *R&D Magazine* presents these awards to the top 100 industrial, high-technology inventions submitted to its competition for outstanding achievement in research and development.

The five Livermore inventions honored are as follows:

• The Autonomous Pathogen Detection System, which is an automated, lectern-size instrument that can monitor the air for all three types of biological agents (bacteria, viruses, and toxins). A deployed system needs only weekly human intervention and can report any pathogen releases in its vicinity to operators at a central location.

• A Diode-Pumped, Pulsed Laser for Humanitarian Mine Clearing, which can be used to uncover and safely neutralize buried land mines. Today, an estimated 100 million land mines are spread throughout 70 nations.

• Inductrack, a magnetic levitation (maglev) system that uses new arrangements of permanent magnets to create its levitating fields. The maglev system offers a simple, low-cost solution to the country's growing need for efficient intercity and urban transportation networks. Livermore researchers and San Diego–based General Atomics share this R&D 100 Award.

• Chromium Software, which provides a way for interactive two- and three-dimensional graphics applications to take full advantage of powerful distributed, graphics-enabled clusters of commercially available personal computers. The software was designed and developed in collaboration with researchers from Stanford University; the University of Virginia, Charlottesville; and a commercial company, Tungsten Graphics.

• Gene Silencing with SiHybrids, which is a gene-silencing technique that has revolutionized laboratory research and clinical therapy. A number of applications of the technology are envisioned for both basic research and in improving cancer therapies.

S&TR will devote its October issue to detailed reports on these award-winning inventions and the teams that created them.

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Secretary of Energy visits the Laboratory

On July 8, 2004, Department of Energy (DOE) Secretary Spencer Abraham visited the Laboratory, accompanied by University of California (UC) President Robert Dynes and UC Vice President for Laboratory Management Robert Foley. Abraham cut a ribbon to officially open Livermore's new Terascale Simulation Facility (TSF) and signed racks that will become part of the facility's BlueGene/L and Purple supercomputers. BlueGene/L will be the world's fastest supercomputer when it is fully operational (June 2005), capable of processing 360 trillion operations per second (teraops). (See *S&TR*, June 2004, pp. 12–20.)

In his remarks at the TSF, Abraham noted that in 1995, DOE's Advanced Simulation and Computing (ASC) Program set out to obtain a computer system that could process 100 teraops—the capability required for three-dimensional, full-system weapons simulations for the Stockpile Stewardship Program. "With the opening of this building, we are much closer to making that promise a reality," he said. "Once completed, [Purple] will represent an improvement in computing power by a factor of over one million over that used for weapons simulations in 1995. Purple's success will be the fulfillment of that very ambitious goal."

Dona Crawford, Livermore's associate director for Computation, praised the Laboratory's strong partnership with IBM in the development of four generations of supercomputers—ASC Blue, at 3 teraops; ASC White, at 12 teraops; Purple, at 100 teraops; and BlueGene/L, at 360 teraops. IBM's Dion Rudnicki said the collaboration provided the opportunity for IBM and the Laboratory "to protect and demonstrate U.S. competitiveness" in supercomputer development.

The Secretary also toured the National Ignition Facility (NIF), which will be the world's most powerful laser facility when completed later this decade. (See *S&TR*, September 2003, pp. 4–14.) While at NIF, he presented DOE Science and Technology Awards to Livermore and Los Alamos national laboratory employees representing the teams that conducted the first experiments at the facility. NIF is "an essential element of our nuclear Stockpile Stewardship Program and our mission of maintaining the reliability, safety, and security of this nation's nuclear deterrent," Abraham said. "That is why it is so important that this facility be completed on time by 2008."

Also during his visit to the Laboratory, Abraham stopped at the Safeguards and Security Department to witness a JCATS (Joint Conflict and Tactical Simulation) demonstration (see article beginning on p. 20), and to present an award to the Laboratory's Protective Force Division. The Secretary's recognition commemorated the Laboratory achieving the highest rating possible for the March 16, 2004, force-on-force exercises. These special security assessments at Livermore were part of the Office of Independent Oversight and Performance Assurance Special Review of DOE Protective Forces that was requested by Abraham. "Our Department of Energy facilities are worth billions of dollars," Abraham said. "We employ many thousands of scientists, engineers, researchers, analysts, and others. And, as is particularly the case here at Livermore, we are custodians of national security assets that, simply put, must not be allowed to fall into the wrong hands."

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(Continued on p. 25.)

Radiation Detection at the Leading Edge of Scientific Discovery

MANY science historians have relegated nuclear science to the 20th century, as if the field were fully mature with nothing left to discover. However, as we address the threats of the 21st century, we are finding that significant advances must be made in our understanding of nuclear phenomena if we are to devise effective countermeasures against nuclear proliferation and terrorism.

Even though Lawrence Livermore has been a leader in nuclear science for more than 50 years, today's technical challenges are markedly different from those posed by earlier nuclear weapon development programs. Instead of needing to rapidly collect and interpret data on large events with strong signals (nuclear tests, for example), we now need to be able to detect and characterize small events with weak signals (smuggled nuclear materials, for example). This challenge is compounded by the fact that the world is filled with radioactivity, and small or distant signals can be swamped by the naturally occurring background.

However, the very nature of radioactive materials makes them detectable at a distance, giving us a technological approach to locating and interdicting such materials. Indeed, different materials and isotopes give off unique emission spectra, making it possible not only to detect them but also to characterize and identify the detected material. This capability in turn allows us to discriminate fissile and other threat materials from the large background of naturally occurring radiation and legitimate sources, such as medical isotopes.

In addition, by understanding the nature of nuclear proliferation and terrorism, we can identify points in the "threat timeline" where we can effectively apply detection and interdiction measures. Clearly, responding after the fact—after a country or terrorist group has obtained or used nuclear weapons—is the least satisfactory approach. Our greatest leverage lies at the front end of the problem—in locking up weapons and nuclear materials, in forestalling proliferators from developing nuclear weapon capabilities, in detecting threat materials and weapons far from their intended target, and in preventing the detonation of any nuclear explosive or radiological dispersal device. At each of these points, novel approaches to radiation detection can make significant contributions. However, we are finding that, in many cases, new scientific understanding is needed to turn detection concepts into real technologies.

For example, the International Atomic Energy Agency has a need for technology that can monitor nuclear power reactors to ensure that nuclear fuel is not diverted for illicit purposes. To this end, Livermore scientists are investigating the feasibility of using scintillator-based antineutrino detectors to provide a near-real-time, nonintrusive way to measure changes in fissile content and total fission rates (that is, power levels) at nuclear reactors and thereby detect the diversion of a significant quantity of plutonium or uranium-235.

New science is also playing an essential role in efforts to detect fissile materials inside cargo containers. Detecting highly enriched uranium (HEU) is particularly challenging, because its quiescent emissions are easily shielded. Livermore researchers recently discovered a delayed gamma-radiation signature for HEU that is two to three orders of magnitude more intense than its delayed neutron signals (the signature most often used in active interrogation). Use of this gamma signature should permit the detection of HEU even when shielded by thick cargo. (See *S&TR*, May 2004, pp. 12–15.)

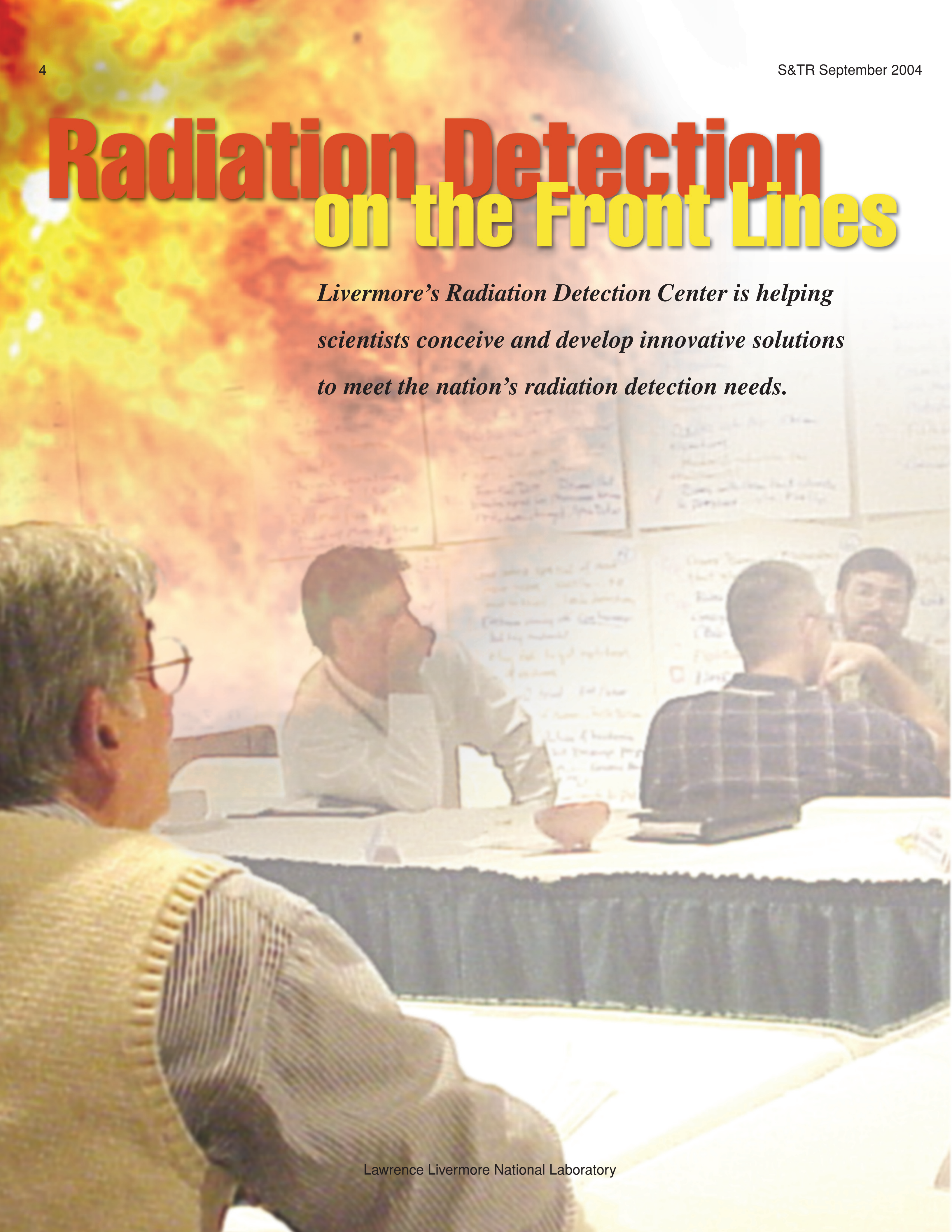
Other Laboratory scientists are working to develop aluminum antimonide (AlSb) as a promising new material for achieving excellent energy resolution without the cumbersome cooling systems required for the germanium-based detectors currently in use. Although this project is in the research stage, Livermore has successfully overcome a number of technical challenges related to crystal purity and stoichiometry that have discouraged other researchers from pursuing AlSb for this application.

As the article beginning on p. 4 describes, the Radiation Detection Center is leading the effort to reinvigorate Laboratory research in nuclear science, with a focus on nonproliferation and counterterrorism. The center is also supporting outreach activities with universities across the country to revive nuclear science as a vital field of study. Both efforts leverage current interest among scientists and students to work on research topics with real-world relevance and, in so doing, help to build the pool of technical talent that is essential to ensuring Livermore's continued preeminence in nuclear science and technology and its ability to fulfill its national security mission today and into the future.

■ Wayne Shotts is associate director for Nonproliferation, Arms Control, and International Security.

Radiation Detection on the Front Lines

Livermore's Radiation Detection Center is helping scientists conceive and develop innovative solutions to meet the nation's radiation detection needs.



IF you think a device that resembles a cellular phone but detects a potential nuclear threat and transmits a description of the nuclear material to every nearby crisis center sounds like something out of a James Bond movie, you are in for a surprise. Since the 1930s, when scientists first used the Geiger counter, radiation detection equipment has gone through an amazing evolution in size, sensitivity, deployability, and power.

Lawrence Livermore, which has been developing radiation-related technologies for decades, continues to adapt radiation detection devices for national security needs. In 1999, the Laboratory began forming its Radiation Detection Center (RDC), a multidisciplinary organization that centralizes Livermore's radiation detection efforts. The RDC is supported through a memorandum of understanding between eight Laboratory directorates. Recently, several new radiation detection projects were funded by the Department of Homeland Security (DHS), which is expected to invest more than a billion dollars this year in science and technology across the nation to help the country detect and respond to terrorist threats.

The RDC helps to initiate and support many projects throughout the Laboratory that are developing new technology for national security and basic science programs within DHS, the Department of Energy (DOE), the Defense Threat Reduction Agency (DTRA), the Defense Advanced Research Projects Agency, the National Institutes of Health, the National Aeronautics and Space Administration (NASA), and others. In addition, the center serves as an institutional resource for these organizations.

Many of today's radiation detection tools were developed in the 1960s. For years, the Laboratory's expertise in radiation detection resided mostly within its nuclear test program. When nuclear testing was halted in the 1990s, many of Livermore's radiation detection experts were dispersed to other parts of the Laboratory, including the directorates of Chemistry and Materials Science (CMS); Physics and Advanced Technologies (PAT); Defense and Nuclear Technologies (DNT); and Nonproliferation, Arms Control, and International Security (NAI).

The RDC was formed to maximize the benefit of radiation detection technologies being developed in 15 to 20 research and development (R&D) programs. These efforts involve more than 200 Laboratory employees across eight directorates, in areas that range from electronics to computer simulations. The RDC's primary focus is the detection, identification, and analysis of nuclear materials and weapons. A newly formed outreach program within the RDC is responsible for conducting radiation detection workshops and seminars across the country and for coordinating university student internships.

Simon Labov, director of the RDC, says, "Virtually all of the Laboratory's programs use radiation detection devices in some way. For example, DNT uses radiation detection to create radiographs for their work in stockpile stewardship and in diagnosing explosives; CMS uses it to develop technology for advancing the detection, diagnosis, and treatment of cancer; and the Energy and Environment Directorate uses radiation detection in the Marshall Islands to monitor the aftermath of nuclear testing in the Pacific. In the future, the National Ignition Facility will use radiation detection to probe laser targets and study shock dynamics."

RadNet is a low-cost radiation detector that includes a cellular telephone, a personal digital assistant with Internet access, and a Global Positioning System locator.

Sorting the Signals

One of the challenges facing nuclear researchers today is developing "smarter" detection systems that distinguish between radiation emissions from legitimate sources (for example, medical isotopes) and those from threatening sources. Nuclear materials, whether used in weapons or cancer therapy, typically emit gamma radiation. Many radioactive isotopes emit a unique spectrum of gamma rays that can penetrate substantial amounts of ordinary matter without being scattered or absorbed as visible light would be. These gamma rays can be analyzed to indicate the specific type of nuclear material.

The problem with early radiation detection systems is that they detected gamma rays from all radioactive material and could not distinguish between isotopes. Radioactive material is everywhere—from the concrete in our streets to the food we eat. Americium-241 is used in smoke detectors; cobalt-60 is used in medical treatment equipment; and potassium-40, a naturally occurring isotope in soil, is found in fruits and vegetables. (See the box below.)

Livermore scientists and engineers have made significant advancements in radiation detection equipment. Isotopes are now more easily distinguishable, reducing the confusion between threatening and nonthreatening sources. "We don't know exactly how a terrorist will build a device," says Labov. "But now we have more sophisticated instruments that have better spectral resolution. These instruments help us to identify common and legitimate radioactive materials, which increases our sensitivity to possible threats." Specialized integrated circuits and microelectronics, improved computer codes, and advancements in detector materials have made these instruments possible.

How many types of detection devices are needed? Labov says, "Several types are necessary because the needs vary depending on the field. A customs agent at a U.S. maritime port will benefit from cargo interrogation systems as well as radiation detectors placed in buoys, while a firefighter responding to a potential dirty bomb threat might benefit from a high-resolution, handheld detector. If smuggled nuclear material is intercepted, an ultrahigh-resolution gamma-ray spectrometer may help identify the origin of the material." (See *S&TR*, January/February 2004, pp. 19–22; May 2004, pp. 12–15.)

Detection devices also vary in cost. The price tag for a large, laboratory-type spectrometer is $50,000 to $80,000, whereas a handheld detector may cost as little as $2,000. In some cases, the low-cost detector may be more appropriate for a particular task. "For example," says physicist Bill Craig, who leads the Advanced Detector Group in PAT, "when you don't know the location of a threat, the dispersion of many cheaper detectors may be more efficient so that first responders can cover more area."

Radiation All around Us

Radiant energy exists in two forms—ionizing and nonionizing. Ionizing radiation has sufficient energy to remove electrons from neighboring atoms, thereby creating charged particles (ions or radicals) in materials it strikes. An effect from such ionization can be biological damage at the molecular and cellular level. Nonionizing radiation, such as laser light and microwaves, does not have enough energy to remove electrons from neighboring atoms. The only observed biological effects of nonionizing radiation are heating effects.

The common types of ionizing radiation are alpha, beta, gamma, neutron, and x radiation. Some atoms, for example uranium and thorium, are naturally radioactive. Other radioactive isotopes, for example tritium and iodine-131, are made in reactors or accelerators.

Radiation deposited in a material, such as may occur in an experiment, is called a radiation dose. Dose equivalent is the term used when determining the effect on humans. Dose equivalent is measured in rems or sieverts. The total number is based on the radiation dose and type and whether the exposure was internal or external. Because the majority of radiation exposures is small, the unit of one-thousandth of a rem, or 1 millirem, is commonly used.

Background ionizing radiation (that is, radiation from natural sources) measures about 300 millirem per year in the U.S. The radiation comes from cosmic rays, radioactive material in the earth, naturally occurring radionuclides, such as potassium-40 in food, and radon gas present in the air we breathe. Sources of human-caused ionizing radiation contribute an additional dose of approximately 70 millirem per year and include medical procedures, consumer products, and fallout radiation from the era of aboveground nuclear testing.

Exposure to large amounts of ionizing radiation (on the order of hundreds of times the natural exposure levels) increases the risk of cancer and genetic mutations that can be passed on to future generations. The extent of cell damage depends on the total amount of energy absorbed, the time period and dose rate of exposure, and the organs exposed.

In 1928, the International Commission on Radiological Protection—an independent, nongovernmental expert body—was established to recommend the maximum radiation dose to which people could be exposed. The commission set the level to not exceed 5 rem (5,000 millirem) per year. That limit is still used for radiation workers.

Most of the exposure associated with human activity is low-dose radiation. Although low-dose radiation does result in some damage to living tissue, the body can repair the damage. Recent research has indicated that low-dose ionizing radiation may activate protective and repair mechanisms and offer protection to the cells from a subsequent high dose of ionizing radiation. (See *S&TR*, July/August 2003, pp. 12–19.) The model used for setting radiation protection limits is based on the risk being proportional to any radiation exposure above zero and is thus called the linear, no-threshold model.

Detector Makes Phone Calls

The recently developed RadNet detector is both inexpensive (about $2,000) and easily dispersed. This handheld instrument combines a cellular telephone, a personal digital assistant with Internet access, and a global positioning system locator with a radiation sensor. A number of RadNet units could be deployed as part of a wide-area network. Data collected by the units could be transmitted and plotted to a geographic map. In this way, law enforcement or other personnel could find the exact location of high-radiation signals from possible clandestine nuclear materials or devices.

In addition to being lightweight and able to operate at low power, each RadNet unit has sufficient energy resolution to eliminate alarms from background radiation emitted by such sources as food, medical devices, and soil. When it is not measuring specific radioactive samples, a RadNet unit monitors the ambient radiation field and communicates with a central processing system in real time. “RadNet is a detection device that first responders, customs agents, and border inspectors can carry and use routinely because of its other features, such as a cellular phone,” notes Labov.

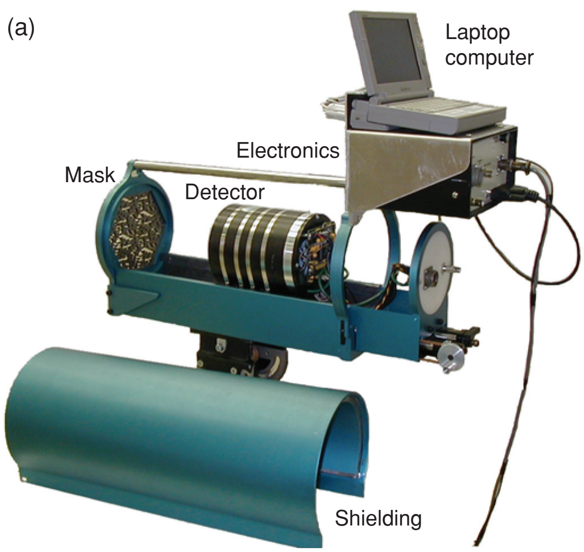
The RDC is using a RadNet prototype in demonstrations to customs officials, fire departments, and other first responders. “Customs officials,” says Craig, “have had radiation pagers for some time. However, those pagers cannot identify the radiation source or send information back to someone who can analyze the data.”

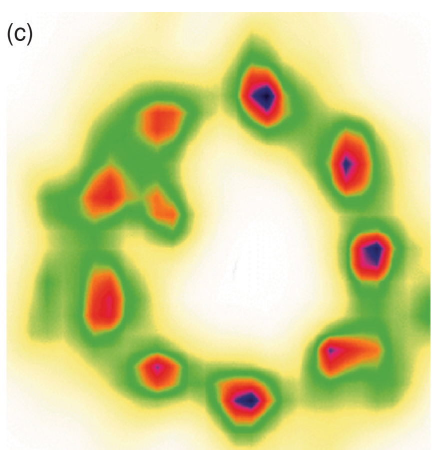
The RadNet project combined resources from directorates across the Laboratory, which is what the RDC management likes to see. “RadNet’s detector technology came from the astrophysics program in PAT,” says Labov. “Engineering supplied electronics expertise for processing the detector’s signals. CMS lent its expertise in detector material, and NAI and Engineering provided expertise in analyzing gamma-ray signatures to identify nuclear isotopes.”

Leave No Gamma Ray Behind

Researchers have also made advances in semiconductor-based, gamma-ray imaging detectors. These imagers use increased sensitivity and spatial resolution to detect weak radioactive sources that would otherwise be masked by background gamma-ray emissions. Gamma-ray imagers are particularly useful when searching for lost, stolen, or hidden nuclear material in a large area. DOE, DHS, and DTRA are interested in Livermore’s research on gamma-ray imaging because they are the agencies likely to be called if such a search is necessary.

Livermore is developing several gamma-ray imagers, each having different capabilities. One imager, called the gamma-ray imaging spectrometer (GRIS), can take gamma-ray “pictures” of the high-energy radiation emitted by nuclear materials. (See *S&TR*, October 1995, pp. 14–26.) This instrument is useful for a variety of applications, including treaty inspections, mapping radioactive contamination, and determining what is inside a suspect object. Because gamma radiation is so difficult to focus, the instrument uses an imaging technique originally developed for high-energy





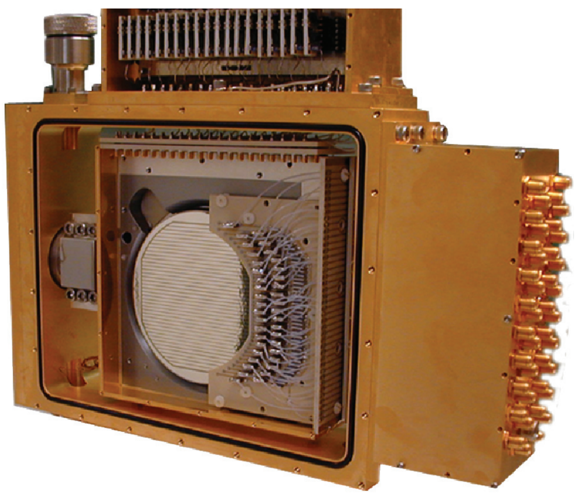
(a) The gamma-ray imaging spectrometer (GRIS) takes pictures of the high-energy gamma radiation given off by nuclear materials. The images are encoded on the detector by using a coded aperture mask that allows the user to recover the image through a computer program. (b) One potential application of GRIS is for nonintrusive treaty inspections. The drawing shows how the instrument might be used to inspect a multiple-warhead missile. (c) The image of a multiple-warhead missile taken with GRIS clearly shows each of the ten warheads.

astrophysics. The images are encoded on the detector by placing a sheet of material opaque to the radiation in front of the detector. The sheet is pierced with a carefully selected hole pattern that allows researchers to mathematically recover the image with a simple computer program. The system is about half the size of a personal computer.

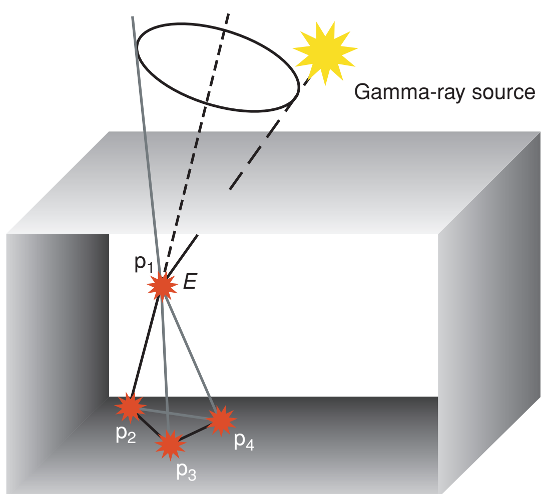
GRIS was first developed for use in treaty inspections to monitor the location of nuclear missile warheads in a nonintrusive manner. In addition to its use in counterterrorism applications, GRIS is also expected to be useful in space to search for distant black holes and in hospitals to better detect, diagnose, and treat cancer.

Another version of GRIS being developed, the large-area imager, will be suited for longer-range searches. The large-area imager—approximately the size of a sofa—will be mounted in a small truck and capable of picking out weak radioactive sources from as far away as 100 meters.

The Compton camera is yet another type of gamma-ray imager under development. In addition to taking gamma-ray pictures, this imager should be able to identify very weak and typically invisible gamma-ray sources. The Compton camera operates without a mask or collimator, which can block many of the gamma rays emitted from a source. Instead, gamma rays coming from all directions at once are tracked as they scatter inside the detector. The camera's omnidirectional sensitivity is significantly higher than that of other imaging systems. Mathematical algorithms are used to retrace the paths of the gamma rays within the detector, and the results reveal the direction of the source.



A two-dimensional, segmented germanium detector is one type of Compton camera. In the center is a high-purity germanium crystal. The detector is connected to individual cables and preamplifiers. The output signals are fed into an acquisition system that digitizes and processes the data to extract energies and three-dimensional positions of the gamma-ray interactions.



The Compton camera's omnidirectional capability significantly increases gamma-ray sensitivity. A gamma ray enters the detector and interacts through Compton scattering until it is fully stopped by the photoelectric effect. Mathematical algorithms combining all of the gamma rays' energies (*E*) at each position (p) are used to identify the path of the gamma-ray source.

Livermore's work on the Compton camera was originally funded through the Laboratory Directed Research and Development Program and later by DOE. Today, DHS is funding a Livermore effort to develop a compact, potentially portable Compton camera. The main goal for the camera is to detect clandestine nuclear materials. However, the instrument could also be used to detect cancer early by using radiolabeled tracers to target unique molecular characteristics of the disease. A field-deployable prototype of the Compton camera is still a few years away. Laboratory researchers continue to test detector materials and determine the best size for the instrument.

Livermore physicist Kai Vetter says, "We are developing various types of gamma-ray imaging systems. Individuals who work in the field, searching for nuclear materials or carrying out stockpile stewardship activities, will tell us which system best suits their needs."

Uncovering Hidden Elements

Another radiation detection instrument is a spectrometer that can detect light elements, such as oxygen, within a heavy matrix, such as plutonium. While gamma-ray spectrometers are ideal for certain applications, in many situations, they cannot detect the presence of oxygen because oxygen is stable and does not usually emit gamma rays. Stockpile stewardship and radioactive waste characterization may benefit from this capability. For example, the neutron spectrometer could measure oxygen bound to plutonium, which may have resulted from seepage through casks containing nuclear weapons or spent nuclear fuel. (See figure on p. 10.)

Physicist Stephan Friedrich of the Advanced Detector Group leads a team developing the ultrahigh-resolution neutron spectrometer. In addition to providing a spectral emission that distinguishes a light element within a heavy element matrix, neutron spectrometers can also detect nuclear material behind a shield and perhaps even determine the composition of the intervening material. If plutonium, for example, were concealed in a lead object, the lead, or any heavy metal shield, would absorb the gamma rays emitted from the plutonium, whereas neutrons would travel through the lead and scatter in ways that provide a signature.

The ultrahigh-resolution neutron spectrometer uses lithium fluoride to absorb incoming neutrons. It then measures the released energy from the neutrons interacting with the lithium fluoride combined with the energy of the neutrons as they enter the detector. The spectrometer will operate in laboratories where the units can be cooled to 0.1 kelvin, the temperature required to obtain ultrahigh-energy resolution.

"A prototype of the ultrahigh-resolution neutron spectrometer could be complete in a year," says Friedrich. "Collaborations at workshops conducted by the RDC helped our team refine ideas for this necessary technology and also revealed potential applications for other areas." The spectrometer is so sensitive that it will be able to detect the energy deposited by a single neutron.

A New Frontier: Sensor Fusion

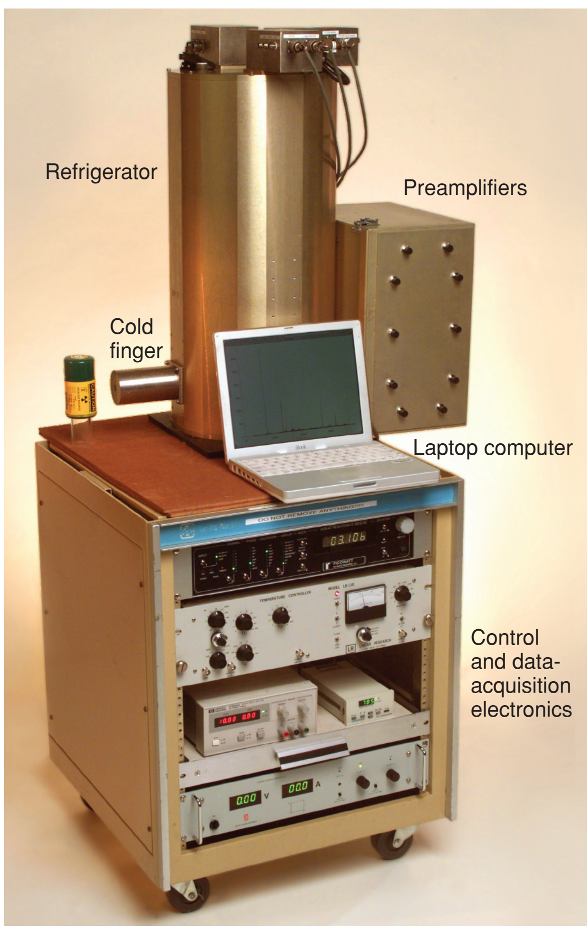
Combining various types of radiation detection devices into a network that maximizes the benefits of each is the next frontier. Craig notes, "The first push was for radiation detectors. Now, there is the realization that a first responder called to check out a potential bomb threat on a bridge, for example, may not be in the best position to analyze the data." This realization has launched the area of sensor fusion—taking information from an ensemble of detectors.

"Sensor fusion," says Craig, "is a discipline that allows scientists to combine data and provide a sum greater than the parts. For example, information from a portable radiation detection system can be combined with that from handheld detectors and video cameras, and all of the data can be integrated to give a more complete report than one type of detector could provide."

Labov says DHS is interested in adding wireless data transmission to radiation detectors, but no system is currently in place to collect and analyze the data. "We could use analyses from science applications at the Laboratory to integrate and interpret the data. With sensor fusion, information gathered from multiple gamma-ray detectors, neutron detectors, and detectors that take visual images, for example, could be combined and analyzed together. Combining the information is a discipline in computer science. We are strategizing on the most effective methods to accomplish this goal."

Sharing Bright Ideas

Running analyses and interpreting the data from a network of different radiation detection equipment requires special skills in nuclear science. Yet despite the increasing demand for this expertise, the last two decades have seen a nationwide decline in the number of students pursuing careers in nuclear engineering, physics, and chemistry because of decreasing job prospects. For



The ultrahigh-resolution neutron spectrometer consists of a large cylindrical demagnetization refrigerator with a cold finger on one side, which contains a detector aimed at a radioactive source, and a box with preamplifiers on the other side. The lithium fluoride detector is held at a temperature of approximately 0.1 kelvin either in the refrigerator or in the cold finger. The rack on the bottom contains temperature control and data-acquisition electronics. Neutron spectra are displayed on the laptop computer.

example, it has been decades since a nuclear power plant was built in the U.S. As a result, many universities are closing their nuclear energy programs and shutting down their research reactors.

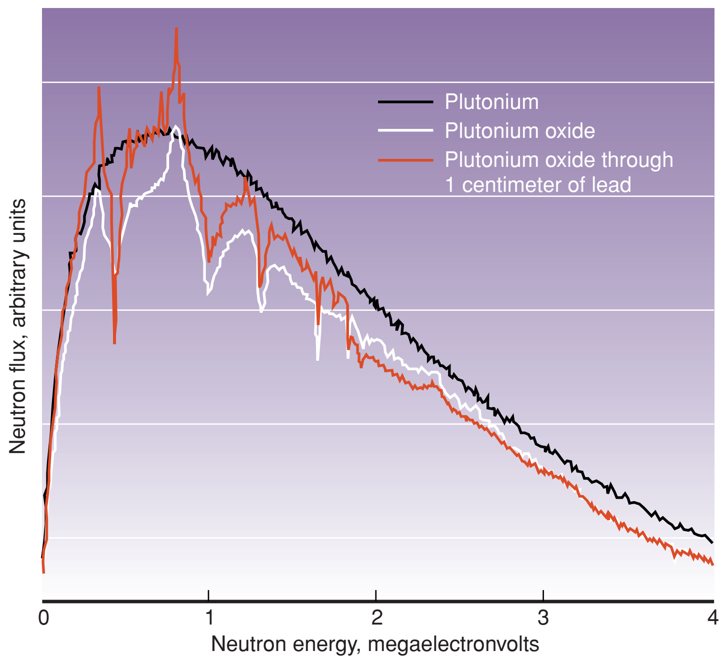
But changes are under way. DOE is investing millions of dollars in the Nuclear Energy Research Initiative Program to support nuclear R&D. The National Nuclear Security Administration (NNSA), the Department of Defense, and DHS also sponsor many R&D efforts and are turning to Livermore to provide technical expertise in radiation detection. Jeff Richardson, a division leader for NAI, notes, "These agencies are looking to Livermore for creative solutions to homeland security and general nonproliferation objectives."

In 2000, the RDC formalized an outreach program to conduct workshops, coordinate technical discussion groups, and provide internships for university students interested in nuclear science. This year, the center hired an education coordinator to put together a plan for attracting new graduates to nuclear science. RDC members are working with students at universities, such as the University of California (UC) at Berkeley, which has a strong nuclear engineering program, and the University of Michigan, known for its nuclear science program. Graduate summer students work at Livermore's Seaborg Institute for Transactinium Science, which was established in 1991 to foster research in fundamental and applied nuclear science and technology.

Christie Shannon, the RDC's outreach coordinator, keeps a pulse on researchers' needs so that the center can arrange for relevant seminars and workshops. "The seminars and workshops provide a forum for collaboration with radiation experts within the Laboratory and from other organizations, including other national laboratories, government agencies, universities, and industry personnel."

To date, the RDC has hosted more than 80 seminars on such topics as detecting cosmic axions and the use of antineutrino detectors for reactor safeguards. In addition, technical discussion groups focus on brainstorming new approaches to radiation detection. For example, a group was formed to discuss using the air filters in police cars to examine air particles after a nuclear terrorist attack.

In a series of workshops held from December 2003 to February 2004, 60 Laboratory scientists and engineers met to identify critical needs in radiation detection and prioritize a list of potential solutions. The idea for a large-scale effort in sensor fusion came from these collaborations. A new effort to develop detectors based on nanomaterials also emerged. A directional neutron detector



The ultrahigh-resolution neutron spectrometer can detect light elements, such as oxygen, within a matrix of heavy elements, such as plutonium. Shown here is a simulated neutron spectrum of plutonium, plutonium oxide, and plutonium oxide detected through lead.

The Radiation Detection Center organizes internship programs for university students in nuclear science. Here, Kelvin Aaron from South Carolina State University operates a superconducting x-ray spectrometer.

and the ultrahigh-resolution neutron spectrometer are two other ideas that were refined at the workshops, enabling them to become fully funded R&D projects. Friedrich notes, "After the workshops, the ultrahigh-resolution neutron spectrometer became a prominent goal for the Laboratory, and it became clear where we needed to go to complete development." The work on this spectrometer is now funded through NNSA's Office of Nonproliferation Research and Engineering.

The RDC also hosts DOE workshops featuring speakers with innovative ideas for detecting nuclear materials. Workshop topics have included investigating alternative signatures for detecting fissile materials; improving tags, seals, and intrusion sensors for container shipping security; and remotely monitoring nuclear material using attended and autonomous intelligent-sensor systems.

Workshops allow scientists and engineers to identify critical needs in radiation detection and share ideas for innovative solutions.

Astrophysics: Past and Future

Many Livermore radiation detection advances have resulted from technical developments in astrophysics. For years, Livermore researchers have collaborated with scientists from the California Institute of Technology, NASA's Goddard Space Flight Center, UC Berkeley, Columbia University, Massachusetts Institute of Technology, Harvard University, and other universities and government laboratories to develop the latest technologies for detecting and imaging space phenomena.

"We are finding ways to combine better science with better security," says Labov. "For example, astrophysicists at Harvard University approached Livermore for assistance on a satellite project in which the scientists needed an 8-square-meter area of crystal to operate as a detector. Some developments from that project resulted in technology later used for RadNet."

The coded aperture system used in GRIS is another example of a technology invented by astrophysicists. And the technology used for the Compton camera came from the Imaging Compton Telescope, COMPTEL, which was built in 1989 at Goddard to study gamma-ray sources such as pulsars, supernova remnants, and molecular clouds.

Although some of Livermore's radiation detection technology came from astrophysics, Craig hopes to see the reverse as well. "We're hoping to help astrophysicists use RadNet-like detection systems for missions, such as probing for black holes."

Detectors have come a long way over the last decade. From sensors on buoys to low-cost networks, today's devices promise almost tailor-made solutions to meet the needs of first responders. Richardson notes, "We are continuing to push the envelope in all areas of radiation detection, particularly in the areas of high sensitivity and selectivity."

As new tools for radiation detection and networking of systems develop, the RDC will continue to pilot efforts to realize the Laboratory's goals. Perhaps there may even be a new gadget for James Bond to take on his next mission.

—Gabriele Rennie

Key Words: Compton camera, gamma-ray imaging spectrometer (GRIS), large-area imager, Radiation Detection Center (RDC), RadNet, Seaborg Institute for Transactinium Science, sensor fusion, ultrahigh-resolution neutron spectrometer.

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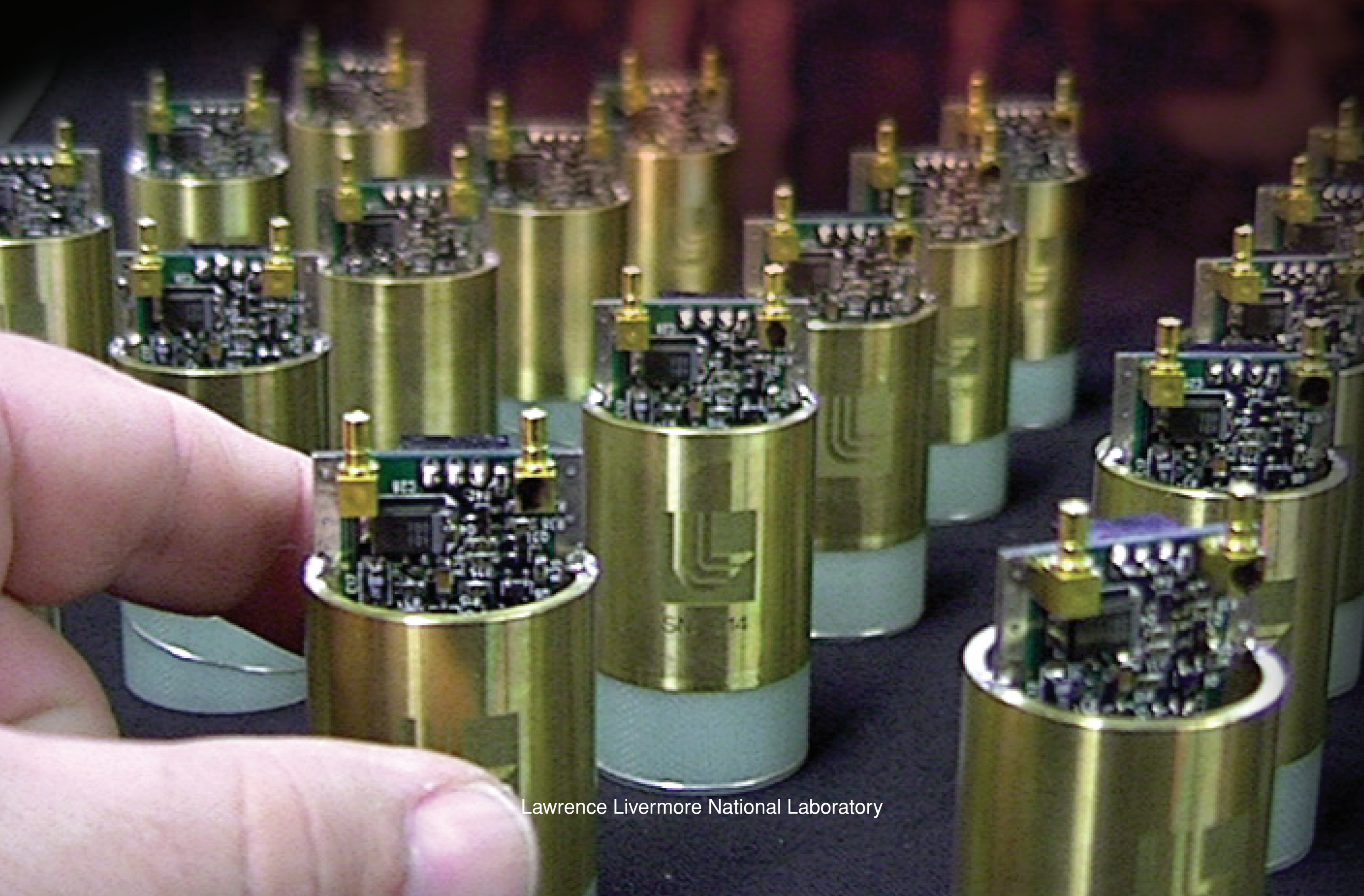
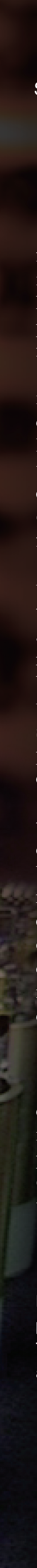
Exploring the Ultrawideband

Compact, low-cost radar and communication systems using ultrawideband frequencies are strengthening national security while changing commercial markets.





LAWRENCE Livermore research efforts and inventions quietly advance many fields. In one instance, however, a Livermore invention that stemmed from laser research has spawned a variety of new commercial products, including some that support national and homeland security.

The invention is called micropower impulse radar (MIR), a fundamentally different type of radar that is compact, low power, inexpensive, and unusually versatile. MIR sends out extremely short electromagnetic pulses in ultrawideband (UWB), an extremely wide range of frequencies. (See the box at right.)

Instead of the continuous energy waves used in conventional radar or radio, MIR transmits UWB pulses that are as fleeting as a few trillionths of a second. The pulses reflect off nearby objects and are detected by a high-speed sampling receiver. MIR is unique because of its ability to efficiently send and detect these very low-power pulses without interfering with nearby electronic equipment.

For the past decade, Livermore has transferred the MIR technology to numerous companies for various applications. (See the box on p. 14.) More recently, Livermore researchers have been applying their experience with MIR to develop new types of UWB-based sensing, imaging, and communication devices that are portable, rugged, energy-efficient, and resistant to detection and interception.

Millions of Pulses Per Second

The Livermore radar and communication devices have a transmitter that emits many millions of pulses per second, with each pulse lasting as short as 50 picoseconds (50-trillionths of a second). A simple, single-wire antenna 4 centimeters long can be used,

Micropower impulse radar sensors used in proximity fuses have been successfully tested. The fuses trigger small bombs to detonate at about 1 meter from the ground.

The Ultrawideband Revolution

Livermore's micropower impulse radar and radio communication systems are part of the ultrawideband (UWB) revolution. Scientists and engineers have known about UWB signals since Guglielmo Marconi experimented with spark-gap devices in the late 1800s, but the signals are more difficult to control or detect than narrowband (single-frequency) signals. The UWB is a wireless communication technology that transmits data in extremely short (50- to 1,000-picosecond) pulses spread out over a wide range of the electromagnetic spectrum. Large data bursts (hundreds of gigabits per second) are possible because data are carried simultaneously at a wide range of frequencies across the electromagnetic spectrum.

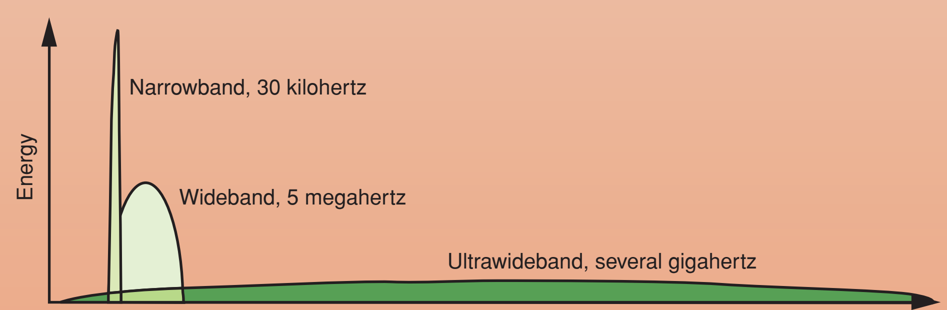
The combination of broad spectrum, low power, and extremely short pulses causes much less interference with other devices than do conventional narrowband wireless systems. In turn, UWB is much more resistant to electrical interference from other devices than competing wireless technologies.

UWB's data capacity, speed, low power requirements, and resistance to interference have attracted the attention of major electronic corporations who recognize the technology's commercial potential. Because UWB can penetrate walls, it could become the center of all communications within homes and small offices. UWB signals could carry voice, data, and video. Products could speed downloading images from a digital camera to a computer, connecting printers to computers, and routing high-definition signals to televisions.

The Federal Communications Commission (FCC) currently restricts commercial UWB applications to between 3.1 and 10.6 gigahertz because of a concern they could interfere with existing transmissions, especially flight radios, beacons, and the Global Positioning System. FCC rules also limit UWB commercial devices to less than 1 watt, which prevents them from working beyond a relatively short distance (about 10 meters).

Using an experimental license, Livermore has developed numerous UWB systems in frequency bands ranging from 200 megahertz to 100 gigahertz. Tests at Livermore have shown that the devices do not cause undue interference with other electronic devices operating in this broad frequency range. Livermore efforts are directed at developing UWB devices for the government that operate both above and below the 3.1- to 10.6-gigahertz band designated for commercial devices.

A task force convened by the Institute of Electrical and Electronics Engineers (IEEE) is developing a new standard for UWB products, called IEEE 802.15.3a. Livermore engineers have been involved with determining this international standard for UWB use.



Ultrawideband (UWB) pulses spread energy over many frequencies, as opposed to traditional narrowband, which covers a limited band of about 30 kilohertz. Cellular phones operate in the wideband, which covers 5 megahertz. Compared to conventional radios and phones, UWB pulses generate a tiny fraction of energy and appear like random noise signals.

but larger antennas provide greater range, directionality, and penetration of materials.

Radar units use an extremely sensitive receiver that is set to detect UWB echoes over a preset distance, ranging from a few centimeters to many tens of meters. When recorded data are combined with special algorithms, MIR imaging applications are possible. For example, to find buried objects, researchers apply image reconstruction software to visualize one "slice" of the object at a certain depth. Many slices stacked together form a three-dimensional view.

The electromagnetic pulses penetrate most low-conductivity materials, such as rubber, plastic, wood, concrete, glass, and dry soil. MIR-based tools can locate wooden or steel studs in a wall and steel within concrete. The signals can also penetrate substances with moderate electrical conductivity, such as the human body. Because penetration of MIR signals decreases as a material's electrical conductivity increases, MIR devices cannot penetrate metal or seawater.

Another advantage of MIR devices is that electromagnetic emissions are typically less than 1 milliwatt; thus, they are safe to use around people and do not interfere with computers, digital watches, cellular phones, or radio and television signals. What's more, these devices are small and relatively inexpensive to manufacture. In most cases, they use commercial components. Typical MIR circuit boards measure less than 10 square centimeters.

Since developing the first MIR devices, Livermore researchers have decreased power requirements, extended the range, enhanced penetration capability, devised new processing algorithms, and found many new applications. About 20 engineers and technicians, led by Steve Azevedo, are working on radar and radio projects, which fall into three general areas: sensors, imagers, and communications.

MIR technology makes possible extremely accurate systems for motion detection and localization. At least one MIR licensee is using the technology for alerting drivers to obstacles in blind spots. Livermore engineers are using modified

Micropower Impulse Radar Reaps Rewards and Royalties

Micropower impulse radar (MIR) was invented in 1993 by Livermore electronics engineer Tom McEwan. The original device stemmed from the single-shot transient digitizer and won an R&D 100 Award for 1993. (See *E&TR*, April 1994, pp. 1–6, and *S&TR*, January/February 1996, pp. 12–18.) McEwan adapted the transient digitizer into a remarkably small, low-power radar system that uses ultrawideband (UWB) pulses and works well at short distances. The first commercial license for MIR technology was issued in 1994; Livermore currently has 16 active licenses to use the radar in various applications.

Since then, MIR has been applied to numerous uses, including an electronic dipstick that won an R&D 100 Award (see *S&TR*, October 1996, pp. 16–17); a land-mine detection system (see *S&TR*, November 1997, pp. 18–20); and a bridge inspection system that also won an R&D 100 Award (see *S&TR*, October 1998, pp. 8–9).

Livermore holds 30 MIR patents, with extensive patent coverage in many foreign countries. Royalty income for the past five years exceeds $5 million. MIR has been one of the most commercially successful licensed inventions both at Livermore and throughout the Department of Energy. Livermore researchers continue to use the technology to support Laboratory research programs.

Livermore engineering technologist Mike Newman used a micropower impulse radar sensor attached to an extender to search through rubble at ground zero of the World Trade Center following the September 11, 2001, terrorist attacks.

versions of MIR motion sensors for such applications as search and rescue under rubble, measurement of explosive velocities up to 3,800 meters per second in Livermore's High Explosives Applications Facility, proximity fuses for rockets and cluster bombs, helicopter blade tracking, demilitarization of rocket motors, medical diagnostics, cargo container intrusion sensing, inspection of bridge decks, and perimeter security.

MIR to the Rescue

Livermore engineers have developed portable MIR motion detectors to assist search and rescue operations. The units use directional, high-gain antennas to detect motion caused by breathing and heartbeats up to 100 meters away. Tests at federal facilities have demonstrated the devices' ability to detect subjects through deep piles of rubble. At a test in May 2004 conducted at the National Aeronautics and Space Administration's Ames Research Center and attended by representatives of the Defense Advanced Research Projects Agency and Department of Homeland Security, the MIR team located five out of five hidden "incapacitated" survivors.

"We want to locate survivors even through thick barriers of concrete," says engineer John Chang. He notes that MIR would complement standard techniques, such as search dogs and listening devices.

Prototypes were unexpectedly put to the test when a nine-member Livermore team was deployed by the Department of Energy (DOE) for 2 weeks following the September 11, 2001, attacks on the World Trade Center. The team used several different MIR devices, which were rapidly configured and tested for breathing detection through several meters of rubble. The team found no survivors (no survivors were found by any of the ground zero search teams) but discovered some previously unknown voids in the rubble, according to team member Doug Poland.

New Kinds of Medical Devices

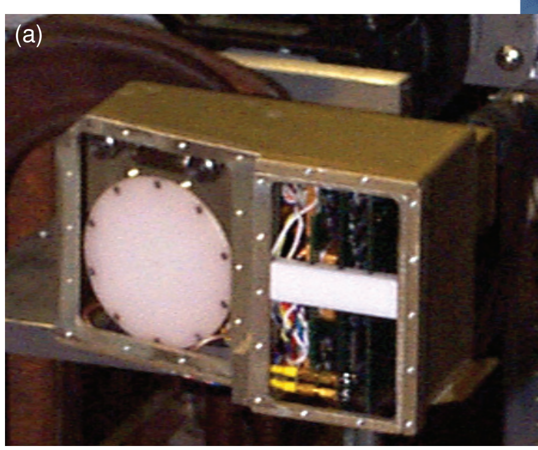
Livermore engineers are also working on MIR sensors for portable, low-cost devices for use in emergency medical care. The instruments are medically safe—electromagnetic emission levels average less than one-thousandth the emissions of a cellular telephone. "Our sensors are noninvasive, portable, cost effective, and generate no ionizing radiation," says Chang.

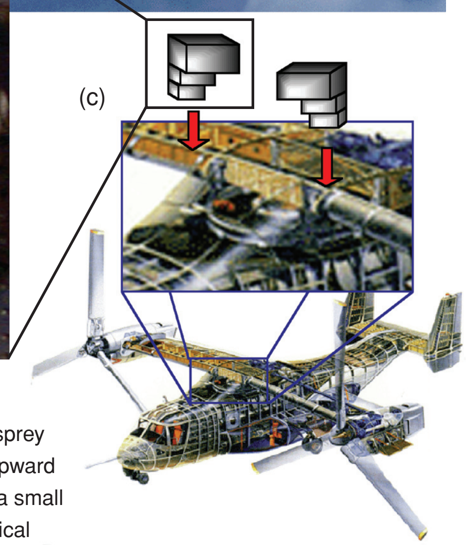
The U.S. Army is interested in using MIR technology to improve combat casualty care. One idea is a wearable device that monitors a soldier's vital signs and relays that information to a medical command post. Medics could carry MIR devices to locate injured soldiers by their breathing. Researchers are developing devices to detect life-threatening injuries to the head and lungs. Lightweight, handheld prototypes are powered by a single 9-volt battery, and connect to a laptop computer.

Rocket Motors and Helicopter Blades

MIR has been the focus of two projects for the Department of Defense (DoD). The first demonstrates the feasibility of using MIR for controlling a water-jet cutter to remove propellant from rocket motors so the propellant can be recycled. Tests of a prototype sensor showed that the powerful water spray did not interfere with the radar pulses. This year, Livermore engineers are building a sensor with three MIR radars; tests of the sensor are scheduled to occur in 2005.

The second effort uses MIR to significantly reduce maintenance costs for U.S. Marine and Navy V-22 Osprey helicopters. The MIR device, called a radar blade tracker, received a DoD Life Cycle Cost Reduction Award. The device is placed





(a) A 96-gigahertz radar sensor significantly reduces maintenance costs for (b) U.S. Marine and Navy V-22 Osprey helicopters. (c) The device emits ultrawideband pulses upward to the overhead rotating blades. Pulses are reflected by a small section of the blade as it passes over the radar. The vertical distance can be precisely calculated from the transit time of pulses to and from the moving blades.

beneath a helicopter rotor and emits UWB pulses upward to the overhead rotating blades. Pulses are reflected by a small section of the blade as it passes over the radar. The transit time of pulses to and from the moving blades is measured, allowing the vertical distance to be calculated precisely. If the rotor blades are outside the required range, rebalancing may be necessary to prevent damage to the rotor or excessive transmission vibration.

Sensors for Troops and Containers

Livermore engineers have developed sensors in response to the military's need for portable, rugged, low-power motion sensors that avoid detection and interception. One device looks like a flashlight and detects motion from up to 15 meters away through nonmetallic barriers, such as wooden doors, drywall, and concrete. A similar device equipped with an omnidirectional antenna can generate a protective "bubble." All motion outside the bubble and limited motion inside the bubble can be ignored, while any penetration of the bubble triggers a data recorder, camera, or audible alarm.

Guardian is a group of individual motion detectors that form a wireless system to monitor environments for both military and civilian applications. The system consists of individual nodes that contain a transmitter, receiver, global positioning satellite module, and processor. The nodes form a network with each other and communicate with a "mother" node that sends information to a remote monitoring station.

The sensors continuously measure reflected signals from a designated distance and issue an alarm when a change occurs. Richard Leach, principal investigator for Guardian, says, "Guardian can form a protective electronic fence around facilities; any penetration of the fence triggers an alarm."

Livermore engineers are also developing a system that monitors the status of shipping containers before they arrive at U.S. docks. The effort is part of a "smart container" program funded by several federal agencies. More than 18 million cargo containers enter U.S. ports every year, and any one of them could contain clandestine material.

The inexpensive system would be installed in every cargo container and would last at least 10 years. Each device would detect any intrusion, monitor radiation levels of that container using an attached radiation sensor, and then transmit the results to a computer on the ship. Engineers are researching how to network thousands of these devices into an efficient system that uses UWB communications.

Imaging Bridges

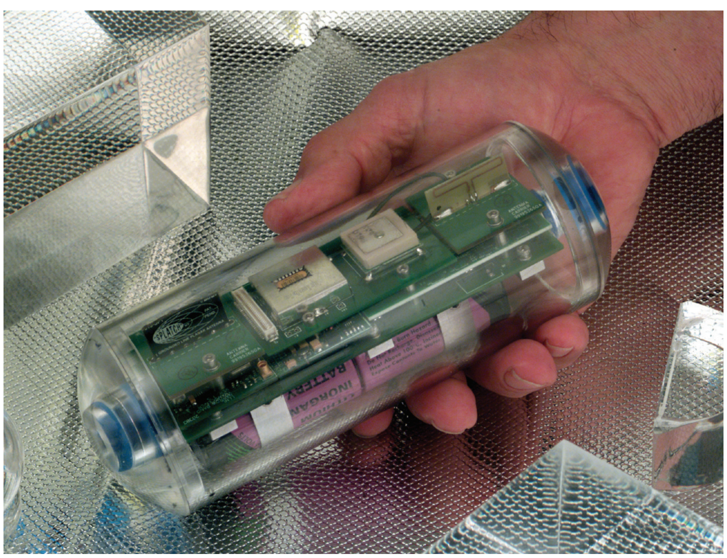
MIR sensors' small size makes them suitable for assembling into arrays that generate images. One imaging effort is the HERMES (High-Performance Electromagnetic Roadway Mapping and Evaluation System) Bridge Inspector for imaging bridge decks and pinpointing needed repairs. Many U.S. bridge decks, the weakest component of bridges, are deteriorating, often because of corroding steel reinforcing bars (rebar) hidden by concrete and asphalt. The Federal Highway Administration and 24 state highway departments have funded HERMES development.

HERMES uses 64 MIR modules mounted underneath a trailer pulled by a vehicle at traffic speeds. The sensors, assembled into an array about 2 meters wide, are spaced about 3 centimeters apart. They send out UWB pulses with frequencies ranging from 1 to 5 gigahertz, penetrating concrete to a depth of up to 30 centimeters. As the pulses propagate through the bridge deck, the echoes are recorded by a computer inside the trailer and compiled into a three-dimensional map of the deck.

A Livermore team, led by Jose Hernandez, is planning extensive field-testing of HERMES, including the comparison of images with the actual state of a bridge deck following bridge demolition. A major goal is to create a national HERMES image database. Azevedo compares the current stage of HERMES development to early computerized axial tomography (CAT) scans in the 1970s, when physicians were unsure what the images signified. "We need more 'bridge cadavers' so when we see a particular image of a bridge deck, we can correlate it to real pathology."

Radar Camera Sees through Walls

A simple imaging system, called Urban Eyes, uses two MIR sensors to provide a



This prototype Guardian system is equipped with an antenna, Global Positioning System (GPS), ultrawideband radar, micropower impulse radar (MIR) antenna and motion sensor, processor, and batteries.

real-time view of motion behind walls. Two radar sensors are placed against a wall 1 meter apart; the computer triangulates the location of moving figures on the other side of the wall. The system provides an image as though looking overhead, while an icon follows the motion of the principal object on a nearby computer screen.

Livermore engineers are using an array of up to 16 or more sensors to develop a handheld MIR radar camera capable of producing real-time video (30 frames per second), which would show much greater detail than Urban Eyes. The camera could aid first responders, such as police units responding to a hostage situation. In such a case, the officer holding the camera against a wall would see a moving picture of people located inside. Special beam-forming hardware and signal processing would show the first real-time images of people through smoke, haze, or walls and could potentially locate concealed weapons.

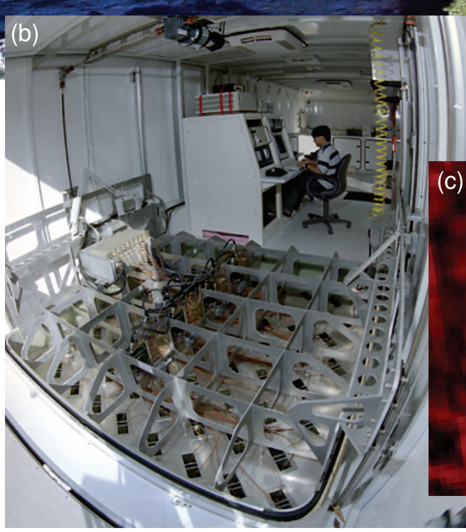
Engineer Carlos Romero says the unit would offer important advantages over current tools, some of which can signal that a threat exists but cannot pinpoint its location. Other tools provide the location of the threat but are slow, complex and bulky and require large computers. The research team is collaborating with the University of California at Davis to study how best to display radar-based images for first responders.

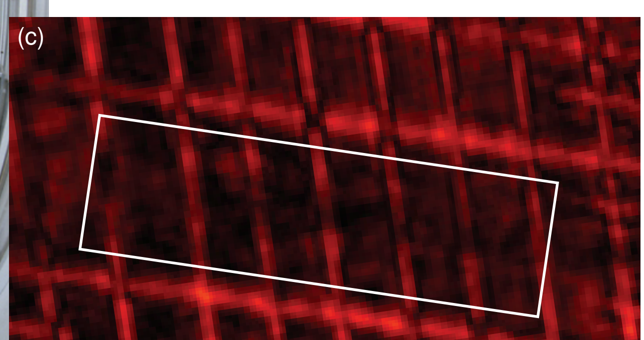
New World of Communications

The MIR research group is extending its expertise in UWB to new types of communication devices, such as radios used in police, military, and intelligence operations. Standard radios are susceptible to detection and jamming because they operate on fixed frequency bands. In addition, in urban areas, radios and cellular phones fade as signals bounce from structure to structure.

Radio communications based on UWB pulses are ideal for combat and surveillance because the signals spread their energy across a wide range of frequencies. The UWB bandwidth provides high capacity, resistance to jamming, and low probability of detection. Furthermore, UWB technology can deliver large amounts of data over distances less than 1 kilometer in extreme multipath and electronic noise environments.

"We want to supply our troops with devices that can rapidly send voice, data, and video information among sensors and participants," says engineer Farid Dowla, who leads Livermore's UWB radio communications development effort. "A useful radio communication system should





(a) The HERMES (High-Performance Electromagnetic Roadway Mapping and Evaluation System) Bridge Inspector is a radar-based sensing system mounted in a trailer. (b) The array of 64 radar modules located beneath the trailer produces images of the insides of bridge decks. (c) This image shows a suspect area where a delamination in the concrete may have occurred.

be able to handle all these sensors with identical radios." Sensors may include everything from temperature probes to microphones to video cameras.

Livermore engineers are designing small and lightweight radios that function for days on batteries and send signals that penetrate walls. Because the radios have a simple physical architecture, they are low in cost and power consumption. Dowla notes that one strength of UWB communications devices is the small number of parts they require.

The team is focusing first on sensor and voice communications between ground-to-ground and ground-to-unmanned aircraft. In 2003, the team demonstrated UWB communications for low-power transmitters and receivers. Data were delivered at 2 megabits per second over a distance of about 20 meters. The team also demonstrated longer-range communications at lower data rates.

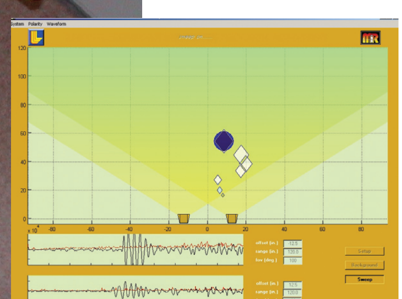
A major challenge is ensuring that signals are not distorted by the harsh electronic environment of battle and urban areas, where signals can be reflected and scattered many times. Just as a cellular telephone fades and drops out when signals interfere at certain locations, pulses in UWB get distorted as they pass from transmitter to receiver in harsh environments.

Livermore engineers developed and advanced a method to detect pulses of data that eliminates distortion yet retains the advantages of UWB. Called transmit-reference signaling, the technique sends a pair of closely spaced pulses, the first serving as a reference to the second. The second pulse is modulated with respect to the first to incorporate data bits. This type of communication could be secure (for military and homeland security applications), reliable (for buildings and tunnels), and noninterfering with existing radios.

In the same way that arrays of radar are used for imaging, arrays of UWB radios will provide more complete information and security. If the precise location of several communicators (for example, soldiers in the field) is known, the radios can transmit to a single location, such as a command base, without detection.

UWB signal processing also permits communicating with a specific point in the distance. For example, transmitters can communicate with a particular spot in a room from the outside of a building, in cases where it is essential to talk to a specific "good guy" in the midst of "bad guys."

The Livermore team members are developing for DOE a network of UWB walkie-talkies that would serve as a backup to typical narrowband radios. They are also exploring video communication over short distances. Video requirements are high—6 megabits per second—but UWB can deliver between tens and hundreds of megabits of data per second.

Urban Eyes uses two micropower impulse radar sensors to provide a real-time view of motion behind walls. In this example, Urban Eyes is attached to a robot, which places the sensors against a wall. A laptop computer displays (inset) an overhead view of rudimentary moving figures on the other side of the wall.

A Lawrence Livermore protective force officer holds a riot shield that has been modified to include antennas for the radar camera array. When the shield is fully functional, the officer will be able to see through the shield and view a display of real-time radar images of objects or humans concealed by walls or smoke.

Cooperative ultrawideband radios can perform long-range communications without being intercepted, a drawback of current military radios. In this artist's conception, communications from all soldiers and air assets can be coordinated so that the transmitted signals are detected and received at only one location—the command station at upper left.

MIR to the Ball Game

The MIR research team continues to develop prototypes that will contribute to national defense and homeland security. There seems to be no end to new applications, especially those in the commercial sector. For example, Northeastern University professor Carey Rappaport recently asked his class for their ideas. One suggestion from a baseball fan was a handheld device that umpires could use to quickly check for corked bats.

It's safe to say we're seeing just the beginning of micropower impulse radar and radio products and the dawn of the age of ultrawideband. In particular, says Azevedo, the future looks bright for powerful arrays of MIR sensors and radios.

—Arnie Heller

Key Words: High-Performance Electromagnetic Roadway Mapping and Evaluation System (HERMES) Bridge Inspector, micropower impulse radar (MIR), narrowband, ultrawideband (UWB).

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Virtual Problem Solving for Homeland Security

During a simulated terrorist attack on a water treatment facility in Opelika, Alabama, the mayor (woman on cellular phone) and other emergency managers train to prepare for an optimal response.

TERRORIST attack on the water treatment plant! The mayor and other emergency responders evacuate schools, respond to medical emergencies, and pursue the perpetrators. Fortunately for the town of Opelika, Alabama, the attack was purely hypothetical.

The town mayor, fire and police personnel, medical staff, school administrators, and other emergency managers used the Livermore-developed Joint Conflict and Tactical Simulation (JCATS) model to train for responding to an attack on the civilian infrastructure. JCATS is a Department of Defense tool for simulating joint military exercises and is routinely used in major military exercises worldwide. (See *S&TR*, January/February 2000, pp. 4–11.)

The Opelika simulation entailed an intentional chlorine gas release. Following the attack, portions of the city were evacuated, schools were locked down, and a SWAT team responded to the terrorists. Triage facilities were quickly established, and hospitals and medical clinics swung into high gear to accept people overcome by the poisonous gas. Opelika's emergency managers ran numerous scenarios, each more complex than the last. Finally, a single field exercise that included the local populace gave emergency managers the opportunity to put what they had learned into practice. JCATS enabled the managers to develop emergency responses and train responders for potential events in a cost- and time-effective manner. Conducting a comparable series of real-life field exercises would have been prohibitively expensive.

JCATS' use at Opelika was its first application in a civilian setting. The successful exercise prompted Livermore to modify JCATS specifically for civilian uses. The new tool, known as Advanced Combat and Tactical Simulation (ACATS), is designed for federal, state, and local agencies to prepare for possible acts of terrorism.

Led by computer scientist Mike Mercer, the ACATS team has incorporated JCATS' capabilities for training, rehearsing missions, exploring tactical possibilities, and assessing vulnerabilities into scenarios in a civilian setting. Hypothetical situations range from the spread of a chemical or biological agent within a building or in the streets to planning evacuations from buildings. ACATS replaces the soldiers, guns, tanks, and missiles of JCATS with firefighters, hazardous materials experts, ambulances, and other accoutrements of civilian emergency response.

ACATS is a tool for analyzing tactical vulnerabilities and determining tactical responses to mitigate the effects of a chemical, biological, radiological, or other terrorist attack. It helps train local and state personnel to work together in response to such attacks. ACATS can also be used to analyze a variety of other homeland security issues. "For example, the U.S. Border Patrol has used a version of ACATS to model enhanced tactical and technical capabilities to protect our nation's borders," says engineer Rob Hills.

From JCATS to ACATS

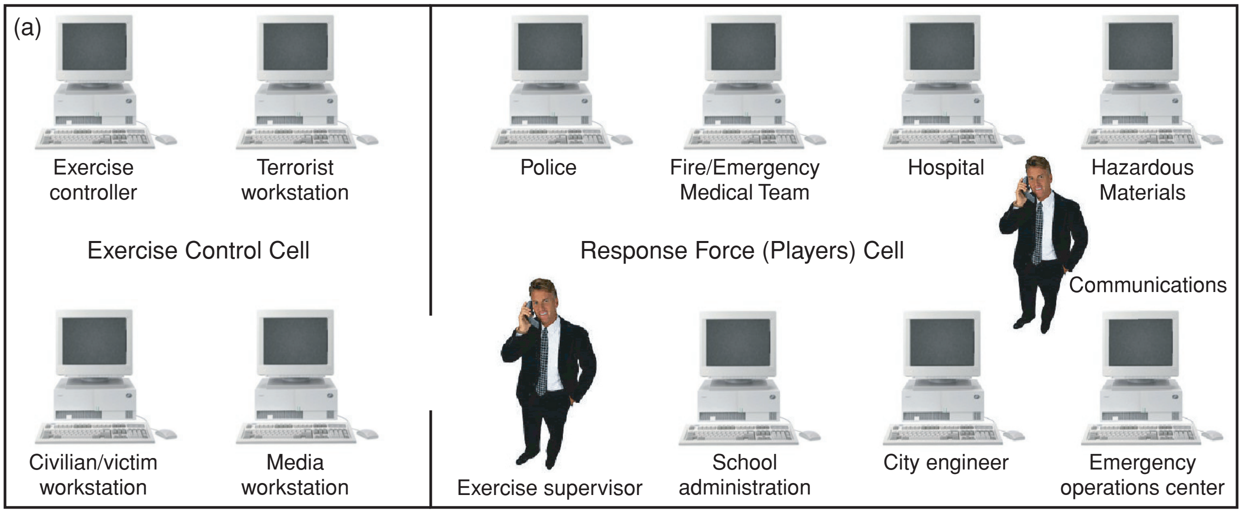
Livermore's 30 years of experience in developing conflict simulation programs led to ACATS' predecessor, JCATS. Less sophisticated conflict simulation programs often represent only aggregate groups of soldiers and vehicles and cannot simulate the interactions between individual soldiers, vehicles, and weapons systems. Such systems use probability tables to determine the outcome of engagements between large forces. In contrast, entity-based simulations like JCATS model the dynamics of individual soldiers, vehicles, and weapons. Entity-based simulations increase the realism of the simulation and allow the "players" to participate more directly.

JCATS gives each soldier, truck, tank, or helicopter its own icon. During a simulation, a single object can be detected, targeted, and destroyed. The largest JCATS exercise to date incorporated more than 40,000 entities.

Players in a JCATS "game" control only the specific entities for which they are responsible and can see and react only to objects within their entities' lines of sight. Meanwhile, the effects of their actions are shown to all players within view on their side. Players can zoom from a theater of operation to a specific room in a building with an accuracy of 10 centimeters.

Entity interactions are based on physics effects models and field data. In a commercial video game, a soldier can jump off a 5-meter cliff and run away unscathed. In a JCATS simulation, on the other hand, the soldier's expected injuries are realistically portrayed.

JCATS was integral to security planning and operational support for the 2002 Winter Olympic Games in Salt Lake City, Utah.



(a) An example of how computer stations would be arranged when a community is developing planned responses to catastrophic events. Each set of emergency responders controls their own personnel and equipment. (b, c) In the simulated attack of the Opelika, Alabama, water treatment plant, the city police and the city manager's staff work interactively as the scenario unfolds.

Simulated games incorporated more than 12,000 entities, modeling Olympics staff and athletes, vehicles, civilian personnel, and equipment. The simulation depicted athletic venues, roads, and other critical areas and mirrored the actual task organization for the Olympics.

JCATS' features are being incorporated into ACATS along with several additions. Mercer's team is using a model developed by the National Institute of Standards and Technology to simulate the dispersion of a chemical or biological agent inside a building. For dispersing an agent outdoors, ACATS links to a validated military model known as VLSTRACK. In the future, ACATS could incorporate higher-resolution dispersion models developed by Livermore's National Atmospheric Release Advisory Center.

Response to a chemical, biological, or radiological attack on a civilian target differs significantly from a military operation. A fundamental difference is the tactical response to the attack, which focuses on minimizing casualties—rather than defeating an enemy—through emergency response coordination, evacuation, and crowd control. This year, ACATS team members began adding features to facilitate modeling of the tactical responses and the movement of large groups of people.

Large groups can be moved more effectively in an ACATS game when crowd behavior is automated, making evacuations from large facilities, such as a military building or sports stadium, easier to model. However, almost every evacuation or large movement of people includes individuals who don't behave as expected. Plans are for ACATS to incorporate the "hero" who doesn't follow orders or the person who behaves irrationally in the face of danger. A goal for ACATS is to include not only the full range of appropriate physics effects but also as many typical human behaviors as possible.

The ACATS team is also working to develop a three-dimensional view of the ACATS field of play. Firefighters and other ground responders playing an ACATS game will get a head-on view of the action, in keeping with how they operate in real life. At the same time, the incident commander will have an overall top-down view.

Effective tools for planning homeland defense are essential to national security. JCATS, which was initially a tool for the Department of Defense, is already proving its mettle for the Department of Homeland Security. Once the transformation from JCATS to ACATS is complete, ACATS will be a major asset for the country.

—Katie Walter

Key Words: Advanced Combat and Tactical Simulation (ACATS), Department of Homeland Security, entity-based simulations, Joint Conflict and Tactical Simulation (JCATS).

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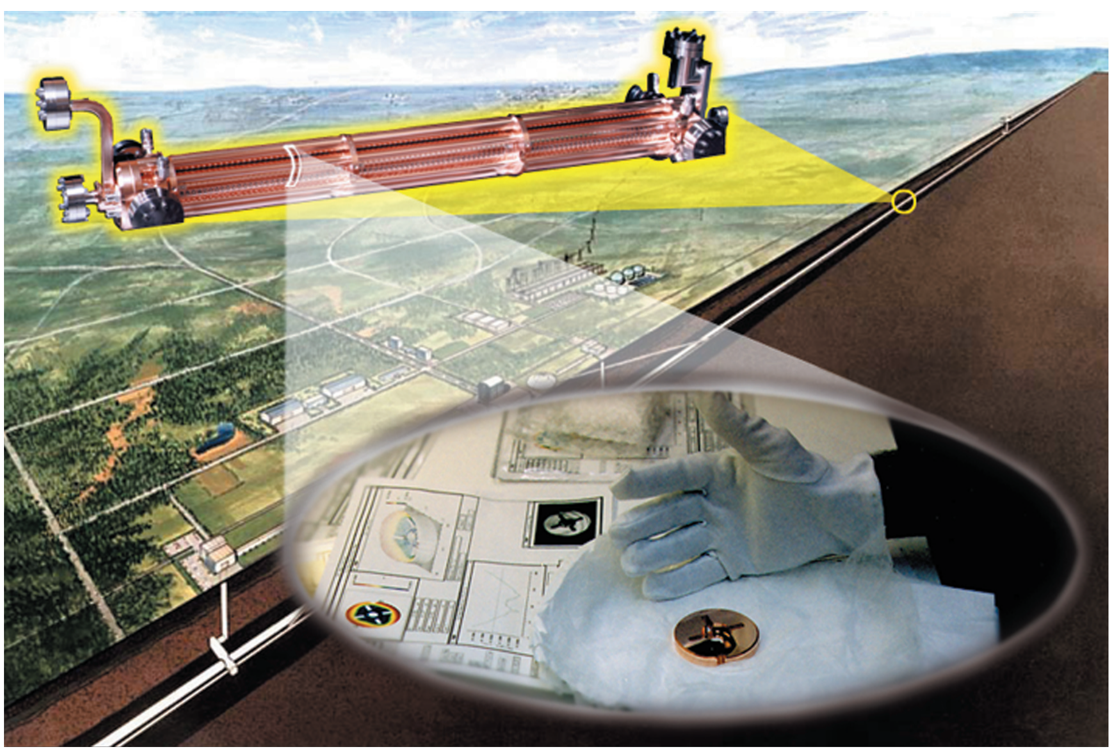
Solid-State Technology Meets Collider Challenge

PROBING the frontiers of particle physics and delving into the mysteries of the universe and its beginnings require machines that can accelerate beams of fundamental particles to very high energies and then collide those beams together, producing a multitude of exotic subatomic particles.

The proposed Next Linear Collider (NLC), being developed by Stanford Linear Accelerator Center (SLAC), Lawrence Livermore and Lawrence Berkeley national laboratories, and Fermi National Accelerator Laboratory (Fermilab), is such a machine. The NLC is expected to produce a variety of subatomic particles by smashing together electrons and their antimatter counterparts (positrons) at nearly the speed of light with energies in the teraelectronvolt (TeV) range.

Plans are that the NLC will initially operate at 0.5 TeV and ultimately be scaled up to 1.5 TeV. (See *S&TR*, April 2000, pp. 12–16.) Work at the facility will complement the research to be conducted at another high-energy particle accelerator, the 14-TeV Large Hadron Collider at the European Laboratory for Particle Physics (commonly known by the acronym CERN from its former name) in Geneva, which is scheduled for completion in 2007.

Achieving beam energy levels in the TeV range requires modulator systems that can convert ac line power—the same type of power one gets from the wall plug—into dc pulses. Ultimately, these pulses are transformed into radiofrequency (rf) pulses that "kick" the particles up to the required energy levels. Livermore scientists and engineers have designed a solid-state modulator to replace old-style modulators based on vacuum-tube technology. These new modulators promise to be far more efficient, reliable, and serviceable than the previous components. Livermore's Laboratory Directed Research and Development Program supported the basic research and development on the solid-state modulator technology, and SLAC supported the systems integration.



A conceptual drawing of the Next Linear Collider, housed in a tunnel approximately 30 kilometers long, inside of which are two opposing linear accelerators (linacs). Within each linac, the electrons (or positrons) are accelerated inside thousands of copper accelerator structures, each made up of more than 200 precision-machined copper cells (see inset).

Start of the Power Train

The NLC will accelerate a beam of electrons and a beam of positrons down two opposing 15-kilometer linear accelerators, or linacs. Each linac is a repetitive system with pulses identical in energy level and wave shape generated at the rate of 120 pulses per second.

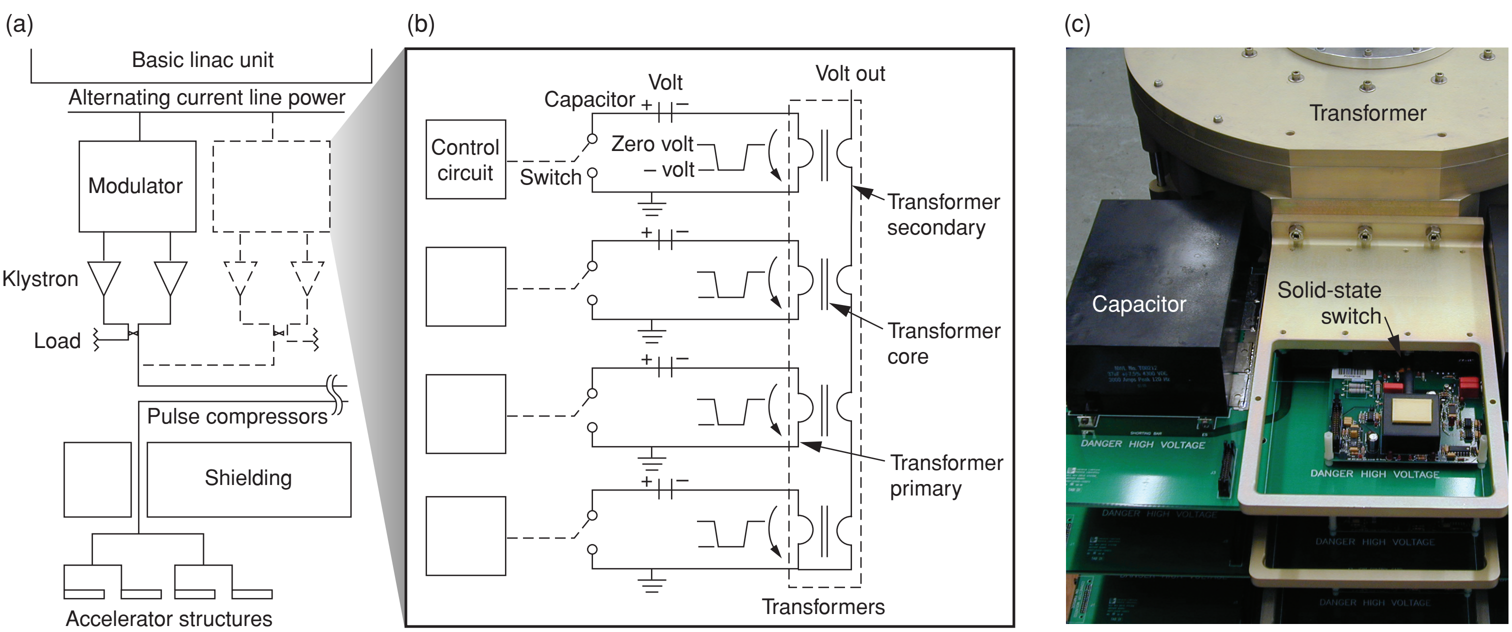
The basic linac consists of a modulator to convert ac line power into dc pulses and klystrons (oscillators) that are driven by the dc pulses to produce 75 megawatts of peak rf power at 11.4 gigahertz. The linac also includes pulse compressors that reformat the rf output into 300-megawatt, 300-nanosecond-long pulses. These pulses are then delivered to accelerator structures constructed of copper disks. The electron and positron particle beams surf the pulses as they travel through these disks, gaining energy as they pass from one accelerator structure to the next. The NLC is an order of magnitude larger in size than any other linear accelerator yet designed and will have between 5,000 and 10,000 accelerator structures.

Modulating Power with Solid State

When Livermore engineers began the modulator design for the NLC, they revisited the possibility of creating a solid-state system. The old-style modulators based on hydrogen thyratron-fired pulse-forming networks (PFNs), a technology dating from the 1940s, have some definite drawbacks for a system the size of the NLC. For example, a thyratron-switched PFN can drive only a single 75-megawatt klystron and has an operational lifetime of 2 years or less before requiring replacement. Engineer Ed Cook notes that few vendors exist today who make thyratron switches. “Fabricating these switches is a bit of a black art. It requires a lot of manual expertise, and that expertise is disappearing. For a long time, we’ve wanted to replace these vacuum-tube switches with solid-state switches.”

The biggest obstacle has been that, until fairly recently, solid-state switches couldn’t handle high voltages. Thyratron switches can withstand the high voltages used in high-energy physics experiments and can easily reach 100 kilovolts. However, 6.5 kilovolts was the limit for a solid-state switch that could be turned on and off with a gate control signal, and the NLC requires a 500-kilovolt pulse. Livermore came up with a design capable of withstanding this voltage level using a series of solid-state switches buffered with a transformer.

The solid-state modulator’s efficiency is vastly improved over thyratron-based modulators. The shape of the modulator’s energy pulse largely determines its efficiency. The ideal pulse shape is rectangular because the energy in the pulse’s rise and fall time is not usable by the klystron to generate rf power. For the NLC, the goal is to have a rise and fall time of less than 200 nanoseconds, which is difficult to obtain with a PFN modulator using thyratrons. The performance of a solid-state modulator based on an inductive

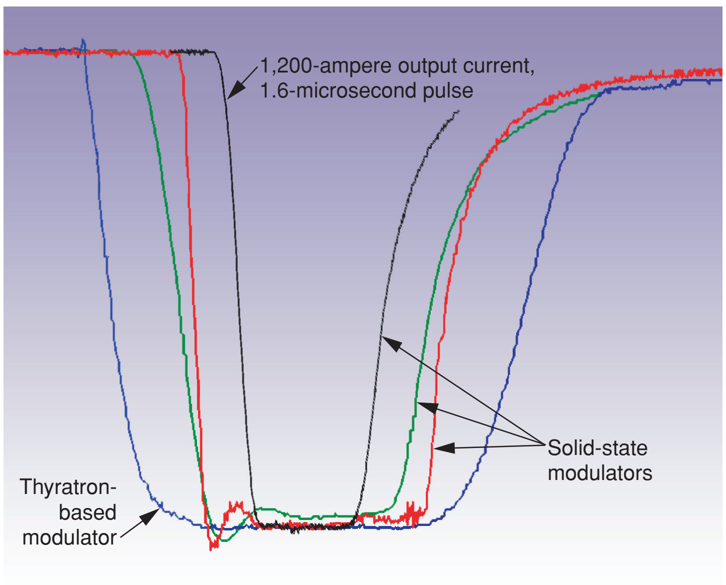


(a) The Next Linear Collider being developed by the Stanford Linear Accelerator Center and other labortories will consist of thousands of basic linear accelerator (linac) units. Each unit consists of modulators, klystrons, pulse compressors, and accelerator structures. (b) This schematic shows a four-cell stack of the Livermore-designed modulators based on solid-state switch technology. (c) A close-up view of the modulator shows a solid-state switch, a capacitor, and a transformer core.

adder circuit topology has the potential for a sharper rise and fall time than the thyratron-based modulator, yielding a pulse with less wasted energy. The pulse duration can also be easily lengthened or shortened.

The modulator's switch—called an insulated gate bipolar transistor (IGBT)—is available from many manufacturers and can operate in environments that make them useful to the NLC. "They're similar to those used in modern rapid transit systems," says Cook. "The technology has advanced to the point where they can be used in a high-current, high-voltage environment."

Each modulator cell consists of two major components: a drive board formed from two circuit boards, each holding a solid-state switch and a capacitor, and a tightly coupled pulse transformer. A solid-state switch can generate a 4-kilovolt, 6-kiloampere pulse; 12 modulator cells can collectively yield a pulse of approximately 50 kilovolts. If a modulator cell needs servicing, a board can easily be pulled and replaced. "We'll need 1,000 modulators, each consisting of 15 cells, to drive 2,000 klystrons for the NLC," says



Modulator efficiency is determined largely by the shape of the energy pulse produced. The new solid-state modulator yields more useful energy per pulse using either Mitsubishi (green and black waveforms) or Eupec (red waveform) insulated gate bipolar transistors (IGBTs), as shown by the far steeper rise and fall times, than the old-style modulator using hydrogen thyratron-fired pulse-forming networks (blue waveform).

Livermore physicist Jeff Gronberg. "We're looking at nearly 30,000 boards in all, so reliability and ease of maintenance are very important." The plan is to have redundant boards and then switch to the backup board if one goes bad, a much less painful process than replacing a failed thyratron. "When a thyratron fails, a section of the linac goes down with it," says Gronberg. "It can take the better part of a day to replace it and have the system running again."

Testing the System

Last year, Livermore delivered the first full-power prototype modulator consisting of 15 cells. The Livermore team and the Power Conversion Group at SLAC are conducting tests on the entire rf system using the solid-state modulators and a new 500-kilovolt, 75-megawatt klystron.

"We're testing each component of the basic linac unit—modulator, klystron, pulse compressor, and accelerator structure—to demonstrate its reliability and performance," says Gronberg. "Reliability is critical. Once the NLC is up and running, it will be on line 24 hours a day, 7 days a week, 9 months a year. Now, with the solid-state modulator, the loss of one or two boards in any given modulator will not affect the accelerator's operation. Routine maintenance can be performed at scheduled down times. Previously, we would have had to maintain 2,000 vacuum-tube thyratron switches for the entire collider. Given the failure rate of the vacuum tubes, we would have been repairing on average one per day."

The modulator prototype recently achieved its design parameters, producing 1.6-microsecond pulses of 500 kilovolts with a 120-hertz repetition rate. "The Laboratory's investment in the modulator project is now paying off in dividends," says Gronberg. "Using this technology will save about $200 million on the cost of the NLC. The benefits are also accruing in other accelerator projects and in pulse-power applications, such as Pockels cell drivers for high-power lasers. Once a new technology is demonstrated, people often find other applications where it can make a difference."

—Ann Parker

Key Words: electron–positron linear collider, Next Linear Collider (NLC), klystron, particle accelerator, solid-state modulator, Stanford Linear Accelerator Center (SLAC), thyratron, vacuum-tube technology.

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(Continued from p. 2.)

Bill may increase Lab's water-resource research efforts

Legislation directing $225 million a year for five years to water-resource research at nine Department of Energy laboratories was announced in the Senate on July 14, 2004. Eight of the laboratories would team with a university and tackle water problems unique to their region.

Republican Senator Pete V. Domenici, whose hometown of Albuquerque, New Mexico, relies on uncertain groundwater supplies for drinking water and a dwindling Rio Grande for irrigated croplands, introduced the bill on the Senate side, and Representative Richard Pombo, a Republican from Tracy, California, introduced its companion bill in the House. Both of their districts struggle with increasing concentrations of trace contaminants from agricultural and natural sources, such as selenium in the California Central Valley and arsenic in New Mexico's lower Rio Grande Valley.

The billion-dollar bill directs scientists to work on novel ways of cleaning up and reusing finite water supplies to meet the needs of agriculture and cities. Sandia National Laboratories, headquartered in Albuquerque, would serve as the national center. Lawrence Livermore, located 24 kilometers east of the Central Valley, would serve as the Pacific regional water laboratory. Livermore scientists are currently working on a three-year Water Initiative managed by Livermore's Energy and Environment Directorate and funded by the Laboratory Directed Research and Development Program. (See *S&TR*, July/August 2004, pp. 4–13.)

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Estimate of photon mass is listed in 2004 compendium

Dmitri Ryutov's paper "The Role of Finite Photon Mass in Magnetohydrodynamics of Space Plasmas," which appeared in a plasma physics journal in 1997, has recently piqued the interest of particle physicists and astrophysicists worldwide. Ryutov's upper estimate of a finite photon mass has been selected to appear in the 2004 edition of the *Review of Particle Physics*, a biannual authoritative compendium of particle data, as the best estimate of photon mass to date, eight years after the original discussion.

For calculations, photon mass is assumed to be zero, but physicists have been trying for years to determine how small the mass actually is. The finite-mass photon is perfectly compatible with Einstein's relativity theory. Ryutov suggested an upper limit based on observations of the solar wind: The photon mass is less than the electron mass divided by 10 billion of trillions. Still, even this tiny mass would have a strong effect on large-scale astrophysical phenomena, says Ryutov.

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High-energy gas-gun shot is another JASPER success

Shot number 28 was successfully executed May 20, 2004, on the JASPER (Joint Actinide Shock Physics Experimental Research) two-stage gas gun located at the Nevada Test Site. The high-energy shot was the eighth consecutive successful experiment.

As part of the National Nuclear Security Administration's Stockpile Stewardship Program, JASPER experiments yield information on the behavior of plutonium at high temperatures and pressures. (See *S&TR,* June 2004, pp. 4–11.) That information contributes to computer simulations of the aging and operation of nuclear weapons to assess their safety and reliability.

Preliminary results from this experiment yielded a shot velocity of 7.22 kilometers per second. Both flash x-ray data recordings were correctly timed, and each of the 14 target pins recorded properly. All initial indicators show shot 28 to be a complete success. Test Director Mark Martinez says, "The shot went very well and gives us added confidence that the gun continues to perform well. The JASPER team deserves kudos for this one."

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Each month in this space, we report on the patents issued to and/or the 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

Low-Cost Fiber Optic Pressure Sensor
Sang K. Sheem
U.S. Patent 6,738,537 B2
May 18, 2004
The cost of fabricating a fiber-optic pressure sensor is reduced by making the membrane of the sensor in a nonplanar shape. The sensor design calls for the nonplanar membrane to become a part of an airtight cavity, which makes the membrane resilient because of the cavity's air-cushion effect. Such nonplanar membranes are easier to fabricate and attach.

Short Pulse Laser Stretcher–Compressor Using a Single Common Reflective Grating
Gaylen V. Erbert, Subrat Biswal, Joseph M. Bartolick, Brent C. Stuart, Steve Telford
U.S. Patent 6,739,728 B2
May 25, 2004
This invention provides an easily aligned, all-reflective, aberration-free pulse stretcher–compressor in a compact geometry. The stretcher–compressor device is a reflective, multilayer dielectric that can be used for high-power chirped-pulse amplification material processing applications. The device is constructed with a reflective grating element that receives a beam for stretching of laser pulses in a stretcher beam path. The element also receives stretched amplified pulses to be compressed in a compressor beam path through the same reflective, multilayer dielectric-diffraction grating. The stretched and compressed pulses are interleaved around the grating element to provide the desired number of passes in each respective beam path.

Shape Memory Polymer Actuator and Catheter
Duncan J. Maitland, Abraham P. Lee, Daniel L. Schumann, Dennis L. Matthews, Derek E. Decker, Charles A. Jungreis
U.S. Patent 6,740,094 B2
May 25, 2004
An actuator system is provided for acting on a material in a vessel. The system includes an optical fiber and a shape-memory polymer material operatively connected to the optical fiber. The shape-memory polymer material is adapted to move from one shape for moving through the vessel to a second shape for acting on the material.

Apparatus for Etching or Depositing a Desired Profile onto a Surface
Michael C. Rushford, Jerald A. Britten
U.S. Patent 6,740,194 B2
May 25, 2004
An apparatus and method for modifying the surface of an object by contacting the surface with a liquid processing solution using the liquid applicator geometry and Marangoni effect (surface tension gradient-driven flow) to define and confine the dimensions of the wetted zone on the object surface. In particular, the method and apparatus involve contouring or figuring the surface of an object using an etchant solution as the wetting fluid and using real-time metrology (for example, interferometry) to control the placement and dwell time of the wetted zone locally on the object's surface, thereby removing material from the object's surface in a controlled manner. One demonstrated manifestation is the deterministic optical figuring of thin glasses by wet chemical etching using a buffered hydrofluoric acid solution and the Marangoni effect.

Gamma Watermarking
Muriel Y. Ishikawa, Lowell L. Wood, Ronald W. Lougheed, Kenton J. Moody, Tzu-Fang Wang
U.S. Patent 6,740,875 B1
May 25, 2004
A covert, gamma-ray signature is used as a watermark for property identification. This new watermarking technology is based on a unique digital signature from tiny quantities of gamma-ray-emitting radioisotopic materials, generally covertly emplaced on or within an object. This digital signature may be readily recovered in the future by placing a sensitive, high-energy-resolution, gamma-ray detecting instrument over the watermark, whose location may be known only to the object's owner; however, the signature is concealed from all ordinary detection means because its exceedingly low level of activity is obscured by the natural radiation background, including the gamma radiation naturally emanating from the object itself. The watermark is used for object-tagging to establish object identity, history, or ownership. Thus, it may serve as an aid to law enforcement officials in identifying stolen property and prosecuting theft. Gamma watermarking is a highly effective and low-cost way to immediately identify most types of property.

Coherent White Light Amplification
Igor Jovanovic, Christopher P. J. Barty
U.S. Patent 6,741,388 B2
May 25, 2004
This system for coherent, simultaneous amplification of a broad spectral range of light includes an optical parametric amplifier and a seed pulse source. A first angular dispersive element is connected to the seed pulse source. A first imaging telescope is connected to the first angular dispersive element and to the optical parametric amplifier. A pump pulse source is connected to the optical parametric amplifier. A second imaging telescope is connected to the optical parametric amplifier and a second angular dispersive element is connected to the second imaging telescope.

Precision Gap Particle Separator
William J. Benett, Robin Miles, Leslie M. Jones II, Cheryl Stockton
U.S. Patent 6,746,503 B1
June 8, 2004
This system for separating particles entrained in a fluid includes a base with a first and second channel. A precision gap connects the two channels. The precision gap size allows small particles to pass from the first channel into the second channel but not large particles. A cover is positioned over the base unit, the first channel, the precision gap, and the second channel. A port directs the fluid containing the entrained particles into the first channel. An output port directs the large particles out of the first channel. A port connected to the second channel directs the small particles out of the second channel.

Carbon Nanotube Coatings as Chemical Absorbers
Thomas M. Tillotson, Brian D. Andresen, Armando Alcaraz
U.S. Patent 6,749,826 B2
June 15, 2004
Carbon nanotubes are used to collect airborne or aqueous organic compounds. Exposure of carbon-nanotube-coated disks to controlled atmospheres of chemical warfare– (CW–) related compounds provide superior extraction and retention efficiencies compared with commercially available airborne organic-compound collectors. For example, the carbon-nanotube-coated collectors were four times more efficient when concentrating dimethylmethylphosphonate (DMMP), a CW surrogate, than Carboxen, the optimized carbonized polymer for CW-related vapor collections. In addition to DMMP, the carbon-nanotube-coated material possesses high collection efficiencies for the CW-related compounds diisopropylaminoethanol, and diisopropylmethylphosphonate.

Optical Distance Measurement Device and Method Thereof
Mark W. Bowers
U.S. Patent 6,750,960 B2
June 15, 2004
A system and method to efficiently scan a target and obtain distance measurements. A light source provides an optical beam, and a frequency source modulates the beam. The modulated optical beam is transmitted to an acoustooptical deflector that changes the angle of the optical beam in a predetermined manner to produce an output for scanning the target. A detector receives the reflected or diffused light from the target and transmits it to a controller, which is configured to calculate the distance to the target as well as the measurement uncertainty in calculating the distance to the target.

Method for Distinguishing Multiple Targets Using Time-Reversal Acoustics
James G. Berryman
U.S. Patent 6,755,083 B2
June 29, 2004
This time-reversal acoustics method for distinguishing multiple targets uses an interactive process to determine the optimal signal for locating a strongly reflecting target in a cluttered environment. An acoustic array sends a signal into a medium and then receives the returned reflected signal. This returned reflected signal is then time-reversed and sent back into the medium again and again, until the signal being sent and received is no longer changing. At that point, the array has isolated the largest eigenvalue and eigenvector combination and has effectively determined the location of a single target in the medium (that is, the one that is most strongly reflecting). Once the largest eigenvalue and eigenvector combination has been determined, the location of other targets is determined. Instead of sending back the same signals, the method sends back the time-reversed signals. Half of these signals will also be reversed in sign. Various possibilities exist for choosing which half to do sign reversal. The most obvious choice is to reverse every other one in a linear array or in a two-dimensional checkerboard pattern. Then, a new send-and-receive, send-time reversed, and receive iteration can proceed. Often, the first iteration in this sequence will be close to the desired signal from a second target. In some cases, procedures must be implemented to ensure the returned signals are orthogonal to the first eigenvector.

Lightweight Flywheel Containment
James R. Smith
U.S. Patent 6,756,091 B1
June 29, 2004
A lightweight flywheel containment absorbs the energy of a flywheel structural failure. It is composed of layers of various materials that act as a vacuum barrier, momentum spreader, energy absorber, and reaction plate. In a demonstration, the flywheel containment structure had an aerial density of less than 6.5 grams per square centimeter and contained carbon fiber fragments with a velocity of 1,000 meters per second. The flywheel containment structure may be composed of an inner high-toughness structural layer, an energy-absorbing layer, and an outer support layer. An optional layer of impedance-matching material may be used.

Oxidation Preventative Capping Layer for Deep-Ultra-Violet and Soft X-Ray Multilayers
Shon T. Prisbrey
U.S. Patent 6,759,141 B2
July 6, 2004
This invention uses iridium and iridium compounds as a protective capping layer on multilayers that have reflectivity in the deep ultraviolet to soft-x-ray regime. The iridium compounds can be formed either by direct deposition of the iridium compound from a prepared target or by depositing a thin layer (for example, 0.5 to 5 nanometers) of iridium directly on an element. The deposition energy of the incoming iridium is sufficient to activate the formation of the desired iridium compound. The compounds of most interest are iridium silicide and iridium molybdenide.

Application of Yb:YAG Short Pulse Laser System
Gaylen V. Erbert, Subrat Biswall, Joseph M. Bartolick, Brent C. Stuart, John K. Crane, Steve Telford, Michael D. Perry
U.S. Patent 6,760,356 B2
July 6, 2004
A diode-pumped, high-power (at least 20-watt), short-pulse (up to 2-picosecond), chirped-pulse amplified laser using ytterbium-doped yttrium aluminum garnet (Yb:YAG)) as the gain material is used for material processing. Yb:YAG is the gain medium for both a regenerative amplifier and a high-power four-pass amplifier. A single common reflective grating optical device stretches pulses for amplification and recompresses amplified pulses before being directed to a workpiece.

Awards

Laboratory engineer **Ray Stout** has been named a fellow of the **American Society of Mechanical Engineers** (ASME). French Commissariat á l'Energie Atomique also invited Stout to be a member of an International Scientific Advisory Board for its nuclear waste storage and disposal program. For more than 10 years, Stout had planning and technical management responsibility for experiments and analyses on radioactive waste performed at Lawrence Livermore, Pacific Northwest, and Argonne national laboratories. In addition, he has extensive background in dislocation and microcrack kinetics.

On June 8, 2004, the Laboratory's **Operational Security** (OPSEC) **Program** accepted **third-place organizational honors**, among 81 nominees, at the **2004 National Operational Security Awards** in Baltimore, Maryland, presented by the **Interagency OPSEC Support Staff**. "OPSEC is so important in today's security environment," said **David Leary**, director for the Safeguards and Security Organization. "The commitment and dedication of the OPSEC professionals and the OPSEC committee are key to our program." Attending the event were Leary, OPSEC Program Manager **Pam Poco**, her deputy **Liz Della Nina**, and OPSEC committee members **Dave Johnstone** and **Kent Oelrich**.

The Laboratory's **Computation Directorate** received a **Department of Energy** (DOE) **2004 Equal Employment Opportunities** (EEO) **and Diversity Best Practices Award** for its program to recruit underrepresented computer scientists to the Laboratory. The award was presented July 1, 2004, at DOE's annual Human Resources and EEO/Diversity Symposium, held in Pittsburgh, Pennsylvania. **Linnea Cook** of the Computation Directorate and **Ellen Hill** and **Susane Head** of Recruiting and Employment accepted the award on behalf of the Laboratory.

The efforts by **DOE and its national laboratories** to transfer research and technology to the private sector have been recognized with a **2004 Licensing Achievement Award** from the **Licensing Executives Society**. Livermore, which has one of DOE's most active technology transfer programs, collected a record $4.1 million in royalty income last year.

The society, with more than 6,000 members involved in various aspects of commercializing intellectual property, recognized the success of DOE's technology transfer program, which last year included 3,687 active licenses, 661 active cooperative research and development agreements, 1,948 active work-for-others agreements with nonfederal sponsors, and more than $25 million in licensing income and royalties collected. In a letter announcing the award, Energy Secretary Spencer Abraham commended the DOE licensing and technology transfer community for "facilitating the exploitation of federally funded research and development programs for the benefit of the American public."

Radiation Detection on the Front Lines

The Radiation Detection Center (RDC) helps initiate and support radiation detection research and development across the Laboratory. More than 200 Livermore employees are involved in radiation detection efforts that range from developing new electronics to improving computer simulations with a principal focus on national and homeland security. Current projects include a gamma-ray imaging spectrometer that takes photographs of the high-energy gamma radiation emitted from nuclear materials, a Compton camera whose omnidirectional sensitivity is significantly higher than that of other imaging systems, and portable radiation detection devices with high sensitivity and energy resolution. The RDC also conducts workshops and focus groups to generate innovative ideas and is involved in ongoing partnerships with universities to engage graduate students in summer work within Laboratory projects.

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Exploring the Ultrawideband

Livermore's micropower impulse radar (MIR) is a different type of radar that is compact, low power, inexpensive, and unusually versatile. MIR sends out extremely short electromagnetic pulses over a wide band of frequencies. Instead of continuous waves of energy used in conventional radar or radio, MIR transmits rapid impulses in ultrawideband (UWB) that last a few billionths of a second. The pulses reflect off nearby objects and are detected by a high-speed sampling receiver. For the past decade, Livermore has transferred the MIR technology to numerous companies for various applications. More recently, Livermore engineers have been developing new types of UWB-based communication devices with reduced power requirements, extended range, and enhanced penetration capability. About 20 engineers and technicians are working on radar and radio projects for sensors, imagers, and communication devices.

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U.S. Government Printing Office: 2004/683-056-70065

Coming Next Month

Livermore Wins Five R&D 100 Awards

Laboratory researchers received five awards from *R&D Magazine*, for developing technologies with commercial potential:

- The Autonomous Pathogen Detection System
- A Diode-Pumped, Pulsed Laser for Humanitarian Mine Clearing
- Inductrack
- Chromium Software
- Gene Silencing with SiHybrids

Also in October

- *Strategic partnerships between Lawrence Livermore and the University of California maximize research capabilities at both institutions.*

University of California
Science & Technology Review
Lawrence Livermore National Laboratory
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