October/November 2009

Science & Technology Review

National Nuclear Security Administration's Lawrence Livermore National Laboratory

Also in this issue:

- **The Hunt for Radiological Sources in Africa**

About the Cover

Livermore researchers captured eight R&D awards in *R&D Magazine*'s annual competition for the top 100 industrial innovations worldwide. Beginning on p. 4, this issue of *Science & Technology Review* highlights the award-winning technologies: an optical device for protecting high-intensity lasers from bandwidth-related damage, a "time microscope" for improving the performance of conventional recording instruments, a miniature high-resolution gamma-ray spectrometer, a precision robotic assembly machine, an open-source compiler infrastructure, an artificial retina, a land mine locator, and a laser beam centering and pointing system. Since 1978, Laboratory researchers have received 129 R&D awards. (The R&D logo is reprinted courtesy of *R&D Magazine*.)

Cover design: George A. Kitrinos

About the Review

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

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Lawrence Livermore National Laboratory

Contents

2009 R&D 100 Awards

Features

Departments

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Carbon Capture Technique Goes Green

Major efforts are under way to reduce carbon dioxide (CO_2) emissions from burning fossil fuel. CO_2 is a heat-trapping gas (also known as greenhouse gas) that must first be separated from its source, a step known as "capture," before it can be sequestered in an underground reservoir. Laboratory scientist Amitesh Maiti has developed a screening method that would use ionic liquids—a special type of molten salt that becomes liquid under the boiling point of water (100°C)—to separate CO_2 from its source. Chemists recently became interested in ionic liquids as solvents because they have almost no vapor pressure and do not evaporate, even under high-temperature conditions.

Over the last few years, several ionic liquids have been experimentally tested and found to be efficient solvents for CO_2, providing data that could be useful in optimizing the choice of ionic liquids for CO_2 capture. "However," says Maiti, "each new experiment costs time and money and is often hindered because a specific ionic liquid may not be readily available." Maiti developed a quantum-chemistry-based thermodynamic approach to compute the chemical potential of a solute (CO_2 in this case) in any solvent at an arbitrary dilution. The computations yielded accurate solubility values in a large number of solvents, including ionic liquids. Maiti confirmed these computational results by comparing computed solubilities with experimental values that have been accumulated.

Maiti used this method to predict new solvent classes that would possess CO_2 solubility nearly two times as high as the most efficient solvents experimentally demonstrated. The accuracy of the computational method will allow scientists to see useful trends, which could potentially lead to the discovery of practical solvents with significantly higher CO_2 capture efficiency than what is used today. The research appeared as the cover article in the July 2009 issue of *ChemSusChem*, a new journal focused on chemistry and sustainability.

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Climate Models Agree on Human "Fingerprints"

Laboratory scientists and a group of international researchers have found that climate model quality does not affect the ability to identify human effects on atmospheric water vapor. The team first tested each of 22 models individually, calculating 70 different measures of model performance. These metrics provided insight on how well the models simulated today's average climate, its seasonal changes, and geographical patterns of climate variability. The information enabled the researchers to grade and rank the models in a multitude of ways and to identify many groups of "top 10" and "bottom 10" models out of the full set of 22 models. From each of these groups, the scientists obtained estimates of the response of water vapor to human factors (the "fingerprint") and the "noise" of natural climate variability. They then repeated the search for a human effect on water vapor with more than 100 combinations of climate model fingerprint and noise data sets. In every case, a water vapor fingerprint arising from human influences could be clearly identified in the satellite data.

"Climate model quality didn't make much of a difference," says Ben Santer of Livermore's Program for Climate Modeling and Intercomparison. "Even with the computer models that performed relatively poorly, we could still identify a human effect on climate. The physics that drive changes in water vapor are very simple and are reasonably well-portrayed in all climate models." The atmosphere's water vapor content has increased by about 0.4 kilograms per cubic meter per decade since 1988, and natural variability alone cannot explain this moisture change, according to Santer. "The most plausible explanation is that it's due to human-caused increases in greenhouse gases," he says. More water vapor—which is itself a greenhouse gas—amplifies the warming effect of increased atmospheric levels of CO_2.

This new study links Livermore's "fingerprint" research with its longstanding work in assessing climate model quality. It tackles the general question of how to best make use of the information from a large collection of models, which often perform very differently in reproducing key aspects of present-day climate. The team's findings appeared in the August 10, 2009, online issue of the *Proceedings of the U.S. National Academy of Sciences*.

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Award-Winning Collaborations Provide Solutions

OUR Laboratory exists to tackle challenges of enormous importance to the nation. While some of our work is basic research, the majority is applied science, devoted to devising and optimizing technologies that offer solutions to scientific challenges in areas such as nonproliferation, climate change, and energy security. The Laboratory's signature approach to problem-solving is a collaborative one that brings together the expertise of many disciplines.

This year's record-breaking eight R&D 100 awards, which are often referred to as *R&D Magazine*'s "Oscars of Invention," were developed by multidisciplinary teams made up of incredibly talented scientists, engineers, and technicians from both inside and outside the Laboratory. Participants include private companies, other national laboratories, research institutions, and universities. In just one instance, a solo researcher captured an award. Since 1978, Lawrence Livermore has garnered 129 R&D 100 awards. Among other national laboratories, only Oak Ridge National Laboratory equaled us this year, also winning eight awards.

The largest collaboration by far among this year's winners is responsible for the first long-term retinal prosthesis, an artificial retina that can function for years inside the eye to treat certain kinds of blindness. Four national laboratories, four universities, an industrial partner, and the Department of Energy (DOE) came together several years ago to create this sight-saving device. The prosthesis has to date vastly improved the vision of 18 patients. My own family has been affected by macular degeneration, and it is good to be working with colleagues who are helping to provide solutions for this debilitating disease.

An internal Laboratory collaboration has developed GeMini, a portable gamma-ray spectrometer with a germanium detector. GeMini is so small it fits in the palm of one's hand. The device is already being used in the National Aeronautic Space Administration's MESSENGER spacecraft to collect the first-ever gamma-ray data of the planet Mercury.

Laboratory experts and a private company produced the land mine locator, an aerial detection system designed to decrease the time and cost of demining operations while improving the safety of personnel and equipment. Another private company, which is commercializing the technology, was a collaborator in this effort.

A time microscope called the FemtoScope dramatically improves the performance of recording instruments such as oscilloscopes and streak cameras. This development collaboration included three universities in addition to Livermore researchers.

Spectral sentry is a technology developed by a team of Laboratory scientists and engineers to protect laser systems from pulses that contain insufficient bandwidths. The device inspects individual laser pulses, which travel at the speed of light, and stops those pulses that could potentially damage laser materials.

Another Livermore collaboration is responsible for ROSE, a compiler software infrastructure used to convert source code into binary code and to optimize code performance. ROSE is open-source software that for the first time makes compilers accessible to any software developer or scientist.

A precision robotic machine for assembling National Ignition Facility targets is the product of a collaboration involving Livermore experts and three private companies. The machine can manipulate millimeter-scale components with 100-nanometer precision and 100-milligram resolution force feedback in an operating arena the size of a sugar cube.

An individual Laboratory physicist saw the need and devised a method for combining two critical laser alignment measurements—centering and pointing. The laser beam centering and pointing system uses a special dual-imaging bifocal lens to capture two images simultaneously and combine them into one. With no moving parts, this innovative device provides huge advantages in stability and repeatability compared with conventional alignment systems.

We will be making collaborative problem-solving even easier with our new Livermore Valley Open Campus, a joint effort with Sandia National Laboratories California. DOE has authorized us to proceed with planning and infrastructure development for a campuslike, low-security area to facilitate our work with private companies and other government agencies. We are also establishing teams both internal and external to the Laboratory that can take advantage of funds from the American Recovery and Reinvestment Act of 2009. Sixty-five proposals with potential funding of nearly $145 million have been submitted to date.

The Laboratory performs amazing science, often in collaborative ways, every day. Winning R&D 100 awards is the metaphorical icing on the cake.

■ Steven D. Liedle is deputy director of Lawrence Livermore National Laboratory.

Light-Speed Spectral Analysis

SCIENTISTS and engineers have harnessed the power of laser light for an astonishing array of applications. High-intensity lasers are used extensively in basic science, energy, and defense research. However, the ever-greater levels of strength and brightness that these lasers can achieve make the amplified light a danger to the laser system's optical components. A team of researchers led by Paul Armstrong has won an R&D 100 Award for its lightning-fast solution to the threat of damaging laser light. The technology, called spectral sentry, was developed under the Mercury laser project for the National Ignition Facility (NIF) and Photon Science Principal Directorate.

When energized electrons are stimulated to produce an initially weak laser pulse, all the photons emitted will be the same wavelength, or color of light. Within a laser system, these initial pulses are amplified trillions of times. While the intense energy produced is essential for modern laser applications, it can, at upper limits, produce unwanted effects. High-power pulses can create intense acoustic waves that ruin experiments by distorting the pulses, scattering useful light, or even cracking laser optics. For example, stimulated Brillouin scattering (SBS), a damage-producing process, tends to disperse laser light backward toward low-energy laser components or perpendicularly, creating damage sites on optics while sapping energy from the laser beam. Even a single pulse could create enough damage to result in system repairs and downtime.

Broader Bandwidth Solution

Undesirable scattering is a source of great concern to high-intensity laser designers, who need the light to behave in a useful, focused, predictable way. Researchers have found that broadening the bandwidth—the range of colors—of the laser light before amplification can suppress SBS and stimulated Raman scattering as well as reduce hot spots in the beam's profile, which are created when a laser interferes with its own reflections. Broad bandwidth also enables creation of the extremely short-duration pulses that are necessary for many high-intensity physics experiments.

Spectral sentry ensures that high-intensity laser systems amplify only laser pulses with sufficient bandwidth, preventing potentially damaging low-bandwidth, high-energy laser pulses from being produced. This optical device can analyze a single laser pulse traveling at the speed of light and stop that pulse if it does not meet the minimum bandwidth requirements.

The spectral sentry device has been successfully tested and used on Livermore's Mercury laser and is the fourth R&D 100 Award-winning technology to emerge from the Mercury project. Mercury is a one-beam, high-average-power, solid-state laser used to develop and demonstrate fusion-energy system technology. When Mercury operates with single-color light, it may be run only at energies of up to 65 joules to prevent unwanted optical effects. When Mercury generates broader bandwidth light, the operating energy levels may be safely increased. However, the risk of a small

Spectral sentry development team: (front row, from left) Rob Campbell, William Molander, Paul Armstrong, Christopher Ebbers, and Noel Peterson; (back row) Steven Telford, Richard Shuttlesworth, Glenn Huete, Rodney Lanning, Nick Schenkel, and Andy Bayramian.

# of a Laser Pulse

Developer Paul Armstrong peers into the spectral sentry optical device used to protect laser systems from pulses with insufficient bandwidths.

electrical glitch, hardware failure, or human error causing narrow bandwidth beam production is great enough that the safe operating limit is still kept at the single-color level. With the addition of spectral sentry, the system can safely operate at 100 joules, in line with design goals, without fear of bandwidth-related damage.

The need for spectral sentry was clear for Mercury—its repetition rate of up to 10 shots per second is simply too fast for experimentalists to visually check diagnostics and confirm appropriate bandwidth for each shot. However, users of a range of other broad-bandwidth and high-energy lasers worldwide could also find spectral sentry's technology, generally referred to as bandwidth interlocking, essential for performing experiments requiring confidence that optics will be protected from damage.

Results within Nanoseconds

Spectral sentry completes its work in three steps, all in the span of 34 nanoseconds, during which time the beam continues on its path toward the laser's amplifiers. A small sample of the beam is first separated into its individual colors using a high-resolution spectrometer. This sample is divided into three spectral regions, and mirrors reflect the long- and short-wavelength portions onto the second part of spectral sentry, the two high-speed photodiode detectors. The central wavelengths are either terminated or propagated to yet a third detector for further analysis. The use of two photodiode detectors provides an additional level of verification that the beam truly has sufficient bandwidth, because a misaligned beam may appear to a single photodiode detector as having an adequate spectral spread. The final portion of spectral sentry is an electronic subsystem that receives signals from the photodiode detectors and logically analyzes them. If the bandwidth is acceptable, a digital signal is sent to an optical switch, allowing that individual pulse to pass.

The tremendous speed with which this detection and analysis process is completed allows it to be used on lasers with pulse repetition rates up to 5 million shots per second. "Speed is our 'wow' factor," says Armstrong. "Spectral sentry can measure pulses traveling at the speed of light and can actually get an electric signal ahead of the pulse by adding just a slight delay. Its job is to protect high-value lasers from unpredictable high-speed events."

Spectral sentry combines the extreme speed required for same-shot bandwidth interlocking with the flexibility needed for use in a wide range of applications. The adaptability component of the device enables it to address virtually any form or amount of bandwidth a laser designer may need. As technology improves and laser energy levels and repetition rates continue to climb, spectral sentry can be expected to safeguard lasers in many areas of research, including inertial fusion energy, defense, materials processing, and high-energy-density physics.

—Rose Hansen

Key Words: bandwidth, interlock, Mercury laser, optics damage, R&D 100 Award, spectral analysis, spectral sentry.

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Capturing Waveforms in a

HOW will scientists "see" what happens inside the National Ignition Facility (NIF), the world's largest laser, when it creates the extreme temperature and pressure conditions found in stars? Instruments such as oscilloscopes and streak cameras cannot capture all the details of fast-moving, complex events such as fusion burn. Their dynamic range (the ratio between the smallest and largest possible values) and their temporal resolution (the precision of a measurement with respect to time) are coupled. As a result, these conventional instruments lose dynamic range with faster temporal resolution or lose temporal resolution with more dynamic range.

To meet the emerging need for greater dynamic range and temporal resolution, scientists can turn to the new FemtoScope—a "time microscope" that is attached to the front end of a conventional recording instrument to dramatically improve its performance. Livermore researchers, in collaboration with colleagues from Stanford University, the University of Southampton, and the University of California at Davis, won an R&D 100 Award for their invention of the FemtoScope. Initial efforts for this work were funded by Livermore's Laboratory Directed Research and Development Program.

Slowing Down the Signal

The FemtoScope improves the performance of an oscilloscope or streak camera much in the same way that a high-performance lens improves a camera's output. (See *S&TR*, June 2007, pp. 4–10.) It is not a recording instrument in itself. Rather, it dramatically enhances the performance of any conventional recording instrument to which it is connected by ultrafast processing of waveforms. The FemtoScope improves the dynamic range of these instruments and their time resolution from tens of picoseconds (trillionths of a second) to hundreds of femtoseconds (quadrillionths of a second).

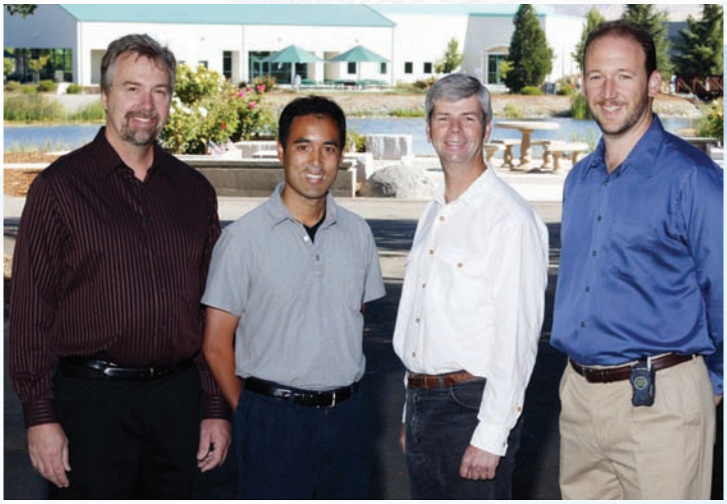
"The temporal imaging technology on which the FemtoScope is based is fundamentally a time-scale transformation tool that can be configured to magnify, compress, reverse, and even Fourier-transform ultrafast waveforms," says Livermore scientist Corey Bennett. "We have concentrated our efforts on developing a time-magnification system." Just as a scanning electron microscope's powers of magnification can reveal nanometer-size details of an object's structure not viewable with an ordinary light microscope, so the FemtoScope's powers of time magnification can reveal the peaks and valleys in a 1-picosecond signal not detectable by a standalone oscilloscope or streak camera.

In the past, other instruments have obtained very high resolution by conducting repetitive waveform sampling and averaging with ultrashort time intervals. However, because NIF will be fired a maximum of four times a day, diagnostics must operate in a single-shot mode, and repetitive sampling approaches are not an option.

By slowing down or "magnifying" the time scale of the signal before it enters the recording instrument, the FemtoScope allows the capture of signals that otherwise would be too fast to record in any detail. This process not only improves the resolution of the recording system but also increases the available dynamic range at a given speed. In the figure on p. 7, a simulation shows how three optical pulses separated by 6 picoseconds (first to last) can be "time magnified" so that they occur over 18 picoseconds at the output.

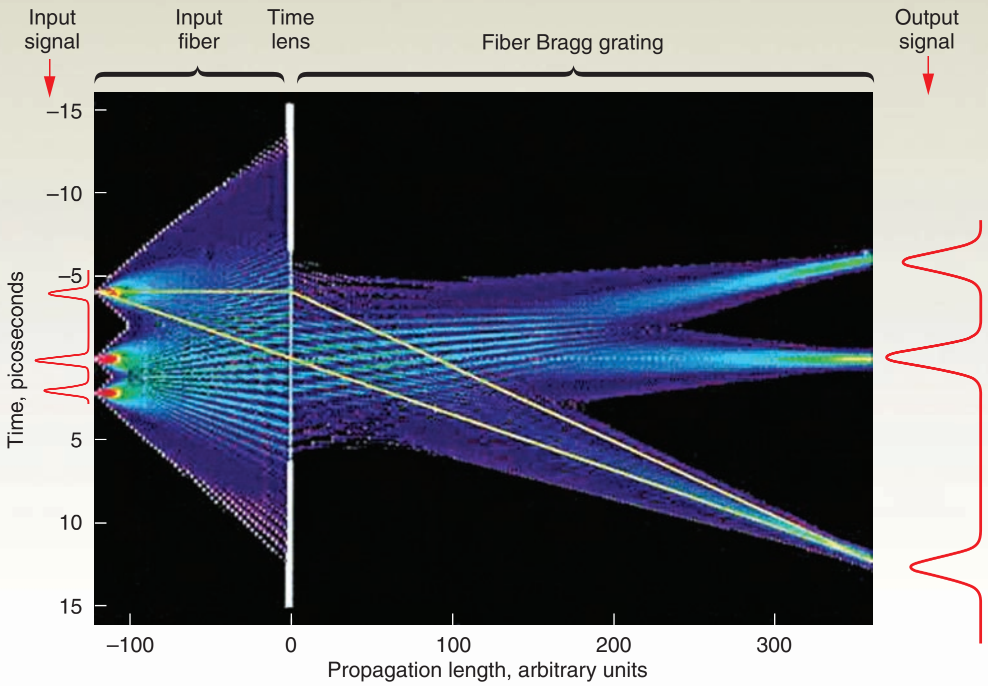
The FemtoScope uses a single-shot process in real time to capture each window of time (or frame) of interest and stretches out the waveform so that greater detail is revealed. Furthermore, this process can be repeated at a rate of more than 100 million frames per second to record the real-time evolution of a signal. With ultrafast resolution and nearly endless recording length, this instrument can uncover waveform data with peaks and valleys never before detectable.

When combined with an oscilloscope, the FemtoScope produces an instrument capable of recording 100-picosecond frames at 155 million frames per second until its memory is full. When



Livermore development team for the FemtoScope (from left): Bryan Moran, Vincent Hernandez, Alex Drobshoff, and Corey Bennett.

Quadrillionth of a Second



A false-color image shows three pulses propagating through a temporal imaging system with a magnification of three times. Color here represents intensity or brightness, with red being the brightest. The simulation shows how three optical pulses occurring in a 6-picosecond time frame can be "time magnified" so that, at the output, they occur over 18 picoseconds.

combined with an optical streak camera, the FemtoScope produces an instrument with a 20-times increase in temporal resolution and a 30-times increase in dynamic range, resulting in an overall improvement of 600 times compared with the performance of the streak camera alone.

Emerging Needs

The FemtoScope represents a fundamental paradigm shift in high-speed imaging technology. As researchers improve their understanding of physical phenomena, they will need to examine processes on shorter and shorter time scales. The FemtoScope will be an invaluable tool for collecting detailed dynamic data at faster temporal resolution.

The Laboratory plans to use the FemtoScope on NIF experiments, which will need diagnostics with time resolutions on the scale of 1 picosecond or less to determine when high-energy photons first appear and what happens from their first appearance to their peak production. The FemtoScope will also be useful for detecting and recording a broad range of signal strengths—from very weak signal intensities to very strong.

The true potential of temporal imaging is just beginning to be explored. The FemtoScope could also be applied to several other high-energy-density-physics and fusion-energy research facilities and experiments with diagnostic needs similar to NIF's. The Defense Advanced Research Projects Agency is cofunding Livermore to develop the technology for lidar (light detection and ranging), which measures the properties of scattered light to gather information about a distant target.

The FemtoScope will also be a valuable tool for Livermore researchers who are beginning development of a new energy concept known as Laser Inertial Fusion Engine, or LIFE, which is based on physics and technology developed for NIF. (See *S&TR*, April/May 2009, pp. 6–15.) LIFE has the potential to meet future worldwide energy needs in an inherently safe, sustainable manner without carbon dioxide emissions, while dramatically shrinking the planet's stockpile of spent nuclear fuel.

—*Karen Rath*

Key Words: dynamic range, FemtoScope, R&D 100 Award, temporal imaging, temporal resolution, time microscope.

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Gamma-Ray Spectroscopy

BOTH natural radioactive materials, such as potassium found in the soil, and manufactured radioactive materials, such as plutonium created in a reactor, emit energy in the form of gamma rays, x rays, electrons, or alpha particles. Gamma rays are often the most useful radioactive emission to measure, because they provide a unique fingerprint of a material's isotopic composition. Gamma-ray spectrometers provide the means to identify and quantify these isotopes.

Gamma-ray spectroscopy has proven to be a successful tool in many fields, such as in solar physics to learn more about the Sun, in astrophysics to determine the composition of galactic and extragalactic objects, and in nuclear physics to discover the basic structure of matter. In support of national security, the technology helps locate radioactive materials at shipping ports and border crossings. In support of nuclear safeguards, it helps identify and quantify the isotopes present at nuclear processing facilities. Additionally, in the field of medicine, gamma-ray spectroscopy is used with tracer drugs to identify biological processes and is a component of imaging systems that help locate tumors.

A team of Lawrence Livermore scientists and engineers, working with the U.S. Defense Threat Reduction Agency and the National Nuclear Security Administration's Office of Dismantlement and Transparency, has developed GeMini, a portable detection device that significantly advances the field of gamma-ray spectroscopy. The device design depends on the element germanium (hence the "Ge" in GeMini) for accurately detecting and identifying nuclear materials. Compared with other instruments, GeMini identifies nuclear materials with a higher level of certainty and at a considerable cost savings. Its design incorporates an innovative ultraminiature cooling system (hence the "Mini" in GeMini) with an infrared shielding mechanism developed at Livermore. Other features include rugged construction, low power consumption, automated operation, and small size. In fact, the instrument is so small it fits in the palm of one's hand.

The Laboratory has commercialized GeMini technology with NucSafe, a radiation detection company based in Oak Ridge, Tennessee. The GeMini development team, led by Livermore physicist Morgan Burks, received an R&D 100 Award for this innovative technology.

Resolution Is Crucial for National Security

GeMini's outstanding energy resolution is particularly important in national security applications, when it is critical to differentiate between legitimate and illicit sources of gamma rays. The portable instrument can easily be carried by first responders to determine radiation levels and identify isotopes at sites of nuclear incidents, and homeland security personnel can use it to help prevent terrorists from smuggling nuclear materials into the country.

GeMini features a detector made from an ultrapure germanium crystal. Gamma rays interact with the germanium and liberate electrons in proportion to the energy of the gamma ray. These electrons are collected by a strong electric field applied to the crystal and then read out with precision low-noise electronics. Many other substances can be used to detect gamma rays, but

Development team for GeMini (from left): Dennis Carr, Morgan Burks, Marianne Ammendolia, and Livermore retiree Del Eckels.

in the Palm of Your Hand

germanium offers the best resolution. However, germanium achieves its spectacular resolution only when cooled to cryogenic temperatures of about 100 kelvin (–173°C) or less. This cooling is typically achieved using liquid nitrogen.

Before the addition of electromechanical cooling technology, germanium-based spectrometers were confined to the laboratory, where liquid nitrogen is available. Livermore has played an important role in developing this technology. (See *S&TR*, May 2006, pp. 4–10 and September 2003, pp. 24–26.) The Laboratory's latest-generation GeMini eliminates the need for liquid nitrogen with its ultraminiature electromechanical cooling system and novel thermal isolation capability.

In recent years, germanium-based spectrometers that are electromechanically cooled and therefore free from the constraint of liquid nitrogen have appeared on the market. However, GeMini's extremely low power consumption, small size, and low cost enable it to excel in applications where rapid deployment and portability are important.

The GeMini gamma-ray spectrometer fits in the palm of your hand.

New Applications for Spectroscopy

GeMini's unique attributes take gamma-ray spectroscopy applications into new territories. The instrument was the first electromechanically cooled germanium spectrometer ever deployed in deep space. High resolution is important in space missions to accurately determine the surface composition of a planet or an asteroid. A version of GeMini was launched on the National Aeronautic and Space Administration's (NASA's) MESSENGER spacecraft in 2004 and is currently collecting the first-ever gamma-ray data from the planet Mercury. In addition, GeMini may be part of a NASA mission to the Trojan asteroids near Jupiter. No other gamma-ray detector provides the high resolution, low weight, and rugged durability required in space exploration.

The portability of GeMini makes it ideally suited for civilian first responders in the case of a natural disaster where a concern of radioactive contamination exists. In addition, U.S. military personnel could find the detector useful when responding to potential terrorist threats involving nuclear weapons or dirty bombs (devices made of conventional explosives and radioactive materials). A version of GeMini is being built for the international safeguards community to use in field inspections of nuclear processing facilities.

GeMini has opened up a wide range of new applications for high-resolution, gamma-ray spectroscopy. The detector will soon be available to emergency first responders, homeland security personnel, and International Atomic Energy Agency inspectors. Wherever a need exists to identify nuclear materials with high precision, whether on the planets of our solar system or closer to home, GeMini will offer that capability in a low-cost, handheld package.

—Arnie Heller

Key Words: gamma-ray spectrometer, GeMini, germanium, International Atomic Energy Agency, nuclear safeguards, radiation detector, R&D 100 Award.

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Building Fusion Targets with

As the National Ignition Facility (NIF) prepares to begin fusion ignition and sustained burn experiments for the first time ever in a laboratory setting, a team of Livermore scientists and engineers is focusing on ways to efficiently and cost-effectively produce the tiny, intricate fusion targets that will be at the center of these experiments. Producing these targets is extraordinarily demanding when it comes to assembling components. Accurate alignment of target components on the micrometer scale is one of the critical requirements for achieving ignition with energy gain.

Historically, building laser fusion targets required a significant amount of handcrafting skill and technique involving microscopes and manually driven fixtures. Now, Livermore scientists are transforming the way fusion targets are manufactured with a new device called the precision robotic assembly machine. The Livermore development team is led by systems engineer Richard Montesanti and funded by the National Ignition Campaign Program. Early investments from Livermore's Laboratory Directed Research and Development Program and Engineering Directorate provided roots for the expertise in precision engineering needed to take on this challenge. The team, along with three private companies, has won an R&D 100 Award for the technology. Collaborators are from General Atomics in San Diego, California; Aerotech, Inc., in Pittsburgh, Pennsylvania; and Indicate Technologies, Inc., in Santa Clara, California.

The precision robotic assembly machine can manipulate tiny fusion target components with unprecedented precision in an operating arena the size of a sugar cube. Unlike in other machines, the innovative use of visual and force feedback allow an operator to drive the machine like a surgical robot and automate the assembly process. Furthermore, the precision robotic assembly machine demonstrates improved target quality and a tenfold reduction in manpower needed to assemble laser fusion targets.

Precision Mechanics

The precision robotic assembly machine was developed to manufacture small and complex laser-driven fusion ignition targets for NIF, although it can be adapted to build other complex miniature devices. The machine can manipulate five target components at once in a 1-cubic-centimeter operating arena. Each target is designed so that the inner physics package can be tailored independently of the surrounding thermal–mechanical package.

At the heart of the precision robotic assembly machine is a Livermore-developed reconfigurable manipulator system that assembles millimeter-scale components with micrometer accuracy and 100-nanometer precision (repeatability). Nineteen motorized axes and ten manual axes are arranged to form six manipulators for positioning the target components. The manipulator system is integrated with an optical-coordinate measuring machine that provides dimensional measurements of the target with micrometer accuracy during assembly. Auxiliary mirrors provide this measuring tool with multiple views of the target while it guides the initial

Development team for the precision robotic assembly machine: (front row, from left) Richard Montesanti, Monika Witte, Robert Kent, Manuel Carrillo, Dawn Lord, Elizabeth Dzenitis, and Jeff Atherton; (back row) Robert Bickel, Jack Reynolds, John S. Taylor, Richard Seugling, Jeffrey Klingmann, Ethan Alger (General Atomics), Evan Mapoles, Abbas Nikroo (General Atomics), and Carlos Castro. (Not shown: Livermore retiree George L. Miller.)

Precision Robotics

Systems engineer Richard Montesanti operates the precision robotic assembly machine. The inset shows an assembled fusion ignition target.

alignment of the target components and measures their relative positions and orientations. The force and torque feedback is used to guide the final alignment and mating of delicate target components that fit together with zero to micrometer-level clearance.

A Standout Machine

A unique attribute of the precision robotic assembly machine is its ability to stitch together multiple millimeter-scale operating arenas—within each, many components can be manipulated with 100-nanometer precision and 100-milligram resolution force feedback—over distances spanning tens of centimeters. The machine's manipulator system provides precise and repeatable motions, the force and torque feedback enables deterministic mating of delicate components, and the real-time dimensional metrology enables precise alignment of components and immediate verification of as-built accuracy.

"The multiple technologies integrated into the precision robotic assembly machine bridge the gap between building miniature- and man-size machines," says Montesanti. "Our machine could provide a key enabling platform for significant advances in the development and manufacture of centimeter-scale systems that integrate millimeter- and micrometer-scale optical, electrical, mechanical, and biological subsystems."

Other systems for manufacturing fusion targets are limited to simultaneously manipulating just two or three components in the assembly arena, and only a few of those systems can do so with 100-micrometer precision and micrometer accuracy. No other system uses force and torque feedback, which according to Montesanti is crucial when assembling a complex miniature machine made up of delicate components that contact each other.

The success of the initial precision robotic assembly machine motivated the building of a second machine to expand target production capability. "We need to build at least one target per day for the campaign, while maintaining flexibility for changes in target parameters," says Montesanti. "The precision robotic assembly machine enables that production rate, and its reconfigurable nature has already accommodated changes to the target design."

Fusion in Our Future

Assembling fusion ignition targets requires a deterministic and efficient manufacturing system that can simultaneously manipulate many delicate components with precision and accuracy. Repeatable and consistent production of high-quality, precision ignition targets will play an important role in using NIF's 192 laser beams to explore high-energy-density regimes relevant to developing commercial fusion energy.

NIF fusion ignition experiments will bring the study of stars and their environments into the laboratory, with the potential to greatly expand our understanding of the nature and origin of the universe. Fusion targets will be at the center of this monumental achievement. "Our precision robotic assembly machine is building the targets that will become the miniature Suns on Earth during the fusion ignition process," says Montesanti.

—Kristen Light

Key Words: force and torque feedback, fusion ignition targets, National Ignition Facility (NIF), precision robotic assembly machine, R&D 100 Award.

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ROSE: Making Compiler Technology

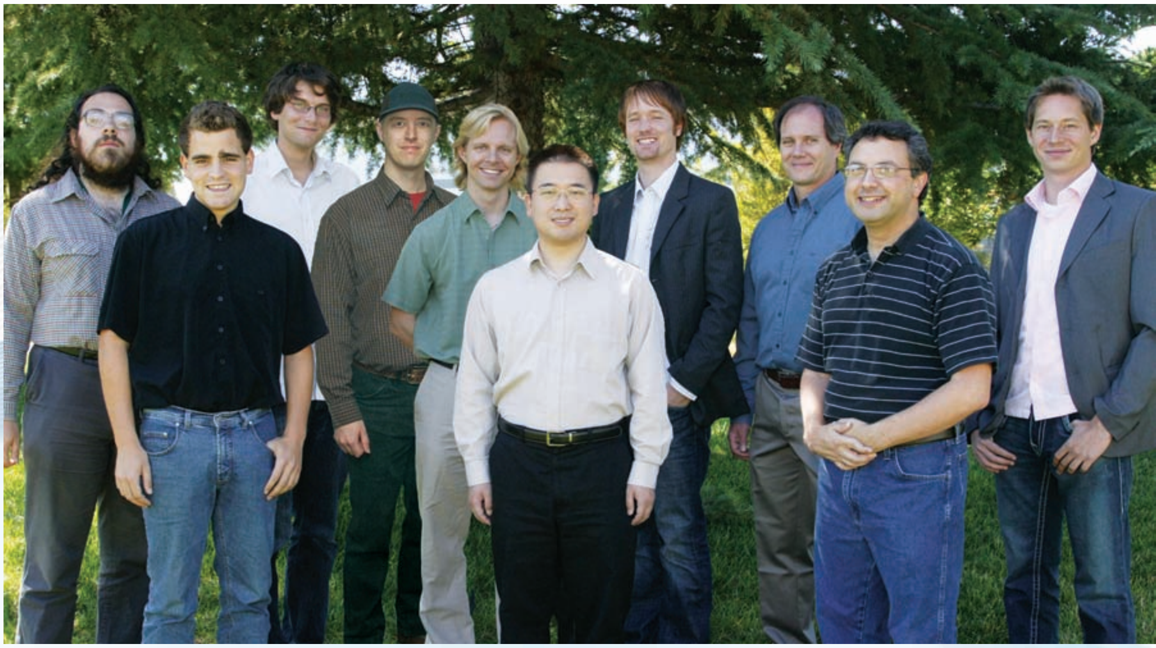
IN software development, a critical step is compiling—converting human-friendly source code into the machine-friendly binary code a computer needs to execute a program (that is, "executable" files). The conversion of source code into binaries is performed by specialized software applications called compilers. Only compiler experts, rare in the industry, know the ins and outs of this arcane task. With the increasing complexity of computing today, the conventional reliance on these experts to build sophisticated compilers has become a bottleneck.

Computer scientists at Lawrence Livermore have radically altered the programming landscape by creating ROSE, an open-source customizable compiler infrastructure that gives all programmers easy access to complex, automated compiler technology and assistance. ROSE accepts code in today's most common programming languages, including C, C++, and Fortran. Fortran is commonly used at Department of Energy (DOE) and National Nuclear Security Administration (NNSA) sites.

Because ROSE has full knowledge of these languages, it can be used to optimize code performance and find errors. For example, millions of lines can be scanned for source-code defects (bugs that are allowed by the programming language but still cause system failures when run) or malicious elements hiding in the code. Additionally, ROSE returns these improvements to the user in revised source code rather than in the form of machine-readable binaries. The ROSE development team won an R&D 100 Award for this major computing breakthrough. Initial efforts for this work were funded by NNSA's Advanced Simulation and Computing Program and DOE's Office of Advanced Scientific Computing Research. Further funding was provided by Livermore's Laboratory Directed Research and Development Program.

Strong Tools, Easy to Use

ROSE is unique on several fronts. Only ROSE offers such a rich set of analysis, debugging, and transformation capabilities that even novice software developers can build their own expert tools. "What ROSE does is convert the user's source code into an intermediate representation to encapsulate complex compiler knowledge in a form that can easily be accessed and manipulated



Development team for ROSE (from left): Peter Colllingbourne, Martin Bauer (formerly of Livermore), Thomas Heller (formerly of Livermore), Robb Matzke, David Hamilton, Chunhua Liao, Andreas Saebjornsen, Daniel Quinlan, Jeffrey Keasler, and Thomas Panas.

More Accessible

by nonexperts," explains Dan Quinlan, who led the project. "The developer can then build customized tools using ROSE to analyze that code for bugs, security problems, inefficiency, or poor performance—basically, any glitches an expert might find during manual inspection but in a much shorter time frame."

Beyond this, more advanced ROSE users can create compilerlike tools specific to their individual needs with an easy interface. For example, when a program fails and no reason is given, a developer may not quickly find the cause in the source code. Using ROSE, however, a developer could write a tool that adds itself to the source code to perform self-diagnosis. "That is, a developer could annotate the source code with just a few lines so that when the program fails, it fails with a graceful error message, relaying exactly what went wrong and where it went wrong," says Thomas Panas, a member of the ROSE team.

The ability to directly optimize one's own source code is especially significant. "All modifications to a user's code are performed through an easy interface," says Quinlan, "so a user never needs to touch or understand the underlying sophisticated compiler technology that makes the application work. The user puts in source code, ROSE works on it in the context of the same source code, and then ROSE generates back improved, compiler-ready source code."

This new source-to-source capability is a strong draw to ROSE users. It allows them not only to be in control of their programs but also to develop and apply various cutting-edge optimizations regardless of platform. Without this tool, developers are forced to rely on compilers to optimize their code or have the experts do it for them.

Free and Easy: Open for Business

The open-source ROSE compiler software is available to use at no cost on the project's Web site (www.rosecompiler.org). Software developers can quickly leverage compiler technologies to build and perfect their own tools, allowing them to debug, optimize, and transform their source code as needed. In addition, the Web site content is continually updated, and automated messages are distributed to users so that the most recent versions of ROSE are available. Enhancements for ROSE developed by collaborators are added to the software for others to use, and ROSE tests itself robustly each night.

With the open-source ROSE compiler infrastructure, computer programmers and software developers can build their own debugging, analysis, optimization, and transformation tools to quickly, efficiently, and inexpensively improve and compile their source code.

The documentation on the Web site includes an installation guide, a developer's guide, a user manual, and nearly 5,000 HTML pages of programmers' references. An extensive tutorial provides users with more than 50 examples of application scenarios. "Compiler expertise is continually added into the infrastructure," says team member Chunhua Liao. "It is a truly open infrastructure, one with an excellent development, testing, release, bug-tracking, and collaborative environment."

ROSE has already shown a strong ability to leverage the power of supercomputing technology. Future applications of ROSE are limited only by the imagination of developers using the software's public interfaces.

—Jason Carpenter

Key Words: binary analysis compiler, compiler infrastructure, program analysis, R&D 100 Award, ROSE, source code optimization, source code transformation, source code translation, source-to-source.

For further information contact Dan Quinlan (925) 423-2668 (quinlan1@llnl.gov).

Restoring Sight to the Blind

MILLIONS of people worldwide suffer from ocular diseases that degrade the retina, the light-processing component of the eye. As the population continues to age, the number of Americans blinded by age-related macular degeneration and inherited retinal disorders such as retinitis pigmentosa will increase. A retinal prosthesis can be used to treat blindness caused by these diseases. However, no company in the world has obtained regulatory approval to market a retinal prosthesis.

In collaboration with four other national laboratories, four universities, and one industrial partner, Livermore scientists have developed the first long-term retinal prosthesis that can function for years inside the harsh biological environment of the eye. The device, called an artificial retina, uses application-specific integrated circuits for transforming digital images from a camera into electric signals in the eye that the brain can use to create a visual image.

In 2004, the team was established through a Cooperative Research and Development Agreement with the mission of developing the world's most advanced high-density microelectronic–tissue prosthesis for imaging. This year, the team won an R&D 100 Award for the second-generation technology. In clinical trials of patients with vision loss, the patients successfully identified objects, increased their mobility, and detected movement using the artificial retina. Livermore team leader Satinderpall Pannu says, "The artificial retina has become the state of the art in visual prostheses and will enable blind individuals to accomplish things they have not dreamt were possible."

System Specs at a Glance

Patients afflicted with retinitis pigmentosa or age-related macular degeneration lose their ability to perceive light when the disease destroys the retinal photoreceptor layer. To restore sight in these patients, the artificial retina system converts images from a digital camera into controlled electrical impulses that stimulate the remaining bipolar and ganglion cells. The brain perceives patterns of light spots corresponding to the stimulated electrodes.

The artificial retina system includes a tiny video camera and transmitter mounted in sunglasses, with a small visual processing unit and battery pack worn on a belt. The camera captures an image and sends it to the visual processing unit, which converts the image to an electronic signal and sends it to the transmitter. The retinal implant receives this signal via wireless transmission and encodes it into specific patterns of stimulation pulses, which are conducted through a tiny flexible cable to an electrode array. These pulses stimulate the retina and enable the brain to perceive patterns of light.

The artificial retina development team at Livermore: (from left) Erika Fong, Emil Geiger, Satinderpall Pannu, Maxim Shusteff, Kedar Shah, Terri Delima, Julie Hamilton, and William Benett. (Not pictured: J. Courtney Davidson and Phillipe Tabada.)

Seeing Results

In ongoing clinical trials, human subjects using the artificial retina successfully identified the position and approximate size of objects, and detected movement of nearby objects and people. Objects were recognized within 2 to 3 seconds, and the device's

with an Artificial Retina

The artificial retina can function for years inside the harsh biological environment of the eye.

second-generation 60-electrode prosthesis showed improved image resolution over the first-generation 16-electrode prosthesis.

The prosthesis is now of sufficient resolution to allow recognition of doors, windows, edges, low-lying branches, and the square on a basketball backboard. Preclinical testing is under way of an implant with more than 200 electrodes, which will further improve a patient's mobility and object recognition. Additional research and development will produce artificial retinas with more than 1,000 electrodes, which potentially will allow patients to recognize faces and read.

The team's artificial retina is the only retinal stimulator in large-scale, long-term clinical trials. The device has a fully portable external system, and the implant can withstand daily use for many years. Patients in clinical trials have used the artificial retina system outside clinical settings—both at home and in public. In contrast, all competing retinal stimulators have been used for only short-term research that restricted subjects to a clinical setting. In addition, competing retinal stimulators use polymers to protect their microelectronics, resulting in implants that will function for just weeks to months if used daily. The artificial retina, however, with its metal–ceramic biocompatible electronics package is designed to last more than five years with daily use.

"Our implantable technology allows microelectronics to be placed safely within the eye without damaging the biological tissue," says Pannu. "The microelectronic system can send and receive information, opening the window to a number of therapeutic and diagnostic modalities. Eventually, a nanoelectronic system will be possible."

Foresight

Technology used in the artificial retina could conceivably be adapted to help patients with spinal-cord injuries, Parkinson's disease, deafness, and many other neurological disorders. For example, the technology may be adapted for existing cochlear implant systems to improve hearing, for spinal-cord stimulators to treat pain, for deep-brain stimulators to help control tremors, and for sensors to control prosthetic limbs or mobility aids. The same microelectronic system may also be modified to interface with other cell types such as plants and bacteria, which means it could ultimately be used for a variety of different applications including environmental cleanup and countering bioterrorism. "This strategy may be adapted for many applications," says Pannu. "We have just begun to look at the tip of the iceberg."

—Kristen Light

Key Words: age-related macular degeneration, artificial retina, blindness, ocular disease, R&D 100 Award, retinal implant, retinal degeneration, retinitis pigmentosa.

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Eradicating the Aftermath

DECADES after armed conflicts end, land mines continue to maim and kill thousands of innocent civilians. Today, 79 countries are plagued by mines buried under thousands of square kilometers of land, and most of these countries possess limited resources to remove them. The use of metal detectors and the manual prodding of soil remain the most trusted demining techniques, but they are hindered by false positives and are time-consuming, costly, and dangerous. In fact, for every 1,000 to 2,000 mines cleared using conventional techniques, one deminer is killed or maimed.

A safer method that would reduce the number of false positives and the time and cost of demining operations has long been needed. To meet this need, a team of Lawrence Livermore engineers led by Christine Paulson and Kique Romero, together with colleagues at First Alliance Technologies, LLC, in San Ramon, California, and Hystar Aerospace Corporation in Vancouver, Canada, has developed the land mine locator. The developers received an R&D 100 Award for this innovative technology. Initial work was funded by Livermore's Laboratory Directed Research and Development Program.

The land mine locator is an aerial detection system. The system is equipped with Livermore's LANDMARC (land mine detection advanced radar concept), which features an ultrawideband radar-sensing technology called iRadar and tomographic algorithms that provide three-dimensional subsurface images. LANDMARC is deployed on the remotely operated Hystar aerial platform, thereby reducing the time and cost of demining while significantly improving the safety of personnel and equipment.

Land Mines Are Long-Lived

Land mines are explosive devices placed in the ground and triggered by mechanical or electronic proximity sensors. After conflicts cease, unexploded land mines can remain intact for decades, killing and maiming civilians, impeding reconstruction efforts, and rendering agricultural lands useless. The *Landmine Monitor Report 2008* assesses that many thousands of square kilometers of land are contaminated by up to 100 million mines and other explosives. In 2007, about 1,400 people were killed and 4,000 injured by mines or other explosive remnants of war.

An estimated 100,000 mines are removed each year. At that rate, clearing 40 to 50 million mines would require 450 to 500 years, assuming no new mines are laid. However, the pace of mine removal is far slower than the rate at which new mines are being placed.

According to Paulson, current demining methods are decades old and are extremely tedious because metal detectors cannot discriminate metallic mines from innocuous metallic clutter. Some antipersonnel mines are mostly plastic except for small metal parts. Detecting these metal parts requires the metal detector's sensitivity to be turned up. As a result, most "mines" turn out to be harmless objects such as bottle caps, bullet casings, nails, or tin cans.

Development team for the land mine locator at Livermore: (front row, from left) Sean Lehman, Benjamin Fasenfest, Noel Peterson, Christine Paulson, Kique Romero, Pat Welsh, Bob Yamamoto, and Dave Chambers; (back row) Jim Zumstein, Brian Guidry, Mark Vigars, Philip Top, John Parker, Garth Pratt, Steven Bond, Greg Dallum, Peter Haugen, John Chang, John Breneman, and Matthew Breneman. (Not shown: Steve Azevedo, Christopher Gardner, and Jae Jeon.)

# of War

Lead engineers Christine Paulson and Kique Romero demonstrate the iRadar array at Livermore's inert mine test pit.

Demining teams typically uncover 100 to 1,000 innocuous metal objects for each mine found.

Two Technologies Combine

For more than a decade, Livermore researchers have been working on applying their patented ultrawideband technology to the worldwide problem of demining. The iRadar sensor is compact, low power, inexpensive, and unusually versatile. The sensor can send out extremely short electromagnetic pulses over an exceptionally wide range of frequencies, permitting much finer resolution of materials than other sensing systems.

Livermore's LANDMARC technology consists of an array of lightweight, ground-penetrating iRadar sensors and a signal-processing "engine" that detects and maps land mines in three dimensions. (See the figure above.) In this way, pipes can be distinguished from rebar, rebar from land mines, and land mines from clutter in general.

The land mine locator combines LANDMARC with the revolutionary Hystar helium-filled aerial platform, which can cruise at 72 kilometers per hour. The platform can also rotate 360 degrees while hovering or in directional flight. The 12-meter-diameter unit uses a reversible fan propeller at its center to ascend and descend, and jet engine propellers on its rim to move forward, backward, or sideways and to spin in place.

Hystar's telescoping mast lowers a sensor bar on which individual iRadar units are secured. The sensor bar typically hovers between 1 and 2 meters above the ground. An onboard central control unit handles power, sensor coordination, and data acquisition.

Operators on the ground in a mobile base-station vehicle wirelessly control the land mine locator. The raw data collected from the iRadar array are entered into a Livermore software application developed specifically to help detect and precisely locate land mines during demining operations.

Technology Soars over Alternatives

Paulson notes that several alternative technologies have been studied for mine detection, including ground-penetrating radar and mechanical demining vehicles that till the soil. "However, each has had significant drawbacks," she says. Unlike other methods, the land mine locator uses a remotely operated aerial platform, allowing mine detection to be performed without placing personnel or equipment in danger. Other potential applications for the land mine locator, according to Romero, are the detection of roadside bombs and improvised explosive devices, and the nondestructive evaluation of roadways, bridges, and buildings.

With the land mine locator in use, the world will at last have a safer method to detect mines. As a result, nations will be able to confidently reclaim millions of square kilometers from this long-lasting scourge of war.

—Arnie Heller

Key Words: demining, Hystar, iRadar, LANDMARC, land mine locator, R&D 100 Award, ultrawideband radar.

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Compact Alignment for

AS the idiom says, necessity is the mother of invention, which is exactly what led Livermore physicist and optical engineer Mike Rushford to develop the laser beam centering and pointing system (LBCAPS). His inspiration was the Advanced Radiography Capability (ARC) System, a petawatt-class quad of laser beams used at the National Ignition Facility (NIF) to diagnose the compression and ignition of a target during a shot.

"Each of ARC's beams must be pointed parallel to a specific input axis and centrally focused to safely reach the target," says Rushford. Previous instruments to ensure this accuracy required two separate sensors, two cameras, and various pieces of equipment in between. "However, where ARC is located on NIF," says Rushford, "space doesn't exist for a conventional system. We needed something smaller, cheaper, and with fewer cameras because of ARC's proximity to the main chamber and the risk of damage that might require system replacement." The result is a 17.8-centimeter-long cylindrical tube with one bifocal lens that images both the centering and pointing information onto one camera, cutting the cost of beam alignment in half. Rushford received an R&D 100 Award for his invention.

Physicist and optical engineer Mike Rushford developed the laser beam centering and pointing system.

Aligning the Beams

Precisely aligning a laser beam involves adjusting the beam's position within the component apertures through which it passes, as well as sending the beam in the correct direction toward the target. Basic geometry tells us that two points make a line. To achieve alignment, therefore, the beam must intercept two fixed image points in space. The first point determines if the beam is centered in its path, while the second determines if the beam is pointed in the right direction. In conventional laser-beam alignment systems, a sensor is needed at each alignment point to relay that information to the beam control system. These two alignment sensors can be mounted separately, each with its own camera, or as a single optic system and camera, in which case a centering lens is exchanged for a pointing lens.

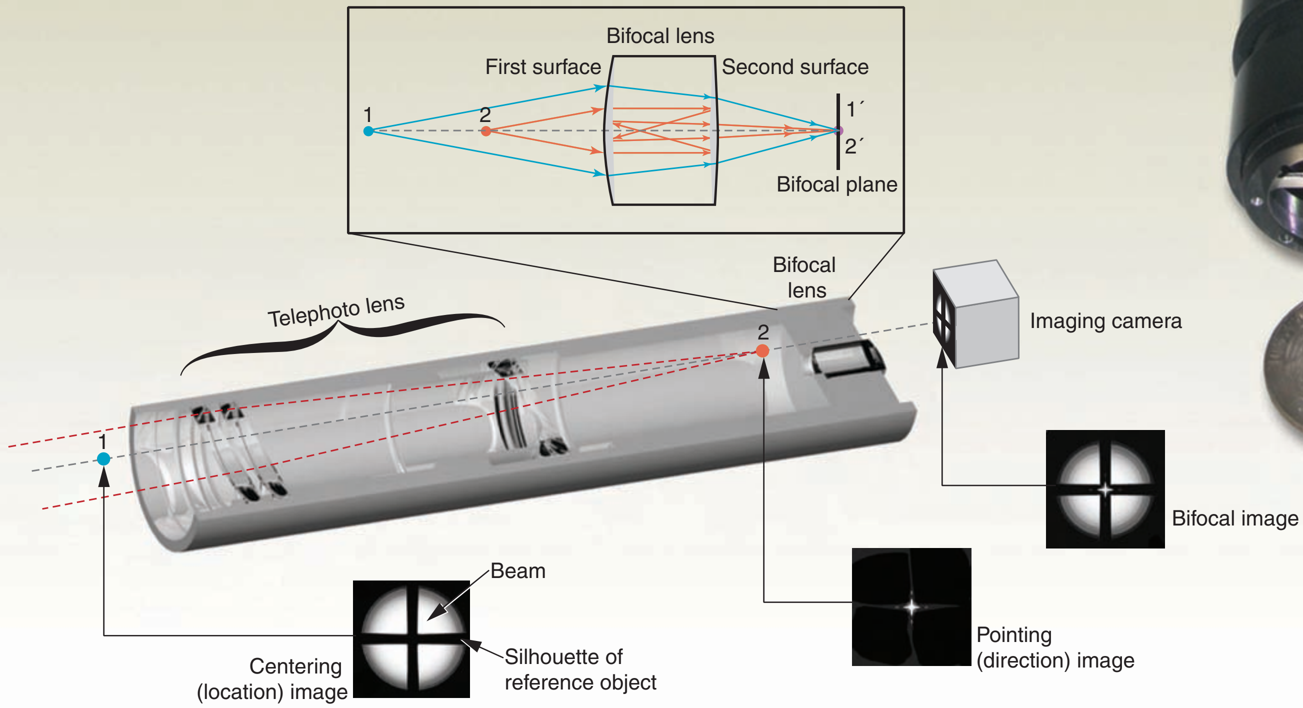
In one mechanically simple optic tube, LBCAPS performs the work of both sensors. It uses a single bifocal imaging lens to view both points simultaneously, combining and transmitting their images to one camera. The image contains both the centering and pointing data needed to align the beam. Because LBCAPS combines two alignment sensors in one, it cuts the cost of alignment components in half and saves precious space and computing resources. In addition, LBCAPS is monolithic, formed in a single piece, with no moving parts, which provides substantial advantages in stability and repeatability over conventional alignment systems that have two separate sensors mounted on an optics table.

How It Works

The rigidly mounted LBCAPS tube contains a three-element telephoto lens and a two-surface bifocal lens, whose two focal lengths allow it to produce images of both near and distant objects. The laser beam entering LBCAPS backlights a crosshairlike reference object near the first element of the telephoto lens, forming a silhouette. (See the figure on p. 19.) The telephoto lens and the bifocal lens together image the reference object and the beam onto the camera (see blue lines in the inset figure). The resulting combined image shows the beam's centering location relative to the reference object.

As the beam travels through the tube, the telephoto lens focuses the beam near the bifocal lens. Both surfaces of the bifocal lens have a 30 percent reflective coating, which refracts the light path at a different angle as it goes through the first surface, reflects it back at

Diagnostic Laser Beams



The laser beam centering and pointing system combines two laser beam alignment sensors—centering and pointing—into one. The dual-imaging bifocal lens images both the "centering" and "pointing" data onto the camera.

the second surface, reflects it again at the first surface, then finally refracts it once more at the second surface (see ray path 2 to 2´ in the inset figure). The position of the focus spot in the resulting image on the camera reveals the beam's pointing direction.

Setting the focal lengths and positions of the telephoto lens and adjusting the curvatures and thickness of the bifocal lens allows for optimal magnification of both the centering and pointing images for a particular application. Because beam centering and pointing can be monitored relative to the backlit fixed reference object, LBCAPS is self-referencing and does not depend on the location of the camera for beam alignment. Consequently, centering and pointing references are not lost if a camera has to be replaced.

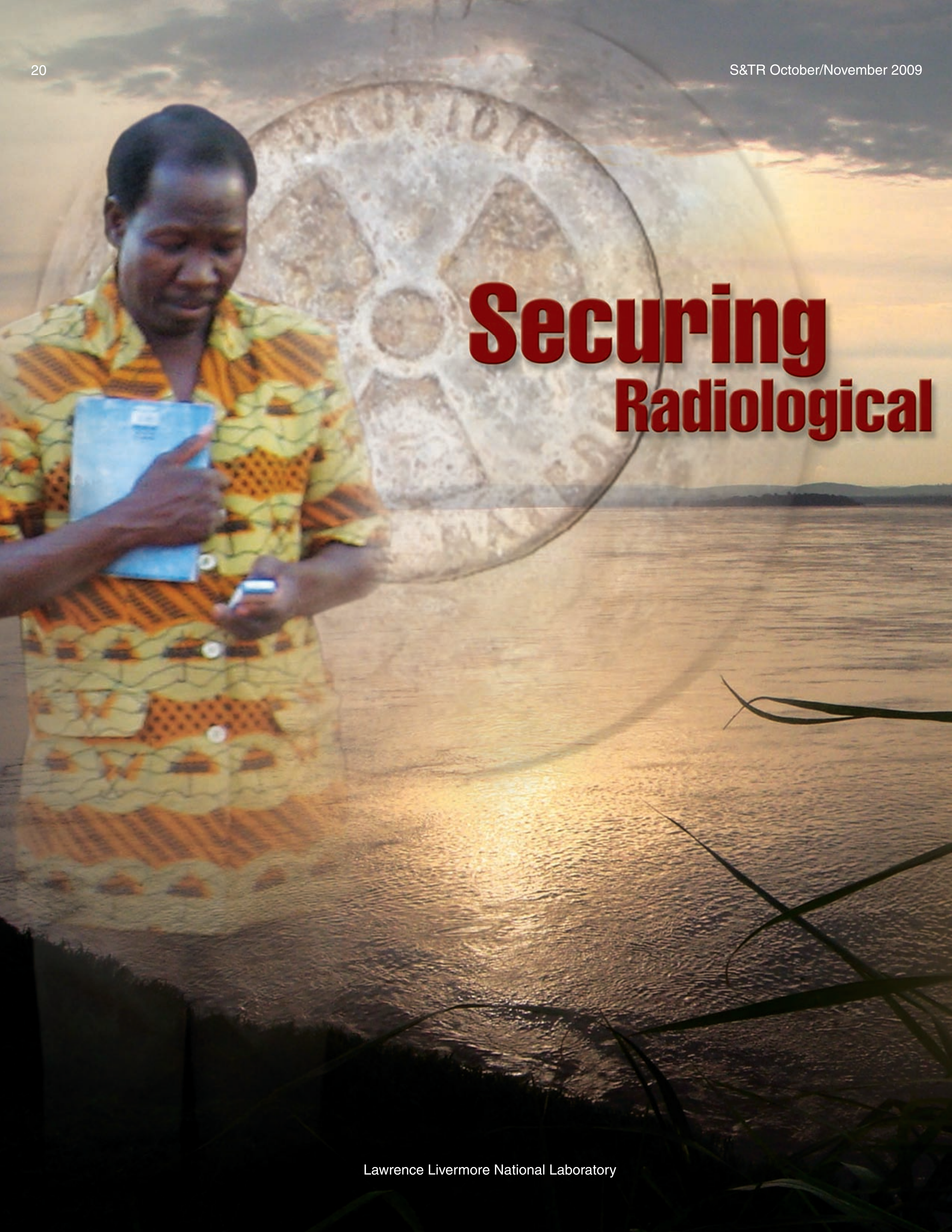
Future Applications

This compact, reliable, and cost-effective system is being tested for the Laboratory's Mercury laser project and the Livermore-developed extreme x-ray system used in nuclear materials detection. In addition, incorporating a stable local reference for both centering and pointing could be beneficial in many industrial high-power laser applications, such as laser welding and cutting, and in scientific experiments to explore the nature of atoms and molecules. "LBCAPS is effective and provides huge advantages in stability and repeatability over conventional alignment systems," says Rushford.

—Cindy Cassady

Key Words: Advanced Radiography Capability (ARC), bifocal lens, imaging camera, laser beam alignment, laser beam centering and pointing system (LBCAPS), National Ignition Facility (NIF), R&D 100 Award.

For further information contact Mike Rushford (925) 424-6349 (rushford1@llnl.gov).



Securing Radiological

Sources in Africa

Safeguarding nuclear materials at civilian sites in Africa is part of the business of the National Nuclear Security Administration's Global Threat Reduction Initiative.

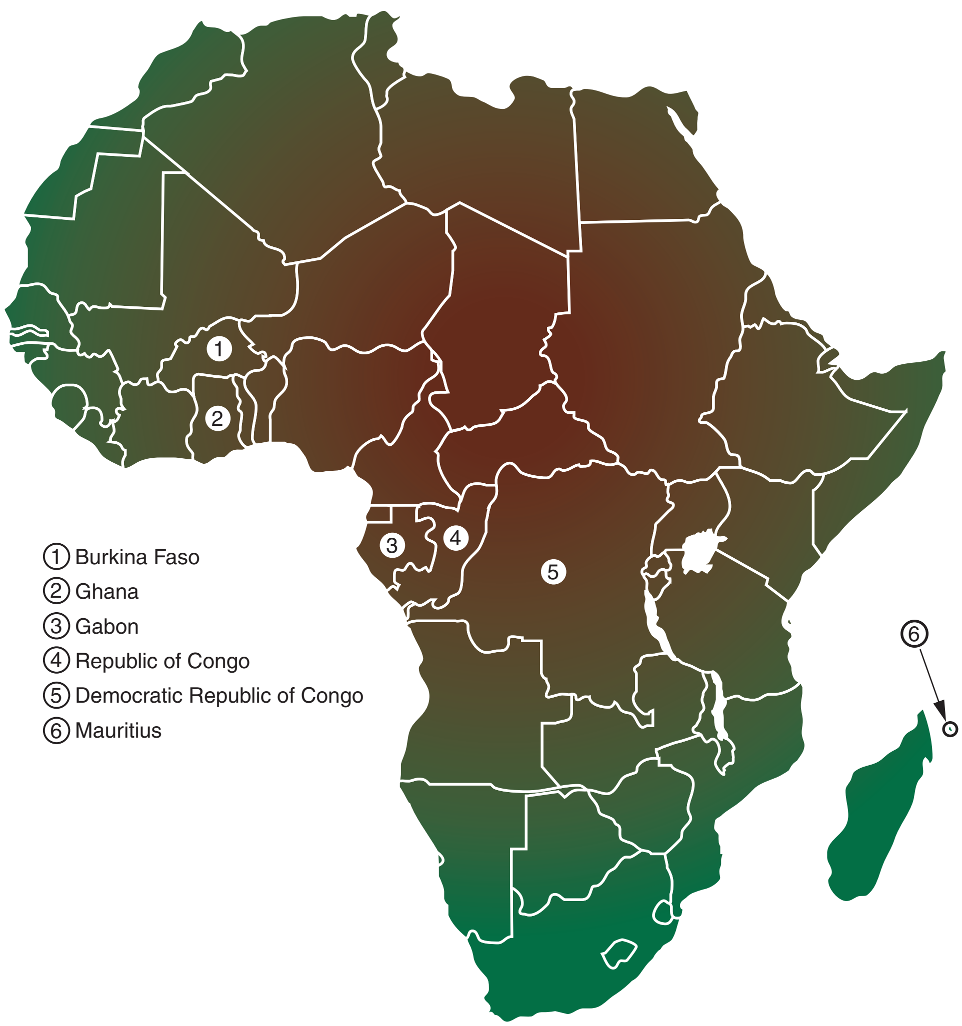
KEEPING radiological materials out of the hands of potential terrorists and other adversaries has long been a goal of the Department of Energy's National Nuclear Security Administration (NNSA). NNSA's Global Threat Reduction Initiative (GTRI) is tasked with reducing and protecting vulnerable nuclear and radiological materials at civilian sites worldwide. GTRI works closely in this endeavor with the International Atomic Energy Agency (IAEA), which issues international standards and guidance on how to safely control radioactive sources. Lawrence Livermore, Sandia, and Pacific Northwest national laboratories, among others, have been active contributors to GTRI for years.

According to Phil Robinson, who is NNSA's GTRI regional coordinator for Africa and the Middle East in Washington, DC, more than 120 countries worldwide are participating in GTRI efforts. "Work started in Russia in the 1990s and branched out to other former Soviet Union republics," says Robinson. "Then we began efforts to protect radiological sources in ever-larger concentric circles, including Africa, South America, and the Far East." GTRI provides international support in the form of equipment and funding (for low-income countries) so that each country's own national programs can secure their nuclear and radiological materials.

The kinds of radiological materials that typically make the news are weapons-grade plutonium and uranium or fuel from nuclear power plants. However, radiological sources come in all shapes and sizes. Millions of radioactive sealed devices are used worldwide for legitimate and beneficial commercial endeavors such as cancer treatment, food and blood sterilization, oil exploration, remote electricity generation, radiography, and scientific research. To prevent radiological materials from being diverted for malicious use, countries must keep these sources in secure locations and maintain them under regulatory control.

Since the early 1990s, NNSA and its national laboratories have focused on three goals: to convert, remove, and protect nuclear and radiological materials. Converting materials entails developing

Lawrence Livermore has worked to protect civilian radiological sources in six African countries.



low-enriched uranium fuels to replace the highly enriched uranium fuels currently used in many research reactors. Each reactor that is converted, or where possible shut down, eliminates a source of bomb material. Removing and disposing of excess nuclear and radiological materials from civilian sites reduces the risk of such materials falling into the hands of potential terrorists. Protecting high-priority nuclear and radiological materials from theft and sabotage is accomplished by improving security at civilian sites.

"The countries of Africa present some serious challenges for us," says Robinson. "In the former Soviet Union, a single overarching infrastructure was responsible for nuclear weapons, reactors, and other radiological materials. In Africa, 56 countries each have their own regulatory organizations."

From IAEA to Livermore

Health physicist Carolyn Mac Kenzie leads the Livermore team, which includes Con Turner, a specialist in physical protection, and Tim Horgan, who is responsible for arranging security upgrade contracts with local African vendors. Both Turner and Horgan spent several years helping to secure radiological sources in the former Soviet Union. (See *S&TR*, December 2007, pp. 4–10.)

Mac Kenzie, a longtime Laboratory employee, spent three years at the IAEA in Vienna, Austria, and another year on assignment at NNSA's GTRI headquarters in Washington, DC, as a Livermore contractor. She returned to the Laboratory in October 2007. While in Vienna, she led the IAEA Orphan Source Search and Secure Program and worked in more than 35 countries to establish strategic plans for locating and securing orphan and legacy radiological sources.

An orphan source is typically a small volume of radioactive material that may be in an uncontrolled situation, leaving it vulnerable to theft. For example, the responsible party for an orphan source may not be readily identifiable, or the security of a source may not be assured. Another situation that creates an orphan source is when the responsible party is not licensed to possess it.

Orphan radiological sources can be found in all sorts of places. For example, a measuring device containing radioactive materials may be disposed of as scrap metal and found at a metal recycler. Or, a gauge containing radioactive material used in road or building construction may be discarded and found on the side of a road or in a river. Also, sealed radiological sources previously used in oil and gas exploration may be found abandoned and forgotten in old warehouses. Many developing countries simply do not have radioactive-waste storage facilities, in which case local options do not exist for disposing of disused sources. Orphan sources abound and are often the trickiest to locate.

"Orphan sources are a serious concern, because they are outside of regulatory control," Mac Kenzie says. "The IAEA Orphan Source Search and Secure Program focused on large, highly radioactive sources that could seriously injure or kill people. The program first focused on republics of the former Soviet Union and then moved into the Balkans, China (in preparation for the 2008 Olympic Games), and Africa."

When Mac Kenzie left the IAEA to work at GTRI in Washington, DC, she continued her efforts to locate and secure sources in Africa. Since returning to the Laboratory, her team has worked through GTRI in six countries: Burkina Faso, Gabon, Ghana, Democratic Republic of Congo, Mauritius, and Republic of Congo. "We had started a project in Madagascar but a coup derailed our work," says Mac Kenzie. "We are awaiting more peaceful times before returning."

Into a New Country

Mac Kenzie's team follows a well-established process when beginning work in a new country. The first step is coordinating with the U.S. Embassy to gain their approval and cooperation. "We sometimes meet with the ambassador of the country," says Mac Kenzie, "and the economic officer may participate in our meetings with the country's ministries."

The Livermore team, plus GTRI's Robinson or NNSA representative and Sandia employee Michael Itamura, meet with the staff and leadership of the relevant ministries. Together, this team gets "the lay of the land" during the weeklong initial visit to the country. The team works closely with the country's regulators to locate and visit sites with large radiological sources, such as teletherapy machines used in cancer treatment, industrial irradiators, or instrumental calibrators.

Some radiological sources are well known to the team before they arrive in a country. Burkina Faso has an irradiator for sterilizing tsetse flies, which is helping to rid Sub-Saharan Africa of sleeping sickness in both people and livestock. (See the box on p. 25.) Mauritius currently has an inactive irradiator for Mediterranean fruit flies (medflies) but is obtaining a new one, for which it will need a radioactive source. Ghana has a food irradiator for promoting longer shelf life and is in the process of obtaining a new radioactive source for it. A hospital in Gabon has a machine for delivering radiation to treat cancer, but the machine's radioactive source is depleted. The depleted source will be secured in place, and the country hopes to replace it in the future.

The team also visits locations with large accumulations of smaller sources, such as radioactive-waste storage facilities, mining sites, ports, and oil-drilling regions. Gauges and well-logging devices containing radioactive materials are more commonly present in these locations. In addition, if a country has a research reactor facility, the team may offer security upgrades for the facility.

A variety of orphan radiological sources used in mining have been found in the six African countries where Livermore has worked.

The IAEA has established various threshold levels for different radionuclides. Consequently, not every radioactive source needs the same degree of attention. Radionuclides of particular interest are americium-241, which is widely used in industrial gauges; plutonium-238 and -239, which are well-known fissile materials; and californium-252, which is used in downhole well logging for oil exploration. Other common radionuclides include radium-226, which was used in medical applications in the past; cesium-137, which is found in moisture and density gauges, calibration devices, and industrial irradiators; and cobalt-60, which is used in radiation treatment for cancer. Also of interest are iridium-192, an industrial radioisotope used to locate areas of weakness in metal pipes, and strontium-90, which is used extensively as a radioactive source in radioisotope thermoelectric generators for powering lighthouses and in radiotherapy for some types of cancer.

Inventorying can be a challenge. "One country thought it had about 100 sources in their inventory, but they in fact had close to 400," says Mac Kenzie. Often the problem is orphan sources. Some countries do not have regulators or regulations in place, or they have people who are still new to their jobs. "New regulators may understand the safety concerns of nuclear sources but are not fully aware of the threat of theft and the need for physical protection," says Mac Kenzie.

Developing Indigenous Expertise

To assist countries with their own search efforts, GTRI offers a one-week "Search and Secure" workshop, which teaches local officials how to search for, locate, and identify orphan sources. Search equipment is provided based on a country's needs. The workshop includes instruction on organizing and implementing a search for orphan sources, use of search equipment, and packaging and transportation of orphan sources to secure storage facilities. The workshop curriculum includes hands-on field training and exercises. GTRI may also offer workshop participants help in developing verified inventories by visiting suspected orphan-source locations in their country.

GTRI's Search and Secure project was launched in 2004 and is closely coordinated with IAEA to avoid duplicating efforts and to maximize assistance in each country. A goal is to help countries develop their own indigenous capabilities for assessing orphaned and disused radiological sources. The project was first deployed in the republics of the former Soviet Union. Since 2004, equipment has been deployed in 30 countries, approximately 550 people have been trained, and thousands of orphan sources have been found.

Safe and Secure

"When working in a particular country, local officials will take us to where radiological materials are located," says Turner. "If the quantities of radionuclides present in these materials exceed the established thresholds, my job kicks in." Turner's task is to assess the security of such facilities. For example, cobalt-60 may be found in a teletherapy bunker. (In the U.S., cobalt-60 has been replaced with accelerators for cancer treatment.) "We work from the source outward, examining the security of the source itself, the teletherapy bunker, and then the hospital," says Turner. "When we approach security from the material of interest outward and concentrate security elements close to the

The National Nuclear Security Administration's Global Threat Reduction Initiative (GTRI) offers a "Search and Secure" workshop in participating African countries. (left) A workshop student is trained to use a piece of equipment. (center) A GTRI staff member provides instruction in the field. (right) A student searches for a radioactive source hidden in the field by an instructor.

target material, we can protect radioactive materials not only from outsiders but also from insiders such as employees."

Several ways exist to reduce the threat of diversion of radioactive materials. They include detecting intrusion, such as with motion detectors; assessing intrusions with cameras; installing cages or tie-downs to delay adversaries until appropriate security forces can respond; and improving response capabilities with radios and other communication equipment. The goal is for all security upgrades to be simple, low-tech, locally available, and easy to maintain.

Once radiological sources have been inventoried in a country and Turner has

A newly installed alarm system sends a message to a security staff cell phone. Better communication equipment for security personnel is just one example of the improvements that help to secure radiological sources.

Ridding the Continent of Tsetse Flies

African countries operating tsetse fly irradiators must ensure the safety and security of these radioactive sources, and irradiators have proved to be the best method of eradicating the tsetse scourge. Therefore, these countries have a particular interest in cooperating with the International Atomic Energy Agency and the National Nuclear Security Administration's Global Threat Reduction Initiative (GTRI).

For centuries, the tsetse fly has been the bane of both people and livestock in Central Africa. Trypanosomiasis—the disease spread by 22 species of the tsetse fly and commonly known as sleeping sickness or nagana—is still widespread, especially in Sub-Saharan countries. These large biting flies feed on the blood of vertebrate animals and are the primary transfer agent of trypanosomes. Tsetse flies make livestock production—cattle, sheep, goats, and horses—difficult or impossible throughout large areas of Africa. Agriculture in these areas must function without the many benefits of livestock, such as crop byproduct utilization and manure production. The human population must also do without meat and milk.

Male flies are sterilized with doses of radiation in this tsetse fly irradiator in Burkina Faso.

Until recently, the two most common methods for controlling the tsetse fly have been the spraying of insecticides and baiting and trapping the flies, both of which are costly in chemicals and personnel. Today, the sterile insect technique is the most promising solution. Vast numbers of tsetse flies are reared in "fly factories," and the males are sterilized with carefully controlled doses of cesium-137 gamma radiation. The gamma radiation is sufficient to induce sterility but does not reduce the treated insects' ability to fly, compete with native males, or mate. Mating between the sterile released insect and the native population produces no offspring. Females can mate only a few times in their life, and generally mate only once. If enough sterile males are released, the tsetse population eventually dies off. Burkina Faso, a small, remote, sparsely populated country, now has a fly irradiator that generates income. "Keeping the irradiator operating and safe is essential," notes Tim Horgan, Livermore's contracting officer for GTRI, which helps countries such as Burkina Faso protect their civilian nuclear and radiological materials.

On the island of Zanzibar, which is part of Tanzania, the last tsetse fly was seen in the mid-1990s thanks to efforts to eradicate the flies through radiation-induced sterilization. Routine blood samples taken from cattle have tested negative for trypanosome parasites. Milk production has tripled, local beef production has doubled, and the use of animal manure for crop farming has increased fivefold, according to the Ministry of Agriculture of the island.

evaluated the existing security measures, the team produces a Statement of Work that describes specific recommendations, ranging from moving or securing sources to building or improving storage facilities.

Local Responsibility

During that first weeklong visit to a country, Horgan begins to seek out local vendors who are qualified to undertake necessary security upgrades. As Livermore's contracting representative, Horgan is authorized by NNSA to commit funds and sign agreements, monitor progress of work, resolve agreement issues, and process invoices for payment.

Once a country's appropriate ministries have agreed to undertake the necessary security upgrades, Horgan begins the process of hiring local security firms to implement physical protection or move sources. He issues requests for proposals from local firms, reviews the resulting proposals with Turner, and then negotiates such

Livermore's Tim Horgan visits a source storage facility. (Opposite page, top) A local contractor tests security upgrades installed at a hospital. (Opposite page, bottom) Livermore's Carolyn Mac Kenzie and Zephrin Ouedraogo, a radiation protection regulatory authority in Burkina Faso, examine a tsetse-fly irradiator.

contractual terms as scope, schedule, and price. When an award is finalized, Horgan may authorize advance purchase of up to 100 percent of the equipment and materials. Labor costs are reimbursed after the work is completed.

While work is under way, Turner acts as the technical representative, resolving technical issues and reviewing the acceptability of contract deliverables. Once work is complete, Turner returns to the country to verify that all contract deliverables have been met.

GTRI hopes to begin cooperative work with many more African countries in the near future. According to Horgan, “All of the countries we have visited have been grateful for our help.” GTRI pays for ongoing support for three years but after that period has expired, the African countries agree to maintain and sustain the security devices and storage facilities. Says Mac Kenzie, “The participating countries understand that they hold ultimate responsibility for the safety and security of their radiological sources.”

—Katie Walter

Key Words: Africa, Global Threat Reduction Initiative (GTRI), orphan source, radiological source, search and secure.

For further information contact Carolyn Mac Kenzie (925) 422-7618 (mackenzie5@llnl.gov).

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

Awards

Lynford Goddard, a former postdoctoral researcher in the Laboratory's Engineering Directorate, was named a recipient of the **Presidential Early Career Award for Scientists and Engineers**. Goddard, who is now an assistant professor of electrical and computer engineering at the University of Illinois at Urbana-Champaign, was nominated for the presidential award by Diane Chinn, deputy division leader of the Engineering Technologies Division. The prestigious award is the highest honor bestowed by the U.S. government on young professionals in the early stages of their independent research careers.

Goddard joined the Laboratory after receiving his Ph.D. from Stanford University in 2005. While at Livermore, Goddard worked on two main research topics: photonic integrated circuits (PICs) for secure communications and photonic sensors for trace gas detection. The PIC project involved simulation, design, and testing of high-speed, all-optical logic and memory as well as developing measurement techniques for low-loss dielectric waveguides and turning mirrors. The gas sensor project focused on hydrogen detection with novel edge-emitting laser structure using palladium as a functionalized lateral surface coating. Both projects led to pending patents. Anantha Krishnan, Goddard's mentor at Livermore, says, "Lynford made outstanding and significant contributions to several programs relevant to national security and stockpile stewardship. He is currently continuing these critical collaborations with Laboratory staff members."

Dave Menshew, a science teacher at James C. Enochs High School in Modesto, California, and participant in the Laboratory's Teacher Research Academy, was named first-place recipient of the **2009 Genzyme-Life Technologies Biotech Educator Award**. Menshew was recognized for his work in establishing the nation's only four-year high school forensic biotech program. He completed four levels of study over four summers, which included the opportunity to work as a member of a research team and complete a six-week internship at the Laboratory. The **Biotechnology Institute** established the award to recognize leading high school educators who are bringing biotechnology to their classrooms.

Laboratory scientists and engineers, in tandem with Livermore's Industrial Partnerships Office (IPO) staff, captured two outstanding **partnership awards** and two outstanding **technology development honors** in the **Federal Laboratory Consortium's Far West Region** competition.

One of the Laboratory's two outstanding partnership awards went to a team led by **Morgan Burks** for developing GeMini, a portable gamma-ray spectrometer based on germanium technology. Small enough to fit in the palm of one's hand, this spectrometer is equipped with an innovative low-power, miniature cooling mechanism. (See p. 8.)

The second outstanding partnership award was received for the large area imager, a radiation detection technology that assists in locating illicit nuclear materials. Livermore researchers, including **Simon Labov** and **Karl Nelson**, worked with Oak Ridge National Laboratory and Science Applications International Corporation through funding from the U.S. Department of Homeland Security to deliver a commercial prototype. The large area imager's superior features include unprecedented sensitivity to weak sources, a minimum fivefold increase in searching range, and a 25-fold speedup in search time. **Catherine Elizondo** serves as IPO's business development executive for the GeMini and large area imager efforts.

The Advanced Vision Systems for Minimally Invasive Surgeries Project received one of the Laboratory's two awards for outstanding technology development. This effort led by Livermore **Stavros Demos**, whose project is part of the Laboratory's collaboration with the University of California at Davis Cancer Center, provides surgeons with a real-time view of critical tissue structure during gallbladder surgery. **Genaro Mempin** is the project's business development executive.

The Laboratory's second award for outstanding technology development was garnered by researchers who have been developing carbon nanotubes for water desalination and filtration. Members of the carbon nanotube team are **Olgica Bakajin**, **Aleksandr Noy**, **Jason Holt**, **Hyung Gyu Park**, and **Francesco Fornaseiro**. During their research, the team found carbon nanotube membranes demonstrated permeability that is significantly higher than conventional membranes, despite having smaller pore sizes. (See *S&TR*, January/February 2007, pp. 19–20.) The new technology offers several potential advantages over existing water filtration technology. **Ida Shum** is the project's business development executive.

Securing Radiological Sources in Africa

Millions of radioactive sealed devices are used around the world for legitimate and beneficial commercial uses such as cancer treatment, food and blood sterilization, oil exploration, remote electricity generation, radiography, and scientific research. The Global Threat Reduction Initiative (GTRI), sponsored by the National Nuclear Security Administration, is tasked with reducing and protecting vulnerable nuclear and radiological materials at civilian sites worldwide. After more than a decade of success in the republics of the former Soviet Union, GTRI branched out to South America, the Far East, and, more recently, Africa. Lawrence Livermore has worked in Burkina Faso, Democratic Republic of Congo, Gabon, Ghana, Mauritius, and Republic of Congo. GTRI is also working with other national laboratories and private contractors in an additional dozen African countries to better secure their radiological sources. Through GTRI, the Livermore team hires local contractors to install security upgrades, provide better communication equipment for security forces, and harden storage facilities.

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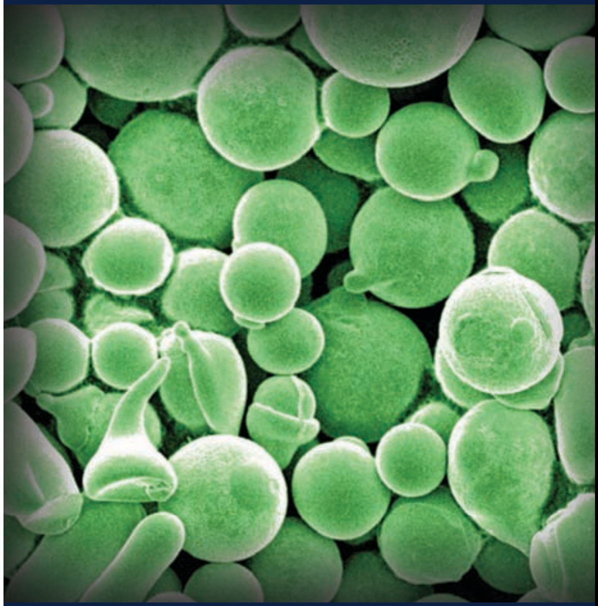
Coming Next Issue

Improved Materials to Protect Metals



Amorphous metal coatings provide the strength and corrosion resistance needed for Laboratory and military applications.

Also in December

- *Laboratory scientists are analyzing the feasibility of using nuclear explosives to divert asteroids on a collision course with Earth.*

- *Livermore is collaborating with 10 computing industry leaders to create Hyperion, a test bed for Linux cluster hardware and software technologies.*

- *An automated device separates viruses, bacteria, and genetic material from tissue samples for speedy identification.*

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