October 2004

Science & Technology REVIEW

National Nuclear
Security Administration's
Lawrence Livermore
National Laboratory

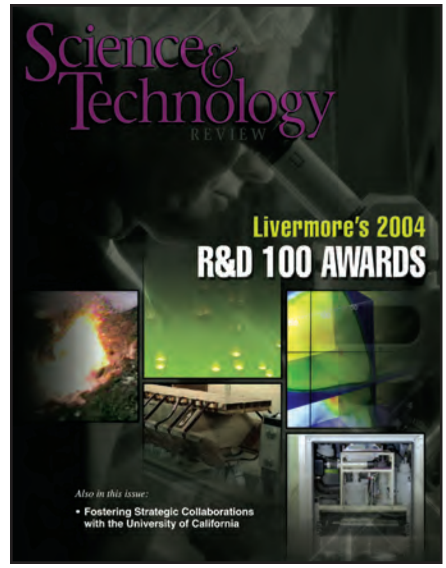
Livermore's 2004 R&D 100 AWARDS

Also in this issue:

- **Fostering Strategic Collaborations with the University of California**

About the Cover

This issue of *S&TR* highlights the Livermore technologies that received awards in *R&D Magazine*'s annual competition of the year's top 100 inventions. The cover shows the five award winners: (clockwise, from the far left) a demonstration of the solid-state pulsed-power laser for neutralizing land mines, cells treated with the siHybrid gene-silencing technology, an example graphic produced with Chromium software, a fully automated system for rapid detection of biowarfare agents, and an energy-efficient magnetically levitated train. Highlights of these technologies begin on p. 4. Since 1978, Laboratory researchers have won 102 R&D 100 awards.



Cover design: Amy Henke

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.

Please address any correspondence (including name and address changes) to *S&TR*, Mail Stop L-664, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, or telephone (925) 423-3432. Our e-mail address is str-mail@llnl.gov. *S&TR* is available on the World Wide Web at www.llnl.gov/str.

National Nuclear Security Administration

Prepared by LLNL under Contract No. W-7405-Eng-48

Science & Technology Review

October 2004

Lawrence Livermore National Laboratory

Contents

Commentary

2004 R&D 100 Awards

Features

Departments

S&TR Staff

S&TR, a Director's Office publication, is produced by the Technical Information Department under the direction of the Office of Policy, Planning, and Special Studies.

S&TR is available on the Web at www.llnl.gov/str.

Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

UCRL-TR-52000-04-10
Distribution Category UC-99
October 2004

Gamma-ray detector on Mercury voyage

Scientists and engineers from Lawrence Livermore, the Space Sciences Laboratory at the University of California (UC) at Berkeley, and the Applied Physics Laboratory at Johns Hopkins University designed a high-resolution gamma-ray detector for use on the Mercury MESSENGER spacecraft. MESSENGER (short for Mercury Surface, Space Environment, Geochemistry, and Ranging) was launched on August 3, 2004, and will conduct an in-depth study of Mercury, the planet closest to the Sun. Its voyage will include three flybys of Mercury in 2008 and 2009 and a yearlong orbit of the planet starting in March 2011. As it orbits the planet, MESSENGER will use the detector to measure characteristic gamma-ray emissions from Mercury's crust as well as solar winds and cosmic rays.

The Livermore team's role in the project was to ensure that the spacecraft's gamma-ray spectrometer could withstand the Sun's heat reflected from the surface of Mercury. To do that, the team combined a rugged, encapsulated germanium gamma-ray detector with a miniature cryocooler and a multilayered thermal shield. The cryocooler and shield maintain the detector at a temperature of less than 90 kelvins, ensuring that the spectrometer operates correctly.

The detector is based on technology originally developed by Lawrence Livermore and Lawrence Berkeley national laboratories for CryoFree/25—a handheld, mechanically cooled detector that can detect gamma rays from radioactive material. (See *S&TR*, September 2003, pp. 24–26.) The MESSENGER detector is cooled by a low-power, compact cryocooler, which eliminates the need for liquid nitrogen yet allows the detector to attain the high-level energy resolution needed for accurate measurements.

More information on the MESSENGER voyage is available online at messenger.jhuapl.edu.

Contact: Norm Madden (925) 423-1934 (madden8@llnl.gov).

Regional change in climate affected gorge formation

Livermore scientist Robert Finkel is part of a collaboration that is studying the geologic history of the Susquehanna and Potomac rivers to better understand how each river's gorge was formed. The team, which includes researchers from the University of Vermont, the U.S. Geological Survey, and the University of Maryland, is measuring the beryllium-10 content in bedrock terraces in these rivers, both of which drain into the Atlantic Ocean.

Comparing the two rivers may help scientists better understand how regional climate changes affect geologic processes. The Susquehanna has been glaciated, but the Potomac has not. Yet, each river has formed a steep bedrock gorge. The Susquehanna narrows as it travels south into Pennsylvania, forming the 5-kilometer-long, 1-kilometer-wide Holtwood Gorge. The Potomac River drops 20 meters as it passes over Great Falls, Virginia, through the 3-kilometer-long, 75- to 125-meter-wide Mather Gorge.

Finkel, who works in the Laboratory's Center for Accelerator Mass Spectrometry, analyzed the samples for beryllium-10, a rare isotope that forms when cosmic rays hit surface rock and sediment. Measuring the beryllium-10 content allowed the team to determine the age of each terrace and then calculate how quickly the rivers had cut through the bedrock.

The team's research indicates that a period of cold, stormy, and unstable climate, which began about 35,000 years ago, led to a pulse of incision, or rock cutting, in both rivers. This increase in the cutting rate created the steep bedrock gorges. Because the Holtwood and Mather gorges formed at about the same time and in the same manner, the researchers conclude that regional climate change, not simply glacial meltwater, caused the gorges to form. The team's results were published in the July 23, 2004, issue of *Science*.

Contact: Robert C. Finkel (925) 422-2044 (rfinkel@llnl.gov).

Sample size changes mechanical properties of metal

Livermore engineer Jeff Florando collaborated on an Air Force Research Laboratory project to develop a technique for more accurately measuring the mechanical properties of micrometer-size samples. In experiments with the new technique, the team found that reducing a specimen to a few micrometers (millionths of a meter) or less affects the mechanisms by which the sample deforms. The finding is important because micrometer-size materials are commonly used to miniaturize electronic devices and other equipment.

The team's technique combines a focused ion-beam microscope and a nanoindentation system to create micrometer-size samples and measure each sample's mechanical properties under compression. According to Florando, this technique can be used to create samples in almost any inorganic material. In characterization studies of nickel, the team found that the material's strength changes dramatically when the sample size is reduced.

The project, which was led by Michael D. Uchic of the Air Force Research Laboratory in Dayton, Ohio, was funded by the Air Force Office of Scientific Research, the Defense Advanced Research Projects Agency, the Department of Energy, and the National Science Foundation. Florando worked on this project when he was studying with William D. Nix of Stanford University. The team's research is presented in the August 13, 2004, issue of *Science*.

Contact: Jeff Florando (925) 422-0698 (florando1@llnl.gov).

Award-Winning Technology in the National Interest

LAWRENCE Livermore National Laboratory plays a vital role in our nation's security by ensuring the safety and reliability of U.S. nuclear forces and providing analyses and technologies to further international nonproliferation goals. Because of its capabilities, the Laboratory is also assuming important responsibilities in homeland security. The successes we've achieved in our national and homeland security programs are due, in large measure, to our focus on mission and the Laboratory's multidisciplinary approach to problem solving. Teams with expertise in physics, chemistry, computing, materials science, engineering, and bioscience work toward defined goals, developing innovative tools and technologies to accomplish their objectives. Many of the advances lead to unanticipated products that benefit scientific research, energy and environmental management, health care, and other areas where there are pressing national needs.

One indicator of Livermore's technological creativity is our success over the years in garnering R&D 100 awards. Each year, *R&D Magazine* announces its choice of the top 100 technological advances that contribute to a national need or improve a system or service in society. Livermore earned five of these prestigious awards this year, bringing the Laboratory's cumulative total to 102 awards. The breadth of Livermore's technical expertise is reflected in this year's winners, which include a pathogen detector for airborne releases of biological threat agents, a laser to neutralize land mines, software that integrates graphics applications, a safe, energy-efficient magnetically levitated train system, and a gene silencer that has potential in treating cancer and other diseases. Highlights of the five technologies begin on p. 4.

The Autonomous Pathogen Detection System (APDS), a follow-on to a pathogen detector that won a 2003 R&D 100 Award (see *S&TR*, October 2003, pp. 6–7), was honored for its ability to rapidly detect airborne releases of three types of biological threat agents—bacteria, viruses, and toxins. The APDS team included researchers from six Laboratory directorates. The two consecutive awards in pathogen detection underscore the important focus on protecting our nation from a possible bioterrorist threat and the vital contributions Livermore is making to meet this need.

The software program Chromium combines graphical data from networked desktop computers to create a seamless, single image. It not only advances parallel supercomputing capabilities, but it also fosters numerous parallel visualization projects at universities and private industries. This project highlights the value of partnering with other institutions. The Livermore team collaborated with two universities and a private firm to develop the software, and more than 21,000 copies of this open-source software have already been downloaded for use.

Inductrack, a magnetically levitated train system, could provide a solution to the nation's urban and intercity rail needs. Development teams from Livermore and General Atomics (GA) in San Diego share the award for Inductrack. GA has licensed the technology to develop a rail system for the U.S. Department of Transportation.

Technologies involving Livermore lasers have received many R&D 100 awards over the years. A novel system to uncover and neutralize land mines with a diode-pumped pulsed laser received a 2004 award. The technology for this laser originated from Livermore's solid-state heat capacity laser, which was designed to destroy mortars and missiles in short-range battlefield defense—a technology that was honored by *R&D Magazine* in 2002. (See *S&TR*, October 2002, pp. 8–9.)

Livermore's fifth R&D 100 Award was earned for a hybrid gene-silencing technology. Gene silencing by ribonucleic acid (RNA) interference keeps detrimental proteins from harming the body by limiting their expression. The new hybrid molecules, which last 10 times longer and cost half as much as conventional molecules, could allow physicians to provide an effective treatment for cancer and other human diseases.

These awards make clear the importance of Livermore's many connections with the broad scientific and technological community as we pursue research and development to strengthen national security. Many of Livermore's 102 R&D 100 awards have been attributable to successful partnerships with universities, other national laboratories, and private industry. These collaborations contribute to the Laboratory's vitality, enhancing Livermore's capabilities, generating new ideas, and leading to science and technology breakthroughs that help us in all our programs. I am proud to extend my personal congratulations to this year's winners.

■ Michael R. Anastasio is director of Lawrence Livermore National Laboratory.

Detecting Bioaerosols When Time Is of the Essence

ABOUT seven years ago, Livermore researchers received seed funding from the Laboratory Directed Research and Development Program to develop an instrument that counters bioterrorism by providing a rapid early warning system for pathogens, such as anthrax. (See *S&TR*, January/February 2002, pp. 24–26.) That instrument, the Autonomous Pathogen Detection System (APDS), is now ready for deployment to better protect the public from a bioaerosol attack, and the development team has been honored with a 2004 R&D 100 Award.

The lectern-size APDS can be placed in airports, office buildings, performing arts centers, mass transit systems, sporting arenas—anywhere an attack might be launched. APDS was designed to get results fast and get them right, without false positives. Biological scientist Richard Langlois, who spearheaded the APDS development effort, explains, "The system provides results on the spot. Faster results allow a faster emergency response, which in the end means saving lives."

The Autonomous Pathogen Detection System (APDS) monitors the air continuously for biological threat agents and uses two identification technologies to reduce the probability of false alarms. It can measure up to 100 different agents per sample and reports identified agents within an hour.

Responding Rapidly, Reliably

One of the methods a terrorist might use to disperse a biowarfare agent is through an aerosol attack. In fact, the anthrax mail room release in 2001 and the ricin release in 2004 involved relatively small amounts of deadly material. Countering such threats in an effective manner requires an automated system that continuously monitors the air, quickly analyzes samples, and identifies a wide range of agents without false positives.

APDS is designed to meet that need. It monitors the air for the three types of biological threat agents: bacteria, viruses, and toxins. Because it operates continuously, the system can detect low concentrations of bioagents that might go undetected by a system that is triggered only when the overall number of particles in the air is high. APDS collects aerosol samples, prepares them for analysis, and tests for multiple biological agents simultaneously. This automation reduces the cost and staffing that would be required to manually analyze samples.

The current system is configured to test simultaneously for 11 agents and can be expanded to 100 agents without a change in instrumentation. "Given the number of pathogens potentially available to terrorists," says Langlois, "the ability to detect and analyze large numbers is critical." APDS also identifies particles within 1 hour—faster than comparable systems, which can take 4 to 20 hours. Having results promptly is crucial for emergency-response efforts, as is being certain that the results are real. "Our goal was to have two independent, autonomous, 'gold-standard' assays to provide the highest confidence in detection results in the shortest possible time," says Langlois.

Checking It Twice

As APDS collects air samples, it first runs them through an immunoassay detector. If that detector returns a positive result, APDS performs a second assay based on nucleic-acid amplification and detection. Having two different assay systems increases system reliability and minimizes the possibility of false positives.

The immunoassay detector incorporates liquid arrays, a multiplexed assay that uses small-diameter polystyrene beads (microbeads) coated with thousands of antibodies. Each microbead is colored with a unique combination of red- and orange-emitting dyes. The number of agents that can be detected in a sample is limited only by the number of colored bead sets. When the sample is exposed to the beads, a bioagent, if present, binds to the bead with the appropriate antibody. A second fluorescently labeled antibody is then added to the sample, resulting in a highly fluorescent target for flow analysis. Preparing the sample and performing this first analysis takes less than 30 minutes.

System software compares the result with preset threshold criteria for a positive identification. A positive immunoassay result triggers the second test—a DNA analysis using the rapid polymerase chain reaction (PCR) technique. For this test, an archived sample is mixed with reagents for the target organism and introduced into the flow-through PCR system, which consists of a Livermore-designed, silicon machined thermocycler mounted in line with the sample preparation unit. Specific nucleic-acid signatures associated with the targeted bioagent are amplified up to a billionfold and detected as a change in fluorescence. The PCR analysis is completed within 30 minutes.

Results are transmitted every hour to a control center, where the instrument's performance is monitored. "The architecture of wireless communication with a command center works well with existing building safety and security systems," says Langlois. "Because malfunctions and failures are rare, a small command staff can easily oversee a network of 10 to 100 instruments and still provide maintenance, scientific interpretation of assay results, and communication with the appropriate authorities."

Saving Time, Saving Lives

In September 2003, APDS passed a series of pathogen exposure tests at a high-containment laboratory at the Dugway Proving Ground in Utah. In these trials, the system clearly demonstrated that it could detect real pathogens and confirm the identifications with a fully automated second assay method. APDS units were also deployed at the Albuquerque Airport in New Mexico and at a Washington, DC, Metro station, where they provided continuous monitoring for up to seven days, unattended.

The system can be adapted for situations where environmental or clinical pathogens require monitoring. For example, APDS could test for mold or fungal spores in buildings or for the airborne spread of contagious materials in hospitals. It also could identify disease outbreaks in livestock transport centers or feedlots. "Basically, there are no fully integrated systems with the capabilities of APDS commercially available in the civilian or military market," notes Langlois. "The system offers ongoing environmental monitoring and rapid detection of harmful pathogens, allowing emergency workers to respond immediately to decontaminate areas and, most importantly, save lives."

—Ann Parker

Key Words: anthrax, Autonomous Pathogen Detection System (APDS), biological agents, bioterrorism, multiplex immunoassay, polymerase chain reaction (PCR), R&D 100 Award, ricin.

For further information contact Richard Langlois (925) 422-5616 (langlois1@llnl.gov).

APDS team members: (from left) Anthony Makarewicz, Donald Masquelier, Les Jones, Robert Johnson, Bill Colston, Bruce Henderer, Fred Milanovich, Kodumudi Venkateswaran, Anne Marie Erler, Benjamin Hindson, Shanavaz Nasarabadi, Mary McBride, Ramakrishna Madabhushi, Steve Brown, Sally Marie Smith, Richard Langlois, Dora Maria Gutierrez, Ray Mariella, Ujwal Sathyam Setlur, John Dzenitis, and Tom Metz. Not pictured: Keith Burris.

Getting the Big Picture

DOZENS to hundreds of interconnected personal computers (PCs), stacked up row after row and operating simultaneously: that in a nutshell describes many of the latest high-performance supercomputers. These collections of inexpensive, readily available PCs are known as commodity clusters, and they offer cost-effective and nearly limitless computational horsepower.

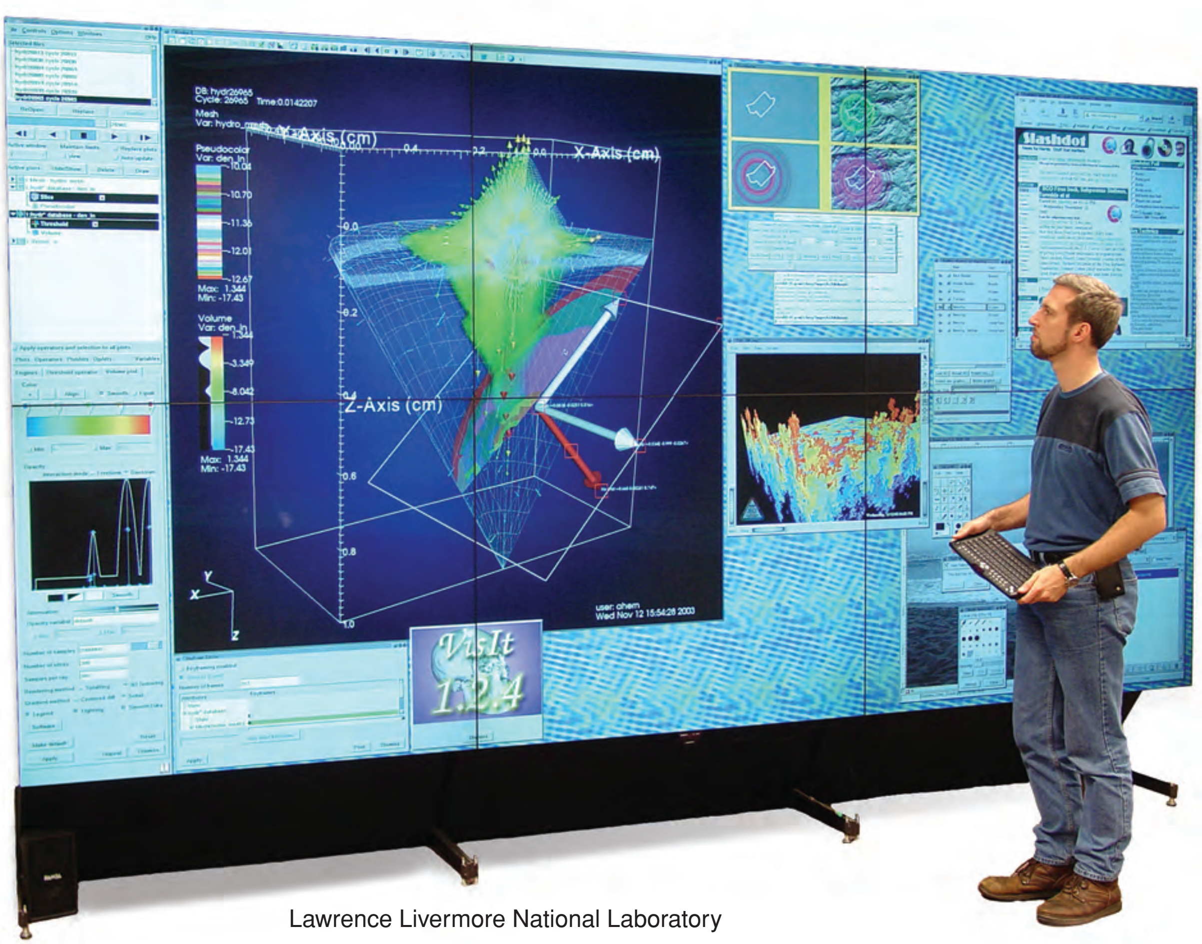
Parallel processing using clusters of PCs has solved many kinds of computational problems at Lawrence Livermore and elsewhere, but graphics and visualization applications have not been able to take full advantage of cluster technology. Consumer graphics cards on PCs are designed for stand-alone operation, not for operating together with other machines. An R&D 100 Award–winning software package called Chromium solves this problem, providing the most effective means yet for PC graphics cards to communicate and synchronize their commands. With Chromium, a cluster of PCs can create a single enormous image from their combined data.

Clustered Rendering

Chromium takes its name from clustered rendering, or CR for short. A member of the development team noticed that Cr is the atomic symbol for the element chromium, and the software's name was born. Chromium is a free, open-source software package developed by two Livermore computer scientists, Randall Frank (now with CEI in Apex, North Carolina) and Sean Ahern, in collaboration with researchers from Stanford University; the University of Virginia at Charlottesville; and Tungsten Graphics of Woodbury, Connecticut.

Chromium is the first graphics library to allow both parallel and serial graphics applications to generate images in parallel. It supports any program that uses the OpenGL programming language, an industry-standard interface for drawing two- and three-dimensional (3D) graphics. Even traditional serial programs can now take advantage of parallel cluster technology without modification.

VisIt, an interactive parallel visualization application, runs on a commodity cluster and displays to a tiled powerwall using Chromium.



In high-performance computing, scalability—a program's ability to handle ever-larger amounts of data—is a critical issue. Chromium is the only parallel graphics library that can simultaneously scale upward along three critical axes: the quantity of data an application can process, the drawing or rendering performance (for example, the ability to render more triangles or more pixels per second), and the size in pixels of a single image. To date, Chromium has been used to handle data sets of up to 23 trillion bytes and output displays as large as 60 million pixels.

The team's product is extremely popular, and more than 21,000 copies have been downloaded since the software's release in August 2003. Chromium's usefulness has fostered numerous parallel visualization projects, such as the Deep View Visualization project at IBM, Boston University's Deep Vision Display Wall, the University of Kentucky's powerwall autocalibration software, and Indiana University's Cluster Rendering.

Intercept and Run

OpenGL-based applications must dynamically link to OpenGL's graphics library to support their own rendering demands. Chromium exploits this dependency by intercepting the link to OpenGL and masquerading as the OpenGL library. Chromium is thus entirely transparent to a running application, and applications need not be modified to take advantage of Chromium. Other parallel graphics products are on the market, but they all require the applications to be modified.

"What we call Chromium's mothership manages the whole operation," says Ahern. The mothership sets up Chromium's processes and orchestrates all incoming and outgoing resources. It controls the rendering done by an application and coordinates the conversion of OpenGL graphics commands into streams of commands that can flow from one computer in the cluster to another.

OpenGL is a serial programming language that executes commands in the order in which they are made, but Chromium does not require such strict ordering for most applications. Instead, its mothership tracks streams of serial graphics commands and coordinates their transformation into sets of parallel streams that can be rendered in a scalable fashion. For example, Chromium can take a single incoming stream of commands and split it into multiple streams. These streams can then be projected on a powerwall display, where each output stream corresponds to one output projector, or tile, of an aggregate display.

Going Above and Beyond

Not only does Chromium provide a way for graphics processing to take advantage of commodity clusters, but it also proved to have abilities that its developers had not envisioned. "With its modular stream processing, we've been able to extend and enhance the OpenGL interface to drive devices that couldn't have been considered before," says Frank. For example, Chromium can perform remote simultaneous rendering operations from clusters to personal data assistants or to large networked displays.

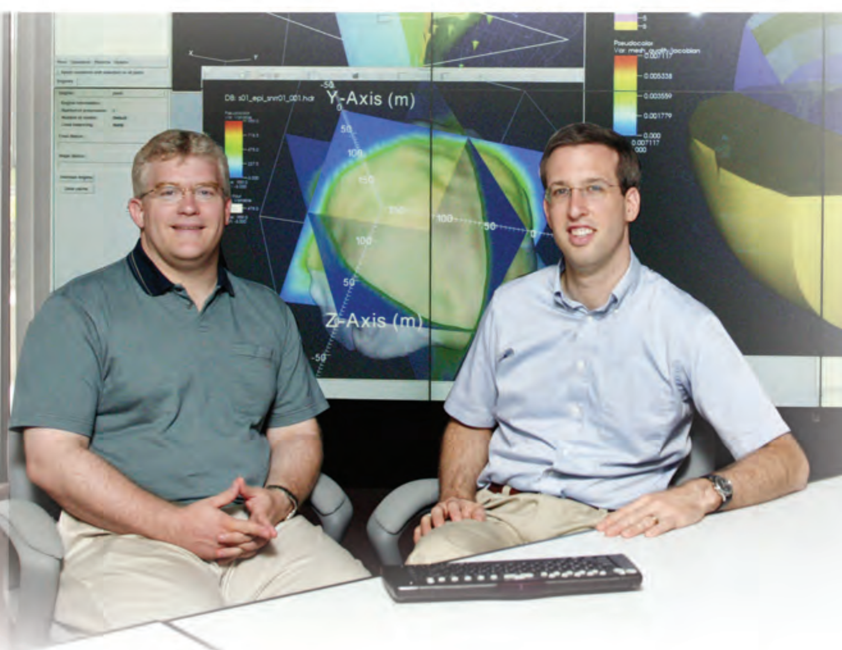
Chromium can also help debug graphics applications and serve as a custom acceleration mechanism for desktop applications. It can easily change the look of a rendering. Plus it can modify, delete, or replace commands in the streams, allowing 3D graphics programs to be changed as they run. Chromium can make a rendering look like a blueprint, or it can break up a scene into floors to look like an architectural walk-through—all without modifying the application.

Feedback from numerous system suppliers and application developers indicates that the Chromium infrastructure has significantly advanced the commercial adoption, acceptance, and exploitation of an entirely new class of expandable supercomputer: the distributed, graphics supercluster.

—Katie Walter

Key Words: Chromium software, clustered rendering, commodity clusters, OpenGL library, parallel graphics library, parallel visualization, powerwall display, R&D 100 Award.

For further information contact Sean Ahern (925) 422-1648 (seanahern@llnl.gov). Chromium software and related documentation are available at chromium.sourceforge.net.



The Chromium software team: (from left) Randall Frank (now with CEI in Apex, North Carolina) and Sean Ahern.

Laser Burrows into the Earth to Destroy Land Mines

ONE of the great scourges of warfare is the land mine. Although an effective battlefield weapon, land mines kill or maim nearly 45,000 civilians (including 20,000 children) worldwide every year. According to the United Nations, more than 110 million antipersonnel and antitank mines have been planted in more than 70 countries. About 100,000 mines are cleared annually, mainly by humanitarian agencies, but military forces lay another 2 million each year.

Current methods to clear mines, called demining, are slow and cumbersome. Some methods, such as dragging a plow across the ground, risk damaging equipment and injuring people. Demining can also be deadly; one deminer dies for every 5,000 mines neutralized. Many nations, the U.S. Army, and humanitarian relief agencies have searched for less dangerous technologies.

Deminers will soon have a better approach: a compact tool that rapidly uncovers and neutralizes land mines from a safe distance by using extremely powerful pulses of laser light. Developed by a team of Livermore physicists and engineers, the Diode-Pumped Pulsed Laser for Mine Clearing (DP-PLMC) won a 2004 R&D 100 Award for its promise of revolutionizing the practice of demining.

The Diode-Pumped Pulsed Laser for Mine Clearing (a) remotely exposes a buried plastic casing similar to that used in an antipersonnel mine and then (b) burns through the plastic.

World's Most Powerful Diode-Pumped Laser

The solid-state DP-PLMC produces high-average-power laser bursts of 25,000 watts of light, making it the world's most powerful diode-pumped laser. The pulse repetition rate is 200 per second, with each pulse producing a peak power of up to 250,000 watts. This pulsed power technology permits the laser beam to burrow into the ground, expose the mine, and then burn it up (a process called deflagration) instead of exploding it.

The laser is a result of work done for the U.S. Army's Space and Missile Defense Command to produce a system that can be used for short-range, tactical defense. The research team found that the laser could penetrate soil at a rate of 40 centimeters per second and, hence, could potentially neutralize buried land mines. With such a quick tunneling rate, the laser also eliminates the chronic problem of false positives, which can significantly slow down the demining process. The current 30-kilowatt prototype version of the laser has demonstrated the technology's key elements and will enable a full-power mobile version to be built within the next two years. Livermore physicist Mark Rotter, who led the development team, says, "By adding a mine detection capability, such as ground-penetrating synthetic-aperture radar, to the laser platform, we can deploy a truly versatile land-mine neutralization system."

The laser builds on the success of Livermore's solid-state heat capacity laser (SSHCL), which won a 2002 R&D 100 Award. (See *S&TR*, October 2002, pp. 8–9.) In the SSHCL, high-average-power bursts are made possible by separating the cooling cycle from the laser's amplifier pumping cycle. As a result, the maximum average power is increased from 5,000 watts to more than 25,000 watts.

Two upgrades to the SSHCL permitted the development of the DP-PLMC. First, the laser's flashlamps, which were used to pump the amplifiers, were replaced by arrays of high-power laser diodes for much greater efficiency. During the past decade, Livermore scientists have pioneered the use of high-average-power diode arrays in lasers to sharply reduce power and space requirements. The second upgrade was to replace the neodymium-doped glass with crystalline neodymium-doped garnet for higher mechanical strength and more rapid cooling, producing a faster turnaround time between laser firings. The two upgrades made possible a compact, efficient laser demining system that can be deployed on a wheeled or tracked vehicle.

Fulfilling the Solid-State Promise

Many demining experts had hoped that mobile, solid-state laser systems could fulfill the promise of the laser to remotely and efficiently neutralize land mines. Solid-state lasers do not require the toxic and corrosive fuels used by chemical lasers, and electrical power is efficiently converted to a high-power beam without producing waste effluents. Although solid-state laser demining systems are commercially available, those systems use a small (several-hundred-watt), continuous output laser. Because that laser has a low power output, unexploded mines must be directly visible to the laser beam. Any sand or soil covering the buried mine prevents it from reaching the temperatures that initiate burning.

In contrast, the extremely powerful, pulsed laser beam from the DP-PLMC requires no human interaction to expose the mine. The beam digs through soil by explosively vaporizing it to remotely reveal underlying mines. Once the laser beam encounters a mine, it quickly penetrates the plastic outer casing of antipersonnel mines or the metal casing of antitank mines. After the laser penetrates the case, its power level is reduced so the mine is neutralized by deflagration rather than detonation.

"We knew that once we demonstrated the laser's capacity to dig into the ground and expose a mine, we had the potential to dramatically alter demining technology," says Rotter. Because the DP-PLMC does not require personnel to manually uncover the land mine, the system dramatically reduces the chance of injury. Based on the output power of the laser, a maximum standoff distance of 1 kilometer can be achieved. Such a distance can be obtained, in principle, by placing the laser on an elevated site or raising the output beam by means of periscope mirrors so as to overlook the mine field without obstruction. In general, mine detection and neutralization would occur at distances less than 1 kilometer.

The DP-PLMC is designed to burn up the mine instead of detonating it, although, says Rotter, the system has yet to be tested on a live mine. With deflagration, the laser will not leave a crater in the earth—a characteristic of other neutralization processes. Keeping the environment unscarred is an important advantage for restoring land to productive use.

Just Add Batteries

The current DP-PLMC prototype is powered by lithium–ion batteries. The Livermore team is working with a U.S. company to adapt the system to a vehicle such as a hybrid-electric-powered Humvee. In this configuration, the Humvee's generator and batteries could power both the vehicle and the laser, requiring only diesel fuel to support full operation.

The DP-PLMC is available for commercial license for demining. Major General John M. Urias of the U.S. Army Space and Missile Defense Command indicates the laser could have related applications. In a letter to Rotter, he says, "It is clear to me that you have accomplished a critical step toward the development of a solid-state laser system that will be useful not only in mine-clearing operations, but also for the challenge of the improvised explosive device problem U.S. Forces currently face in Iraq and terrorists' threats that include unknown bomb devices."

The development of the DP-PLMC grew out of Livermore's work for the Army's Space and Missile Defense Command on a solid-state laser for battlefield use. The laser shows promise as the first high-energy laser compact enough to be considered part of the Army's future combat system for short-range (1- to 10-kilometer) air defense against tactical battlefield threats such as rockets, artillery, and mortars. (See *S&TR*, April 2002, pp. 19–21.)

In more ways than one, the DP-PLMC is shedding light on a vexing problem for the U.S. Army and more than 70 nations.

—Arnie Heller

Key Words: demining, Diode-Pumped Pulsed Laser for Mine Clearing (DP-PLMC), land mine, R&D 100 Award, solid-state heat capacity laser (SSHCL).

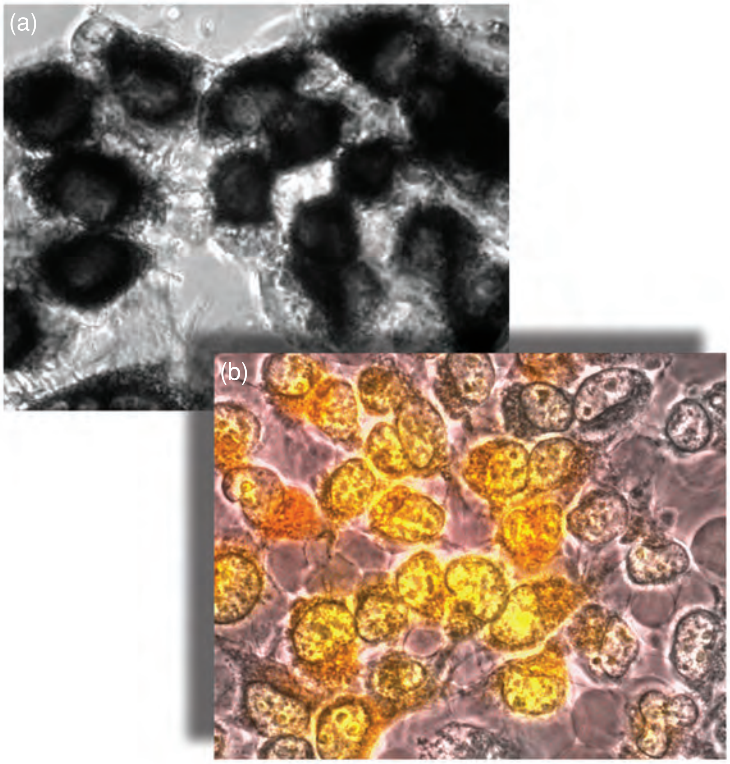
For further information contact Mark Rotter (925) 422-8370 (rotter1@llnl.gov).

Development team for the mine-clearing laser: (standing, from left) Charles Parks, C. Brent Dane, Balbir Bhachu, Scott Mitchell, Scott Fochs, Lloyd Hackel, Kurt Cutter, Charles Boley, Sally Gonzales, William Manning, Tom McGrann, Sasha Rubenchik, and Bruce Roy; (kneeling, from left) Robert Yamamoto, Roy Merrill, and Mark Rotter.

Shutting Down Genes in Cancer, Bacteria, and Viruses

RIBONUCLEIC acid (RNA) interference is a relatively new technique in which small molecules called short interfering RNA (siRNA) can be inserted into cells to turn off a chosen gene. The potential uses for this technique in the fields of functional genomics and drug discovery are far reaching. In fact, because RNA interference can suppress tumor-causing genes, it may even lead to a cure for cancer.

However, several barriers have stymied attempts to apply siRNA techniques to research and clinical use. Current siRNA molecules cannot function in bacteria, which are widely used in biological research experiments. The siRNA molecules also cannot be delivered into cells without disrupting the cells, and the genes do not remain suppressed for long.



Livermore's gene-silencing technology, called siHybrids, has been used successfully to suppress cancer-causing genes. Here, micrographs show cancer cells (a) before and (b) after treatment with siHybrids.

Scientists in Livermore's Biology and Biotechnology Research Program Directorate have overcome the problems of delivery and the duration of effectiveness by changing the molecular composition of the conventional double-stranded RNA molecules used in siRNA. In research funded by the Laboratory Directed Research and Development Program, they combined a single strand of RNA with a complementary single strand of DNA to create short hybrid RNA–DNA molecules, called siHybrids. The project team, which is led by biomedical scientist Allen Christian, received a 2004 R&D 100 Award for the novel technology.

The siHybrids are inherently more stable than siRNAs. They passively enter cells through a mechanism not yet understood by the Livermore researchers and remain stable in the presence of the enzymes in a cell. As a result, the hybrid molecules have a more robust efficiency than siRNA, and their effects last up to 10 times longer than those of the conventional molecules. Additionally, siHybrids cost half as much to produce, and unlike siRNA, they are effective in bacteria.

"With the siHybrids, researchers and physicians could quickly, inexpensively, and precisely shut off a damaged or abnormal gene that is causing a disease, ranging from cancer to bacterial or viral infection," says Christian. A single cell contains more than 6 billion nucleotide bases. Yet, siHybrids can locate the one damaged or misplaced gene in a cell and quickly render it quiescent.

How siHybrids Work

Genes act on the body through the expression of the specific proteins and enzymes that each gene encodes. The genetic code is stored in the DNA sequence, which is transcribed into RNA and finally translated into a polypeptide—that is, proteins, enzymes, or peptide hormones. Genetic disorders result from damage to a gene, which in turn manufactures an abnormal gene product.

Gene silencing by RNA interference attempts to keep detrimental proteins from harming the body by suppressing their expression. These intervention strategies are not limited to silencing endogenous genes—those that occur naturally in the body. They can also be used to silence foreign genes, such as those from an invading virus or bacteria, thereby protecting the body from infection.

To use siHybrids, a technician first identifies a sequence of nucleotides that make up the target gene. Then a piece of RNA–DNA hybrid about 20 nucleotides long is synthesized to match part of the identified genetic sequence. When this inhibiting hybrid molecule is inserted into a cell, it selectively degrades the messenger RNA of the target sequence, which disables the gene's capacity to manufacture its product.

According to Christian, when the Livermore team used siHybrid molecules to target out-of-control cancer genes, experimental results showed that the molecules stopped the rapid growth of cancerous cells. Even more promising is the fact that the treatment had no deleterious effect on the normal cells surrounding the cancer.

A Potential Cancer Therapy

Now that the sequencing of the human genome has been completed, scientists working in functional genomics have turned their attention to identifying the function of each gene and developing corresponding mechanisms to treat genetic disorders. The siHybrid molecules are an effective tool for this research area, providing researchers with a fast, automated test of gene function.

The hybrid molecules are particularly advantageous for the diagnosis and treatment of cancer. Traditional RNA interference applications, including siRNA, require special delivery systems to transport the molecules into the cells. But many delivery agents are toxic to the body, and existing delivery methods are too harsh for use in humans. However, siHybrids enter cells freely without a delivery system. In addition, they are more effective than present RNA interference technologies. Because genes remain suppressed longer when cells are treated with siHybrids than with siRNA, the hybrid molecules are ideal for long-term clinical applications.

With these advantages, siHybrids have the potential to dramatically improve cancer therapy by directly shutting down the cancer-causing genes. Studies indicate that cancer occurs when the expression of mutated genes or the overexpression of native genes stimulates uncontrolled cell division. The Livermore team has demonstrated that siHybrids will silence such genes in cells. For example, adding siHybrids to cell-growth media selectively shuts down the gene that causes prostate cancer. In the laboratory, they also effectively silenced the mutated tumor-suppressor gene that is suspected of being involved in 50 to 55 percent of all human cancers. Other possible cancer targets for siHybrids include suppressing genes that encode drug-resistant proteins, growth factors, and receptors in specific tumors.

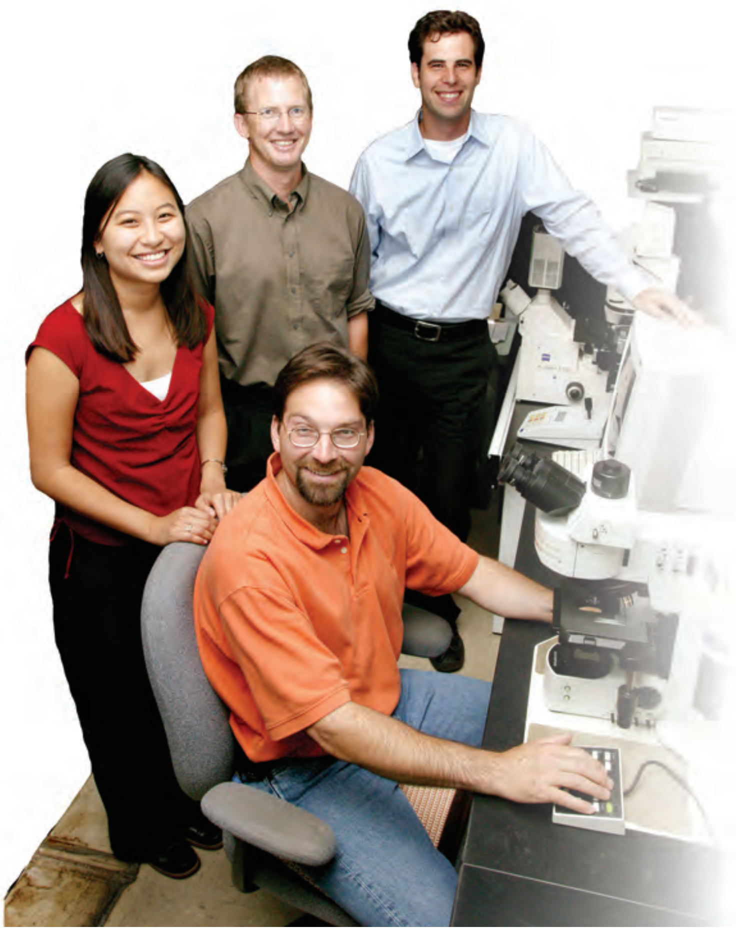
From Genetic Disorders to Infectious Diseases

Christian foresees that siHybrid technology could have numerous applications. For example, virtually all genetic disorders—from neonatal and neurogenerative diseases to immunodeficiencies—are caused by mutated gene expression, which could be disrupted or diminished with siHybrid treatment. This technology also may be effective against bacterial infection, plus the treated organism will not develop a resistance to the siHybrids. The hybrid molecules may even prove successful in shutting down viruses that have already infected a host. In addition, says Christian, applications are possible in such areas as agriculture, toxicology, pharmacology, immunology, veterinary medicine, embryology, environmental science, and counterterrorism.

—Maurina S. Sherman

Key Words: cancer, functional genomics, gene expression, gene silencing, gene therapy, R&D 100 Award, ribonucleic acid (RNA) interference, siHybrids, short interfering RNA (siRNA).

For further information contact Allen Christian (925) 424-5909 (christian4@llnl.gov).



Members of the siHybrids team: (standing, from left) Alice Chen, Allen Christian, and Erik Hofmann; (seated) Larry Dugan. Not pictured: Janelle Lamberton and Rose Latham.

Magnetically Levitated Train Takes Flight

SINCE the 1960s, transportation industry planners have sought an energy-efficient design for a train that can glide through air at speeds up to 500 kilometers per hour. This type of train, called a magnetically levitated (maglev) train, is thought to be a viable solution to meet the nation's growing need for intercity and urban transportation networks. However, despite some promising developments, unresolved concerns with the operation and safety of maglev trains has prevented the transition from demonstration model to commercial development.

Inductrack, a maglev system originally conceived by Livermore physicist Richard Post, is designed to address these issues. (See *S&TR*, June 1998, pp. 20–22; November 2003, pp. 14–17.) Post's work on Inductrack began with funding from Livermore's Laboratory Directed Research and Development Program, and in 2003, the technology was licensed to General Atomics (GA) in San Diego for train and transit system applications. This year, members of the Livermore–GA team received an R&D 100 Award for Inductrack's development.

Inductrack uses permanent magnets to produce the magnetic fields that levitate the train and provides economic and operational advantages over other maglev systems. It can be adapted to both high-speed and urban-speed environments. In the event of a power failure, the train slows gradually until it comes to rest on its auxiliary wheels. The maintenance requirements for Inductrack are also lower than they are for other systems, plus it has a short turning radius and is designed for quiet operation.

Previous designs for maglev systems did not offer the energy efficiency or safety protections that are in the Inductrack design. Electromagnetic systems (EMS) use powered electromagnets to levitate the train. However, these systems are based on magnetic attraction rather than repulsion and thus are inherently unstable. In EMS trains, the levitation gap—the separation between the magnet pole faces and the iron rail—is only about 10 millimeters and, during operation, must be maintained to within ±1 millimeter. Position sensors and electronic feedback systems are required to control the magnetic current and to compensate for the inherent instability. This requirement, plus the onboard source of emergency power required to ensure operational safety during a sudden power loss, increases the complexity of EMS trains.

In contrast, in electrodynamic systems (EDS), large superconducting magnet coils mounted on the sides of the train generate high-intensity magnetic field poles. Interaction of the current between the coils and the track levitates the train. At operating speeds (above a liftoff speed of about 100 kilometers per hour), the magnetic levitation force balances the weight of the car at a stable position. EDS trains do not require the feedback control systems that EMS trains use to stabilize levitation. However, the superconducting magnetic coils must be kept at temperatures of only 5 kelvins, so costly electrically powered cryogenic equipment is required. Also, passengers, especially those with pacemakers, must be shielded from the high magnetic fields generated by the superconductors.

Levitating by Magnets

Inductrack is classified as an EDS because it achieves levitation when the magnetic fields on the train interact with the conducting circuits in the track. But the similarity with conventional EDS trains ends there. Inductrack is a passive system in that it uses no superconducting magnets or powered electromagnets. Instead, it has an array of permanent room-temperature magnets.

Inductrack's other distinguishing feature is that the track is made with a close-packed array of electrically shorted circuits.

Livermore members of the Inductrack team: (standing, from left) J. Ray Smith, Louann Tung, Richard Post, Don Podesta, William Kent, and Edward Cook; (kneeling, from left) Joel Martinez-Frias and Dmitri Ryutov.

In one design, these circuits form a ladderlike array of "rungs" containing cabled insulated wire. As the train moves over the track, permanent magnets induce a current in the track circuits. This current generates a magnetic field that repels the magnet arrays, causing levitation and inherent stability. As long as the train is moving above a few kilometers per hour—a little faster than walking speed—it is levitated 25 millimeters above the track's surface. Such a large gap allows more leeway than systems that require a narrower gap. This advantage is crucial in foul weather such as wind and rain, which could affect the gap size. It also permits looser tolerances for track specifications than are allowed for the EMS designs.

Previous research teams had rejected permanent magnets for maglev systems because designers believed the magnets would yield too little levitating force relative to their weight. Two developments resolved that problem. In the 1980s, the late Klaus Halbach, a physicist at Lawrence Berkeley National Laboratory, invented the Halbach array to focus accelerator particle beams. In this array, permanent magnets are configured so that the field intensity is concentrated below the array but canceled above it. Post says, "Our use of Klaus's array in Inductrack is a good example of basic research being put to practical use to help meet a national need."

At about the same time, a magnet material was developed using the alloy neodymium–iron–boron. Permanent magnets made with this alloy generate a much higher intrinsic magnetic field than those made with other materials.

Although permanent magnets do not require power to produce a magnetic field, Inductrack uses a power source, such as an electrical drive system or a jet turbine, to accelerate the train until it is levitated and to overcome aerodynamic drag. Unlike other maglev systems, the amount of power needed depends only on the train's weight and its maximum speed.

GA is working with the Federal Transit Administration, a division of the U.S. Department of Transportation, to develop an urban transit system. In 2000, GA chose Inductrack as the best approach for a maglev system and, in May 2003, broke ground in San Diego for a 122-meter test track. GA plans to conduct full-scale tests of Inductrack later this year.

Improving Performance Even More

Livermore researchers have continued to improve on the system's design. Inductrack II, which uses a dual Halbach array straddling the track, nearly doubles the levitating magnetic field. This design requires half the current used in the single-sided Inductrack I configuration to achieve the same levitation force per unit area, without substantially increasing the weight or footprint area of the Halbach arrays. Thus, Inductrack II has lower drag forces (higher levitation efficiency) at low speeds than Inductrack I, an important asset for an urban maglev system.

The National Aeronautics and Space Administration (NASA) is also considering Inductrack technology for launching rockets.

Members of the General Atomics team onboard the full-scale model of Inductrack: (from left) Volus McKenna (standing), Richard Hutsell (face obscured), Dave Doll, In-Kun Kim, Robert Kratz, Karl Kehrer, and Sam Gurol. (McKenna and Kehrer are employees of Hall Industries, which is responsible for the vehicle car body and chassis for this project.)

NASA studies have shown that if a large rocket could be accelerated up to about Mach 0.8 before its engines are fired, the amount of rocket fuel used could be reduced 30 to 40 percent. Other potential applications include people movers; spark-free mine cars; and high-speed, intercity freight shipments, where sealed capsules are levitated within 1-meter-diameter underground tubes.

A maglev system using Inductrack may one day provide a more efficient means of high-speed intercity travel. Inductrack's ability to operate on grades and level ground and to make tight (short-radius) turns makes it versatile for intercity or high-speed distant travel. Reduced operation and maintenance costs may soon allow transportation planners to finally reach the long-term goal of an energy-efficient transportation system.

—Gabriele Rennie

Key Words: Halbach array, Inductrack, magnetically levitated (maglev) train, permanent magnets, R&D 100 Award, urban transportation.

For further information contact Richard Post (925) 422-9853 (post3@llnl.gov).

The Power of

Strategic collaborations between Lawrence Livermore and other University

INSTITUTIONS that conduct similar or complementary research often excel through collaboration. Indeed, much of Lawrence Livermore's research involves collaboration with other institutions, including universities, other national laboratories, government agencies, and private industry. In particular, Livermore's strategic collaborations with other University of California (UC) campuses have proven exceptionally successful in combining basic science and applied multidisciplinary research. In joint projects, the collaborating institutions benefit from sharing expertise and resources as they work toward their distinctive missions in education, research, and public service.

As Laboratory scientists and engineers identify resources needed to conduct their work, they often turn to university researchers with complementary expertise. Successful projects can expand in scope to include additional scientists and engineers both from the Laboratory and from UC, and these projects may become an important element of the research portfolios of the cognizant Livermore directorate and the university department. Additional funding may be provided to broaden or deepen a research project or perhaps develop it for transfer to the private sector for commercial release.

Occasionally, joint projects evolve into a strategic collaboration at the institutional level, attracting the attention of the Laboratory director and the UC chancellor. Government agencies or private industries may contribute funding in recognition of the potential payoff of the joint research, and a center may be established at one of the UC campuses. Livermore scientists and engineers and UC faculty are recruited to these centers to focus on a particular area and achieve goals through interdisciplinary research. Some of these researchers hold multilocation appointments, allowing them to work at Livermore and another UC campus. Such centers also attract postdoctoral researchers and graduate students pursuing careers in the centers' specialized areas of science.

Partnership

of California campuses strengthen basic science research and national security.

Another method Livermore uses to foster university collaboration is through the Laboratory's institutes, which have been established to focus university outreach efforts in fields of scientific importance to Livermore's programs and missions. Some of these joint projects may grow to the level of a strategic collaboration. Others may assist in Livermore's national security mission; provide a recruiting pipeline from universities to the Laboratory; or enhance university interactions and the vitality of Livermore's science and technology environment through seminars, workshops, and visitor programs.

Supporting Collaborative Growth

In 1995, Livermore formed its University Relations Program (URP) to facilitate the growing number of collaborations between the Laboratory's researchers and UC faculty. Working with the UC Office of the President (UCOP), URP supports a broad range of programs that improve access to Livermore, contribute to science education (see the box on p. 16), strengthen existing Laboratory programs, and develop new initiatives to facilitate the exchange of expertise among Livermore researchers and university faculty. URP is also assisting in program development for UC's newest campus, UC Merced. (See the box on p. 21.)

Program director Laura Gilliom says, "URP's role, in partnership with the Laboratory's directorates, is to broaden and deepen our levels of interaction with universities. Our strategic-level collaborations with other UC campuses have brought enormous benefits to the Laboratory and to UC. We're also working to enable strategic collaborations with other universities."

URP oversees the six Livermore institutes that have been established in specific fields. Much of the work performed by the institutes is inspired by work originally developed to fulfill the Laboratory's national security missions. And even as joint research advances are

Edward Teller's Education Vision

Livermore's University Relations Program (URP) manages educational programs for kindergarten through graduate school. The programs continue the vision established by Edward Teller, who began his 60-year teaching career in 1934. When asked what scientists could do to help the public overcome their suspicions about new technology and science, Teller responded, "It is not up to the scientists. It is up to teachers."

Teller had a vision to create an educational department at Livermore that would operate as part of the College of Engineering at the University of California (UC) at Davis. In 1963, the Department of Applied Science (DAS) was established. Professors from the university and scientists from the Laboratory have since provided classroom instruction and hands-on experience with Laboratory projects to more than 1,400 M.S. and Ph.D. students.

Livermore expanded its education efforts with the Science and Technology Education Program (STEP), which provides professional development instruction for science teachers and enrichment programs for students. STEP events are aligned with science content standards for California public schools and the California standards for teaching. Livermore scientists identify Laboratory areas that best align with the instructional content of the programs. STEP disseminates the programs through the Edward Teller Education Center, a UC-sponsored professional development center for science teachers.

The Critical Skills Internship Program facilitates undergraduate research interactions with the Laboratory by matching college students with internships within Livermore's Stockpile Stewardship Program. Most of these internships are funded directly by the National Nuclear Security Administration.

Livermore also has a few programs designed to help train and recruit college graduates. The Research Collaborations Program (RCP) links Laboratory scientists with professors, postdoctoral researchers, and students at historically black colleges and universities and minority institutions. RCP has developed 24 technical collaborations connecting the Laboratory with 15 minority universities. The Student Employee Graduate Research Fellowship (SEGRF) Program grants fellowships to Ph.D. candidates from UC. There are currently 60 SEGRF students at Livermore.

Finally, the Lawrence Livermore Postdoctoral Fellowship Program, known informally as the Lawrence Fellowship, is a tribute to Nobel laureate and Laboratory cofounder Ernest O. Lawrence. Researchers are hired by the Director's Office in cooperation with URP. The criteria for acceptance are rigorous. In the first four years of the program, only 15 of 1,849 applicants were accepted as Lawrence fellows. (See *S&TR*, November 2002, pp. 12–18.)

In a survey conducted by *Science* magazine early this year, postdoctoral researchers ranked Livermore the seventh best place for postdoctoral researchers to work, from a pool of 61 U.S. institutions. URP director Laura Gilliom says, "The postdoctoral researchers who come here know they will be able to do cutting-edge research using the world's most advanced lasers, accelerator mass spectroscopy, and nuclear magnetic resonance spectroscopy tools, and couple experimental and computational science."

Livermore scientist Robert Tebbs (far left) and Michele Bennett (second from right, now at the National Institutes of Health) mentor faculty interns from Merced College. The interns worked with the Laboratory to update their knowledge of biotechnology for classroom instruction.

applied to human health, the environment, and other areas of importance, the technologies continue to support the nation's security.

Adapting Adaptive Optics

Livermore's first institute, the Institute of Geophysics and Planetary Physics (IGPP), was founded in 1982, with Livermore astrophysicist Claire Max serving as the first IGPP director. The Laboratory's branch of IGPP is linked to units on several campuses and is known as one of the leading geoscience and astrophysical research centers in the world.

IGPP's astrophysics efforts first received wide recognition through the MACHO (Massively Compact Halo Objects) project. Originally funded by Livermore's Laboratory Directed Research and Development (LDRD) Program, that project was a digital imaging study in search of cosmic dark matter. (See *E&TR*, April 1994, pp. 7–17; *S&TR*, April 1996, pp. 6–11.) Later, IGPP received LDRD funding to develop adaptive optics for ground-based telescopes. Adaptive optics systems measure the distortion of light from a star and then remove the distortion by reflecting the light off a deformable mirror that adjusts several hundred times per second to sharpen the image.

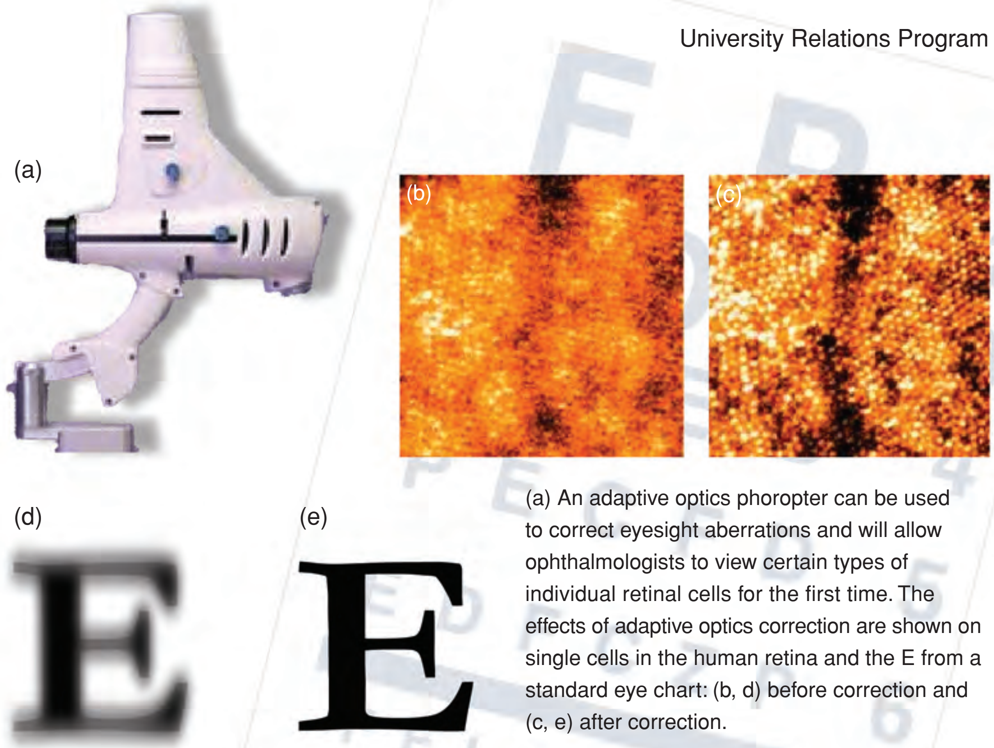
In 1995, Livermore installed a laser guide star—an artificial guide star system with adaptive optics—on the Shane Telescope at UC's Lick Observatory on Mount Hamilton in California. (See *S&TR*, July/August 1999, pp. 12–19; June 2002, pp. 12–19.) Shane was the first major astronomical telescope to use this system. In 2001, a similar system was installed on the Keck II Telescope in Hawaii, which is operated jointly by UC, the California Institute of Technology (Caltech), and the National Aeronautics and Space Administration (NASA).

In 2001, UC also opened the Center for Adaptive Optics at UC Santa Cruz. Funded by the National Science Foundation (NSF), the center's 27 partnering institutions include several UC campuses, Caltech, the University of Chicago, the University of Rochester, four laboratories, and 15 other partners. The center coordinates the efforts of researchers across the country involved in adaptive optics for astronomical and vision science. Max, who is deputy director of the center, says, "The Center for Adaptive Optics allowed Livermore to branch out from astronomy and lasers and apply adaptive optics to vision science, homeland security, and other developing applications."

In one LDRD-funded project, adaptive optics systems are being developed to correct for eye aberrations, detect the onset of eye diseases, and increase vision beyond 20/20. Livermore optical physicist Scot Olivier, who is an associate director of the center, leads a team that is partnering with the UC Davis Medical Center and the University of Rochester to apply this technology to three types of imaging systems. The instruments, which will increase resolution over existing instruments by a factor of three, are being designed to allow ophthalmologists to view certain types of individual retinal cells for the first time. In 2003, one of the instruments, the microelectromechanical systems– (MEMS-) based adaptive optics phoropter, received an R&D 100 Award. (See *S&TR*, October 2003, pp. 12–13.)

Glasses and contacts can correct for two eyesight aberrations: focus, which causes farsightedness or nearsightedness, and astigmatism. Adding adaptive optics to diagnostic instruments will allow optometrists to correct other types of aberrations. This capability will help specialists in prescribing new vision correction procedures such as custom laser refractive surgery. Ophthalmologists can use it to resolve eye cells as small as 2 to 3 micrometers, allowing them to detect diseases such as macular degeneration and glaucoma at an early stage. Physicians will also be able to monitor the effectiveness of drug treatments more closely.

Olivier believes that with adaptive optics, most people can achieve 20/10 or even 20/8 vision. "20/20 is just the average vision that can be corrected by glasses," he says. "Perfect vision would be limited only by the size of the pupil, or diffraction of light, and the ability of the retina and the brain to process the signals." The Department of Energy (DOE) and the National Institutes of



(a) An adaptive optics phoropter can be used to correct eyesight aberrations and will allow ophthalmologists to view certain types of individual retinal cells for the first time. The effects of adaptive optics correction are shown on single cells in the human retina and the E from a standard eye chart: (b, d) before correction and (c, e) after correction.

Health (NIH) are funding construction of the adaptive optics imaging systems on diagnostic instruments at the UC Davis Medical Center in Sacramento.

Detecting Faint Planets

The Center for Adaptive Optics continues to be active in astronomy applications, and a recent concept being pursued with LDRD funding is extreme adaptive optics. A team led by IGPP astrophysicist Bruce Macintosh and UC Berkeley professor James Graham is developing an extreme adaptive optics planet imager, which, for the first time, will allow astronomers to make direct images of planets orbiting stars. (See the figure below.)

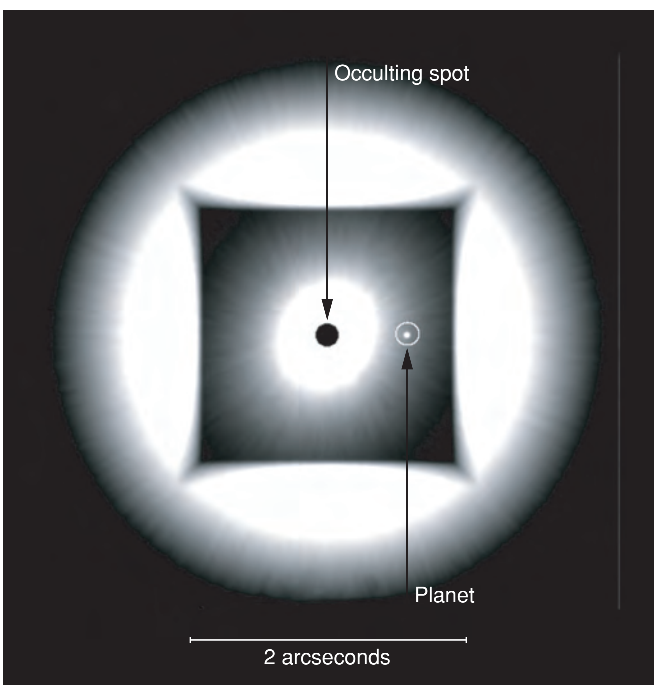
Currently, astrophysicists infer the presence of a planet by the wobble a star makes, which is caused by the tug of gravity from a planet orbiting the star. The scientists then measure the Doppler shift that occurs as the planet makes a complete orbit around the star, a process that can take a decade or more. The challenge in detecting planets and imaging them directly has been that the light from a star is a billion times brighter than the planet orbiting it, making the planet nearly impossible to see. The planets are also 10 million to 1 billion times smaller than their stars. "Existing systems were designed to detect faint objects such as galaxies, and a laser guide star was needed for that," Macintosh says. "Our goal is to image planets next to the bright, scattered light surrounding a natural star."

To discern the faint planets, the team is using MEMS technology to reduce the size of the actuators so that 4,096 actuators can fit on a deformable mirror. By contrast, Lick's system has 127 actuators, and Keck II has 349. With this extreme adaptive optics system, astronomers will no longer need to wait until a planet completes an orbit. Instead, they will be able to see planets far from the star and take measurements of the planets directly.

Livermore and UC Santa Cruz will build an extreme adaptive optics system, and UC Los Angeles is building the spectrometer. NASA's Jet Propulsion Laboratory is providing its expertise in calibrating precision optics. The system could be installed on a telescope by 2008.

Macintosh says the data from this system will be important because scientists still do not understand how a solar system forms. "We think planets are formed in the outer regions of the solar system and move inward," he says, "but being able to study them directly will provide us with more complete answers."

Max adds that applications of adaptive optics extend beyond astronomy and vision science. "The amazing thing is that, as a result of our work in adaptive optics to help astronomy, Livermore is also doing adaptive optics work for homeland security, surveillance, and projects for DARPA" (the Defense Advanced Research Projects Agency).



In this simulation of an extreme adaptive optics system, scattered light from a bright star spills out from behind the dark occulting spot. The adaptive optics system clarifies a dark-hole region, showing a planet (circled) four times the mass of Jupiter.

Analyzing Tiny Samples Fast

Many UC projects take advantage of Livermore's tools to advance their work. One frequently used technology is accelerator mass spectrometry (AMS). AMS is an ultrasensitive technique that measures the concentrations of specific isotopes in samples weighing less than 1 milligram. The process is fast, producing results in days compared with other techniques that can take months.

In 1989, Livermore established its Center for Accelerator Mass Spectrometry (CAMS) to diagnose fission products from nuclear tests and study climate and geologic records. At the time, UC did not have AMS capability. Livermore physicist Jay Davis worked with UCOP for initial funding to help support CAMS. In exchange, UC researchers were allotted a percentage of time with the center's spectrometer. The success of CAMS led to the center becoming a joint UC–Livermore facility, and it is now an established institute.

During the past decade, CAMS scientists have worked with university collaborators to develop analytic approaches that will define environmental and biochemical processes. They have

Scientists at the Center for Accelerator Mass Spectrometry have worked with hundreds of university collaborators in such research areas as materials analysis, global carbon cycles, geophysics, toxicology, and national security.

applied this expertise to research ranging from national security to global climate cycles to biomedicine. The facility has become an important resource to researchers at the UC Davis Cancer Center, which combines Livermore's science, medical technology, and engineering expertise with UC Davis's expertise in cancer research and clinical medicine.

Vitamin Activity in Humans

Early on, CAMS scientists worked with UC collaborators to create an entirely new application of AMS—following isotopically labeled compounds at trace doses through cells from human subjects. Livermore physicist John Vogel received funding from UC and LDRD for his pioneering work in nutrition research, which was instrumental in establishing CAMS for biomedical applications. In 1999, NIH designated CAMS as its only National Research Resource for biological AMS. Worldwide, CAMS is one of the few AMS facilities working on biomedical and pharmaceutical applications. (See *S&TR*, November 1997, pp. 4–11; July/August 2000, pp. 12–19.)

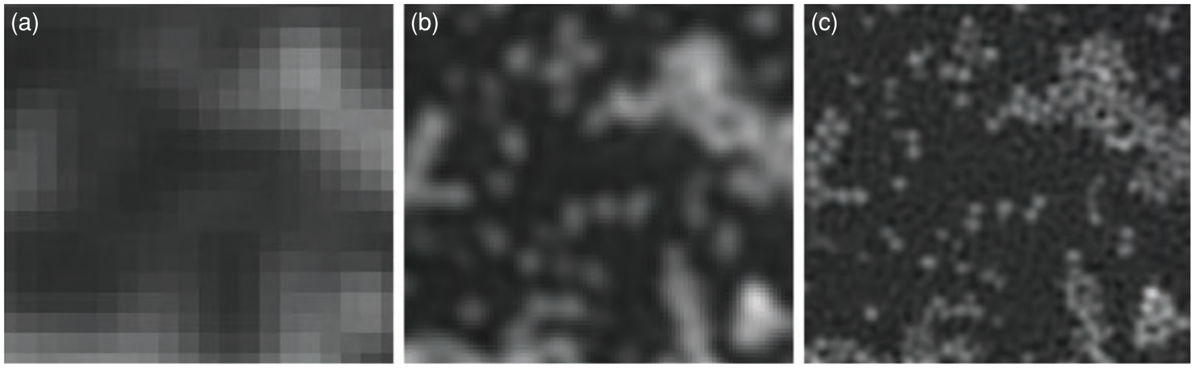
Vogel, who is also an adjunct professor of nutrition at UC Davis, is collaborating with Andrew Clifford, a UC Davis professor of nutrition, to determine whether the recommended dietary allowance (RDA) for vitamins is appropriate for all people. RDAs are currently set by epidemiological studies, which involve determining the cause of a disease once it has occurred. AMS allows researchers to examine vitamins' physiological activity in the body—that is, how vitamins are interacting in the body in real time.

Vogel and Clifford first studied folate, a vitamin that is important for heart health and preventing birth defects. They tracked 13 people with a median age of 24 years—the first folate study to focus on this age population. Tracking this age group has been difficult in the past. Although stable isotopes can be used to track folate, high doses must be given, preventing an accurate picture of the vitamin's activity. Radioisotopes can also be used to track a vitamin, but they give off radiation. Early tests using radioisotopes such as carbon-14 were done on elderly cancer patients, which is not the ideal group for studying dietary requirement levels to prevent birth defects.

The biggest surprise from the team's results, which will appear soon in the *American Journal of Clinical Nutrition*, was that a large amount of folate is recycled in the body and still present seven months after ingestion. The team will next study other populations to compare results.

Another study focused on vitamin A metabolism in six women in their twenties. The team's goal was to determine if a sufficient amount of the vitamin stored in the body modifies the need for beta-carotene, which converts to vitamin A. Results showed that even with sufficient vitamin A stores, adding beta-carotene allowed better absorption and less excretion of beta-carotene. The team's hypothesis is that vitamin A improved the health of the intestines, so absorption of both vitamin A and beta-carotene improved.

Vogel says, "An epidemiological study might conclude that if people have enough vitamin A, they don't need more



Micrographs of fluorescent plastic balls, each 50 nanometers in diameter, show the improved resolution that researchers hope to achieve with living cells: (a) conventional microscopy, (b) linear structured illumination microscopy, and (c) saturated structured illumination microscopy.

beta-carotene. But a physiological study, which can be done using AMS, shows that vitamin A allows beta-carotene to be processed more efficiently, and we see a cascade of events going on in the body. The added beta-carotene also improves antioxidant stores even if it is not needed to make vitamin A. What's more, AMS's sensitivity means researchers don't have to worry about radiation exposures."

Clues to Gulf War Illness

Some of Vogel's early toxicology work using AMS is also bringing more understanding to another health issue of national concern. Results from his collaborative studies with UC Davis and UC Riverside on the effects of low-dose exposures of pesticides are helping physicians better understand Gulf War Syndrome.

Two of the most common types of pesticides are organophosphates and pyrethroids. Organophosphates are also related to the nerve gases sarin and VX. Using a carbon-14 tracer, Vogel's team measured the amount of toxin present in mouse brains after low-dose exposure to one pesticide and to two different pesticides together. Tests were also performed with and without the pharmaceutical pyridostigmine bromide (PYB), which was given to U.S. soldiers to protect them from possible exposure to nerve gas.

Although PYB did have an overall protective effect, the exposure to two pesticides increased the amount of toxin in the brain by 25 to 30 percent, compared with exposure to just one pesticide. For U.S. soldiers, low-dose exposure to nerve gas and subsequent exposure to a pesticide that, for example, controls sand fleas might increase the amount of toxin reaching the brain, even with the ingestion of PYB. In 2003, Vogel presented these findings at a Department of Veterans Affairs research meeting addressing illnesses related to the 1991 Gulf War.

Manipulating Cells with Light

Advances in adaptive optics and AMS are allowing an unprecedented view of living cells. Another emerging area, called biophotonics, uses light and other forms of radiant energy to detect, image, and manipulate biological organisms at the cellular level. Applications of biophotonics include using light to image or selectively treat tumors, sequence DNA, and identify single biomolecules within cells.

The Center for Biophotonics Science and Technology (CBST), which was established at UC Davis in 2002, is the only NSF-funded center in the U.S. devoted to the study of light and radiant energy in biology and medicine. This collaboration brings together about 100 researchers, including physical scientists, life scientists, physicians, and engineers from Livermore; UC Davis, Berkeley, and San Francisco; Stanford University; and other universities.

Livermore physicist and UC Davis professor Dennis Matthews leads CBST along with UC Davis neurosurgeon Jim Boggan. Matthews says, "If we want to see how a single molecule interacts with other molecules inside a cell under different conditions, we don't have the technology to do that right now. Biophotonics, combined with other technologies we are developing, will allow us to see changes in the living cell."

UC San Francisco is leading a CBST project to develop structured illumination microscopy, an ultrahigh-resolution method to study the inner workings of cells. The method illuminates a sample with a light pattern that mixes with high-resolution sample features to produce resolvable low-resolution moiré fringes. (Moiré fringes are interference effects from overlaying two similar patterns, seen for instance when looking through two screen windows or two layers of mesh fabric.) By observing the fringes, the system can computationally reconstruct the original high-resolution information. This effect is pronounced when the illumination pattern is tight. By using tighter patterns, scientists can achieve better resolution than they can by direct illumination. This method, called saturated structured illumination, has produced some of the highest resolution images ever obtained with far-field visible light. (See the figure above.)

Tech Transfer Fills Many Needs

DOE is interested in structured illumination microscopy technology for the Genomics:GTL project, the follow-

The Birth of a University

The University of California (UC) and Lawrence Livermore have entered a new form of strategic collaboration to help establish the newest UC campus, which will be located in the San Joaquin Valley—the most populous region of the state without a UC campus. In 1995, UC chose Merced as the site for the nation's first public research university to be built in the 21st century. When fully developed, the campus will be home to 25,000 students and 6,600 faculty and staff.

The Laboratory's University Relations Program (URP) is helping UC Merced to become an important research university within the UC family, and areas of cooperation were defined in a memorandum of understanding signed on October 6, 2000.

URP's Paul Dickinson coordinates many areas of the collaboration. "Livermore is playing a critical role in recruiting science faculty for Merced," he says. "Faculty candidates visit the Laboratory to meet with potential colleagues, tour facilities, and gain an understanding of how partnering with the Laboratory can help facilitate their professorship at Merced."

As with other UC campuses, some members of the Merced faculty are expected to have multilocation appointments at Livermore. Laboratory researchers are also being encouraged to have multilocation appointments or become adjunct faculty at Merced.

So far, Merced has hired 27 faculty members, in addition to Maria Pallavicini, the dean of Natural Sciences; Jeff Wright, the dean of Engineering; Kenji Hakuta, the dean of Social Sciences, Humanities, and Arts; and Keith Alley, provost and vice chancellor of Research and dean of Graduate Studies. By August 2005, UC Merced is expected to have 60 faculty members and several adjunct members.

Because Merced is expected to become a valuable source of postdoctoral researchers and employees for the Laboratory, Livermore will offer graduate student internships. The Laboratory is also helping to plan a Central Valley institute that will help increase the number of students eligible to enter the university. Wright says, "Our collaboration with Livermore has been invaluable for building our academic programs, recruiting faculty, and providing future faculty the opportunity to see potential areas of research partnership with the Laboratory."

on to the Human Genome Project. Advanced microscopy, such as structured illumination, will allow researchers to study the function and structure of proteins in microbes. DOE is also funding a project to determine whether microbes can be used to synthesize cells for such applications as creating hydrocarbons for fuel, eliminating diseases in plants, purifying water, and scavenging for radioactive particles.

Another CBST project is using Livermore-developed optical probes with Raman spectroscopy to characterize cell function at the nanometer scale. (See *S&TR*, May 2004, pp. 4–11.) Raman scattering can identify a molecule by recording its distinct vibrational fingerprints as the molecule scatters laser light. Livermore physicist Tom Huser leads an LDRD-funded team that developed a method called surface-enhanced Raman spectroscopy, in which nanometer-size gold crystals are attached to molecules or cells. This method increases the signal by a factor of a quadrillion (10^{15}).

The gold nanoparticles, which are about 50 nanometers in diameter, serve as detectors that provide detail about the environment. The particles are covered with molecules of mercaptobenzoic acid, whose Raman spectrum changes with pH. As a cell reacts to external stimuli, its pH usually changes in response. One possible application of this technique is studying the pH of cancer cells while trying to develop better chemotherapeutics.

Matthews has also set up a program within CBST to develop optical-based medical devices in collaboration with industrial partners and UC campuses. Several technologies have already been transferred to industry for commercial development, including a device for treating ischemic stroke; micropower impulse radar for medical diagnostics; an implantable, continuous glucose monitor; and ultrashort-pulse laser microsurgery devices.

The Benefits of Collaboration

Members of the UC faculty have long cited the successful outcomes of their collaborations with Livermore researchers as an important reason to continue institution-to-institution research. Project results often establish a continuum of ideas for faculty to jump-start new research.

UC has two programs that provide grants to support emerging research activities until they become fully funded projects. The Campus–Laboratory Collaborations (CLC) Program funds three-year projects on issues that will affect the state of California. The Campus–Laboratory Exchange Program supports the exchange of people between campuses and the Laboratory. For example, Livermore geochemist Tom Guilderson leads a CLC-funded project with UC Santa Cruz researchers to define the fate of organic compounds in oceans. Understanding the global carbon cycle is an important research area because oceans serve as major reservoirs for carbon.

These programs not only support emerging technology, says Gilliom, but they also help university researchers gain experience in managing multidisciplinary programs. “Academics traditionally follow a focused career path, and gaining tenure doesn’t always require experience as project managers. The interdisciplinary research experience that our scientists and engineers bring helps universities deliver their technologies where they are needed.”

Livermore, in turn, greatly benefits from working with the great minds of academia. UC faculty members have won 32 Nobel prizes, and the current UC faculty includes 18 Nobel laureates.

Fostering Innovation

Postdoctoral researchers also provide the Laboratory many benefits. In general, students are up to date in training for their respective fields, know the latest techniques being used, and have fresh ideas

on how to couple different technologies. Postdoctoral researcher Adam Love says, "Postdocs at Livermore want to carve a unique path for themselves. We want to create novel ways to solve problems, which means we fail most of the time. But when we succeed, it's a big deal because it usually results in a breakthrough for an area of science."

Postdoctoral researchers benefit from having access to Livermore's researchers and facilities. "Virtually any instrument we want," says Love, "can be found here at the Laboratory." Love, who earned a Ph.D. in environmental engineering at UC Berkeley, specializes in contaminant transport processes in environmental systems. He received a three-year minigrant for his dissertation on reconstructing environmental levels of tritium by analyzing tree rings, and access to CAMS was key for his research.

Using AMS, Love measured carbon-14 and tritium levels throughout 150-millimeter cores taken from trees at Lawrence Berkeley National Laboratory. Until recently, Lawrence Berkeley used tritium to synthesize the tritium-labeled biological molecules used in tracing experiments. With his AMS results, Love established dates for the core section used in the tritium analysis by matching carbon-14 levels in the wood with known atmospheric levels. The AMS-measured tritium levels matched the levels reported by Lawrence Berkeley for the corresponding years over the last 30 years. Thus, he demonstrated an effective new application of AMS for retrospective environmental studies and for its use as a verification tool.

Love says that coming up with measurement-based techniques to reconstruct historical contaminant exposure levels is a fairly novel concept. Having access to CAMS was critical because AMS is the only technique that has both the sensitivity and throughput for running the numerous samples required for high resolution in many reconstruction scenarios. "In retrospective environmental studies," he says, "these capabilities are crucial, especially if we want to do a study going back many decades."

Forging Future Collaborations

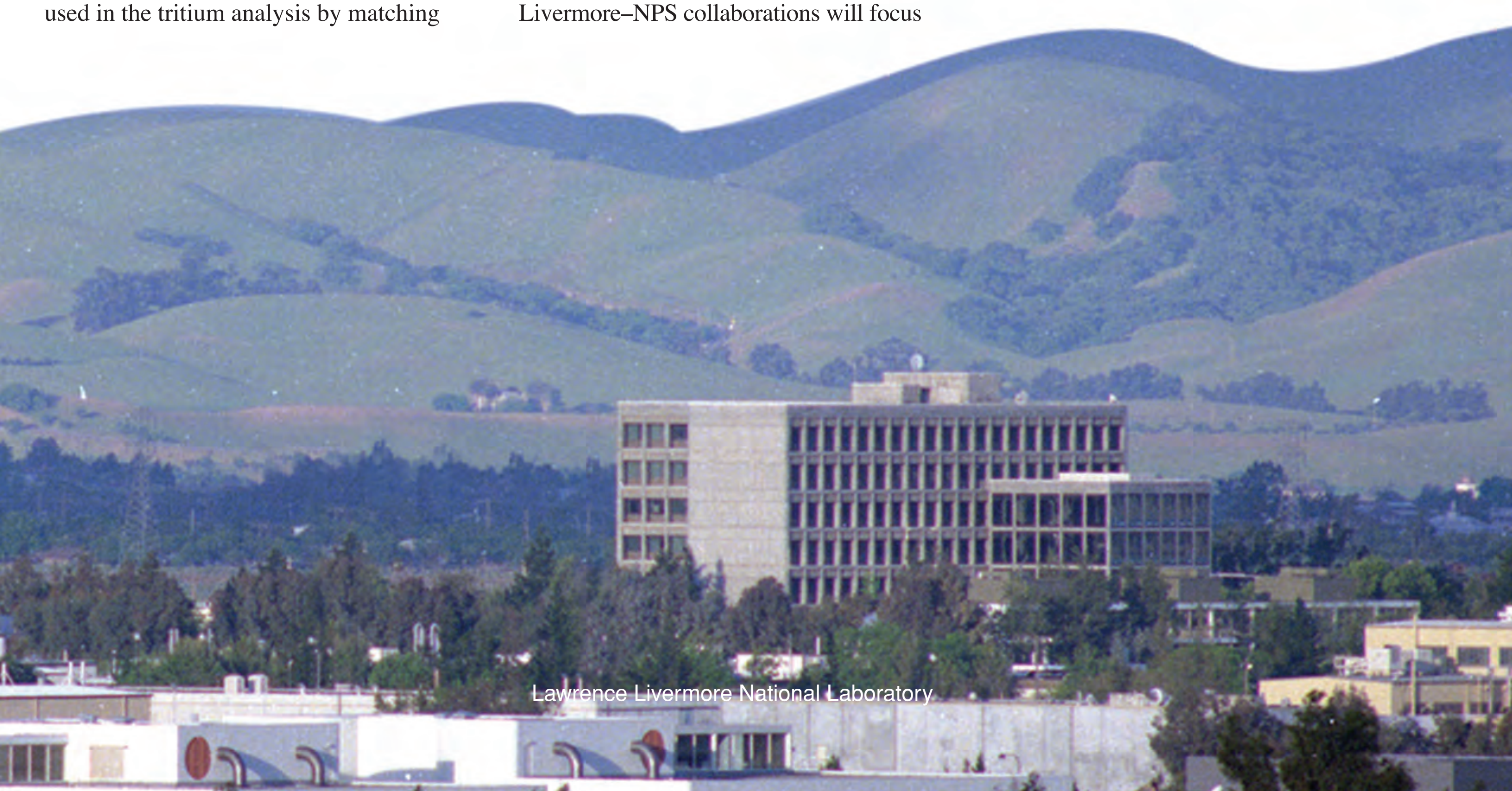
Livermore's strategic collaborations to date have been with UC, but URP is also collaborating with other institutions. This year, Laboratory director Michael Anastasio signed a memorandum of understanding to establish a strategic collaboration with the Naval Postgraduate School (NPS). Livermore–NPS collaborations will focus on joint program development for the Department of Defense.

As the Laboratory increases its number of strategic collaborations with other institutions, UC and Livermore will continue to nourish the relationship they have formed from working together for more than 50 years. "Livermore has powerful, deep, and historic connections with UC," says Anastasio. "Our strategic collaborations have enhanced the quality of the Laboratory's research programs and helped us recruit the best people. These collaborations are good for the Laboratory, good for UC, and good for the nation."

—Gabriele Rennie

Key Words: accelerator mass spectrometry (AMS), adaptive optics, biophotonics, Center for Accelerator Mass Spectrometry (CAMS), Center for Adaptive Optics, Center for Biophotonics Science and Technology (CBST), Institute of Geophysics and Planetary Physics (IGPP), University of California (UC), UC Office of the President (UCOP), University Relations Program (URP).

For further information contact Laura Gilliom (925) 422-9553 (gilliom1@llnl.gov).



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

Alternating-Polarity Operation for Complete Regeneration of Electrochemical Deionization System

Tri D. Tran, David J. Lenz
U.S. Patent 6,761,809 B2
July 13, 2004
This electrically regenerable battery of electrochemical cells for capacitive deionization (including electrochemical purification) and regeneration of electrodes is operated at alternate polarities during consecutive cycles. Each regeneration step in a deionization–regeneration cycle is operated at a given polarity so that the polarity of the deionization step in the next cycle is maintained. In one configuration, an end electrode is placed at each end of the battery, adjacent to the end plates. An insulator layer is interposed between each end plate and the adjacent end electrode. Each end electrode includes a single sheet of conductive material with a high specific surface area and sorption capacity—preferably a carbon aerogel composite. Between the two end electrodes, several double-sided intermediate electrodes, which are generally identical, are placed equidistant from each other. As the electrolyte enters the battery, it flows through a continuous open serpentine channel that is defined by the electrodes and is substantially parallel to the electrode surfaces. Because the cells are polarized, ions are removed from the electrolyte and are held in the electric double layers formed at the carbon aerogel surfaces of the electrodes. As the electrodes of each cell are saturated with the removed ions, the battery is regenerated electrically at a reversed polarity from that during the deionization step, thus significantly minimizing secondary wastes.

Multi-Stage Separations Based on Dielectrophoresis

Raymond P. Mariella, Jr.
U.S. Patent 6,761,811 B2
July 13, 2004
This separation system uses multistage traps based on dielectrophoresis. Traps with electrodes arranged both transverse and parallel to the flow of particles are used with combinations of direct current and alternating voltage to trap, concentrate, separate, and/or purify target particles.

Method for Optical Pumping of Thin Laser Media at High Average Power

Luis E. Zapata, Raymond J. Beach, Eric C. Honea, Stephen A. Payne
U.S. Patent 6,763,050 B2
July 13, 2004
A thin, planar laser material is bonded to a light guide of an index-matched material forming a composite disk. A diode array or other pump light is introduced into the composite disk through the edges of the disk. Pump light trapped within the composite disk is depleted as it multipasses the laser medium before reaching an opposing edge of the disk. The resulting compound optical structure efficiently delivers concentrated pump light to a laser medium of minimum thickness. A high-performance cooler is attached to the external face of the laser medium to reject heat. Laser beam extraction is parallel to the heat flux so that optical distortions are minimized.

Biologically-Based Signal Processing System Applied to Noise Removal for Signal Extraction

Chi Yung Fu, Loren I. Petrich
U.S. Patent 6,763,339 B2
July 13, 2004
This biologically based signal-processing system improves signal extraction by removing signal noise. A wavelet transform used with a neural network imitates a biological system. The neural network may be trained to remove noise from the signal using either ideal data derived from physical principles or noiseless signals.

Material System for Tailorable White Light Emission and Method for Making Thereof

Christine A. Smith, Howard W. H. Lee
U.S. Patent 6,774,560 B1
August 10, 2004
With this method for processing a composite material, the white-light emission of the resulting composite can be tailored during the excitation phase. The composite material is irradiated with a predetermined power for a specific time to reduce the size of the nanocrystals and the number of traps in the composite material. This irradiation process intensifies the blue light that the nanocrystals contribute to the white-light emission and decreases the red and green light contributed by the traps.

High Gain Preamplifier Based on Optical Parametric Amplification

Igor Jovanovic, Randal A. Bonner
U.S. Patent 6,775,053 B2
August 10, 2004
This high-gain preamplifier is based on optical parametric amplification. A first nonlinear crystal is connected to a second nonlinear crystal. A beam-relay telescope is then connected to a second beam-relay telescope and to the first and second nonlinear crystals. Finally, a harmonic beam splitter is connected to a second harmonic beam splitter, the first and second crystals, and the first and second beam-relay telescopes.

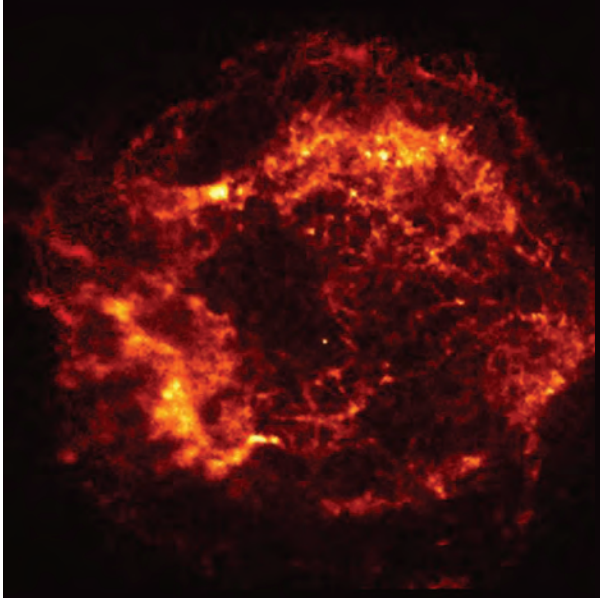
The Power of Partnership

In 1995, Livermore formed its University Relations Program (URP) to oversee the growing number of strategic collaborations with other University of California (UC) campuses and to foster ties with other universities. These collaborations often include the establishment of a center on a UC campus to focus on a particular area of science. For example, the Center for Adaptive Optics at UC Santa Cruz is an outgrowth of early joint work that Livermore and UC conducted within the Institute of Geophysics and Planetary Physics, one of Livermore's six institutes. A new area of science involving a URP-managed strategic collaboration is biophotonics, which uses light and other forms of radiant energy to image, detect, and manipulate biological organisms at the cellular level. URP is also helping to establish UC's newest campus, which will be located in Merced. URP's next goal is to develop strategic collaborations with universities outside the UC system. In addition, the program manages educational programs for kindergarten through graduate school to give students and teachers hands-on experience with Laboratory projects.

Contact: Laura Gilliom (925) 422-9553 (gilliom1@llnl.gov).

U.S. Government Printing Office: xxxx/xxx-xxx-xxxxx

Probing the Universe



High-energy, x-ray focusing optics developed at Livermore will probe deep space and provide new information on exploding stars.

Also in November

• Livermore scientists are developing new ways to analyze the vast amounts of information contained in visualizations from supercomputer simulations.

• A system to quantify cellular processes provides data for predictive models used to understand entire biological systems.

• Ammunition yields may be individually tailored to varying situations and environments using a new Laboratory technology.

Coming Next Month

University of California
Science & Technology Review
Lawrence Livermore National Laboratory
P.O. Box 808, L-664
Livermore, California 94551