Science & Technology REVIEW

September 20

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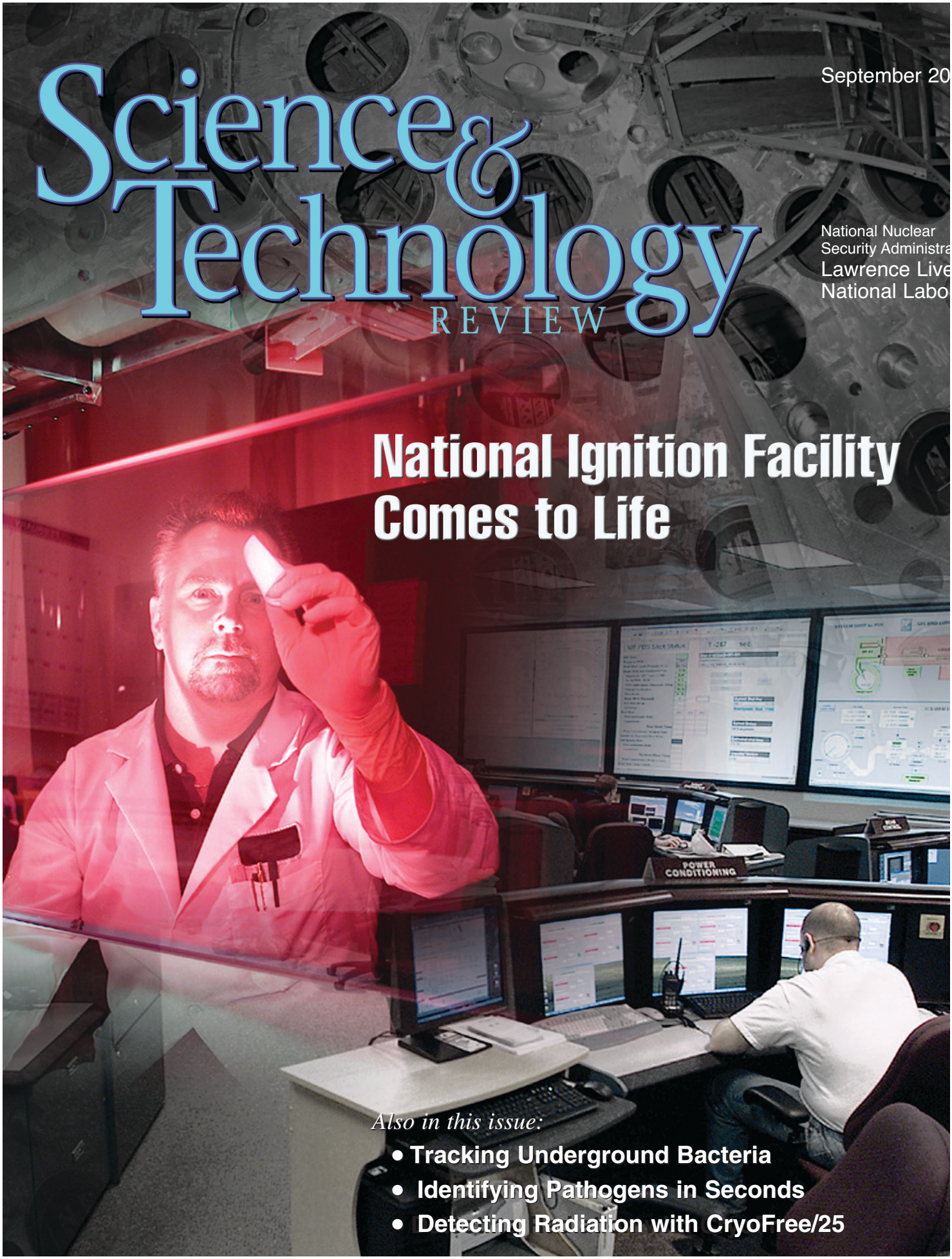

National Ignition Facility Comes to Life

Also in this issue:

- Tracking Underground Bacteria
- Identifying Pathogens in Seconds
- Detecting Radiation with CryoFree/25

About the Cover

Construction on Livermore's National Ignition Facility (NIF) will continue until 2008, but it is already the most energetic laser in the world. With ignition experiments to examine nuclear weapons and high-energy-density behavior, NIF will play a critical role in the National Nuclear Security Administration's Stockpile Stewardship Program. The cover shows two new technologies that make NIF work: its integrated computer control system and high-quality amplifier glass produced with an award-winning manufacturing process. The article beginning on p. 4 reports on current progress in commissioning NIF and on physics experiments just beginning to yield results.

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 assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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National Nuclear Security Administration

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Science & Technology REVIEW

September 2003

Lawrence Livermore National Laboratory

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Homeland security technology is licensed

In a premier example of homeland security technology moving to the marketplace, the Laboratory signed a licensing agreement with ORTEC Products of Oak Ridge, Tennessee, to commercialize RadScout, a lightweight, portable radiation detector and analyzer.

The signing of the licensing agreement took place on June 18, 2003, in a ceremony at the Laboratory attended by National Nuclear Security Administration's Administrator Linton Brooks.

Developed within Livermore's Defense and Nuclear Technologies Directorate, RadScout is intended for emergency first-response teams and inspectors who need rapid detection and identification of material so they can determine the nature and scope of a possible nuclear threat.

RadScout weighs about 9 kilograms. Its miniaturized refrigeration system cools to about 90 kelvins (–280°F) and eliminates heavy, bulky liquid nitrogen cooling for the device's germanium crystal, which is the heart of the device's detection capability. RadScout measures neutrons and gamma rays emitted by radioactive materials and then analyzes them to identify their sources.

The high-performance, high-resolution portable system can be used at border crossings, on cargo ship docks, and in transportation terminals to differentiate between potentially dangerous radioactive materials and otherwise harmless radiation sources.

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Hot on the trail of a solar mystery

Livermore physicist Margarita Ryutova and Theodore Tarbell, a researcher from Stanford–Lockheed Martin Solar and Astrophysics Laboratories in Palo Alto, California, have solved a long-standing astrophysics mystery: Why is the Sun's corona, or uppermost layer of the solar atmosphere, 300 times hotter than the 6,000-degree solar surface, and how does the energy from the Sun's relatively cool surface get transferred to the corona to make it so much hotter than the surface?

Ryutova and Tarbell began to solve this mystery by observing a narrow, 300-kilometer transition region at the bottom of the corona. Using instruments on the Solar and Heliospheric Observatory and the Transition Region and Coronal Explorer, they observed that the collision of magnetic fields of small-scale flux tubes in the photosphere causes a series of regular actions. These actions start from the magnet flux reduction, pass through shock formation, and appear in the transition region as microflares, hot supersonic plasma jets, and explosive events.

"For the first time," says Ryutova, "we could see these shocks in action. When shocks collide, the energy of a system is first squeezed into a very small volume and then gets violently released."

The events are similar to the shaped charges found in modern high explosives. A shaped charge focuses all of its energy on a single line, making it extremely accurate and powerful. Likewise, colliding shock fronts produce dramatic effects in the form of microflares and plasma jets in the solar transition region.

Ryutova and Tarbell's findings provide insight not only into the origin of the solar transition region, but also into how every production, transfer, and release may occur throughout the Sun's and other stars' atmospheres. Their results may help explain the energy output of other cosmic objects that have magnetic fields and gravitation. Results appear in the May 15, 2003, issue of *Physical Review Letters* available at prl.aps.org.

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Monitoring Middle East quakes

Last year, two earthquakes with Richter magnitudes of 5.1 and 4.3 shook the United Arab Emirates (UAE). The ground motion resulted in damage to structures and minor injuries and surprised people because earthquakes are rare for this region.

In October 2002, Laboratory seismologists Keith Nakanishi and Arthur Rodgers traveled to the UAE to talk with various universities about a scientific partnership to record seismic ground motion. The geology department of UAE University in Al Ain welcomed the possibility for collaboration.

In May 2003, Rodgers and technician Pat Lewis installed seismic monitoring stations near Al Ain and Al Hail in a cooperative project with UAE University. This equipment records tiny ground motions, including small earthquakes and explosions in the UAE and large, distant earthquakes. The university's geology department set up a laboratory to analyze data collected through the seismic stations.

"The Persian Gulf," says Rodgers, "is a good place to collect important seismic data, because little or no data have been recorded there. Data from these stations will be used to learn about earthquakes and earth structure in and around the UAE." The Zagros Mountains in Iran, which sit just across the Persian Gulf from the UAE, are active seismic centers, while the Semail Ophiolite, a mountain range that spans Oman and the UAE, is relatively aseismic.

"The new seismic stations will be used to learn where small earthquakes occur and help define seismically active faults," says Rodgers. "This information will help our Emirati colleagues know where to expect and be better prepared for possible future earthquakes."

Rodgers and his colleagues hope to expand their efforts to other countries, so that eventually a network of seismic stations can monitor earthquake activity throughout the Middle East.

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The National Ignition Facility Is Born

OVER the last few months, the National Ignition Facility (NIF) has begun its transition from vast construction project to the largest laser experimental facility in the world. Recent tests of the laser have demonstrated that with just the first four beams operating, NIF is already the most energetic laser ever built. When all 192 beams are blazing in 2008, NIF's extraordinary capabilities will make possible experiments in fusion ignition, weapons physics, and basic science that many researchers have anticipated for 50 years.

With the successful commissioning of these four beams, NIF has made another, more subtle transition as well. Four years ago, the project was widely viewed as having serious difficulties. Today, those much publicized concerns are long gone. Not only is the project back on track, but the laser is also performing spectacularly.

This turnaround would not have been possible without the close working relationship of Laboratory scientists and engineers with numerous industrial partners. The challenges associated with building the world's largest laser are enormous, particularly in managing such a large, technically complex project, developing laser and optical technologies, and constructing and aligning the superclean environmental enclosures that contain the laser beams. But over time, the team cleared one hurdle after another. The result is that many of the components in NIF's laser system represent significant advancements of current technologies while other components are entirely new—and they all work together as designed.

Two years ago, Project Manager Ed Moses conceived of an imaginative and insightful strategy for reaching first light on NIF—commissioning one group of four beams first. We called it NIF Early Light, to show that at least one of every system in the facility could operate in accordance with full performance specifications. With its success, we would be sure that when all construction is complete, the laser will operate at the level required. As the article beginning on p. 4 explains, NIF is already meeting performance specifications.

Much like today's supercomputers, NIF was built to be a parallel system. A typical construction project proceeds linearly from conceptual design through final design, construction, commissioning, and turnover to the owner for operation. With NIF, however, construction and commissioning are continuing in parallel with operation of the laser for physics experiments. Although we still have another five years to go before the last optical system is installed, we are already aiming the laser at targets in the target chamber for physics experiments.

The goal for NIF, of course, is to run successful experiments. With just the first beams, NIF will begin to make significant contributions to the nation's Stockpile Stewardship Program and to basic science in the areas of astrophysics, hydrodynamics, material science, and plasma physics. Ultimately, NIF is designed to demonstrate fusion ignition—the combining, or fusing, of two light nuclei to form a new nucleus and release energy from the nuclear reaction. NIF's powerful array of lasers will start the fusion process. With ignition experiments, Laboratory scientists can examine the conditions associated with the inner workings of nuclear weapons and the processes that power the Sun and stars. Such experiments are a key element in the National Nuclear Security Administration's approach to maintaining the nuclear stockpile. Ignition experiments will also enhance the ability to eventually produce fusion energy for electrical power production.

We at the Laboratory are most appreciative of those who, four years ago, had confidence in our ability to tackle the technical and management challenges that were impeding progress on NIF. They took a risk in allowing us to continue with the project. As NIF comes to life as a mature, high-performing experimental facility, we take pride in showing that their confidence was warranted.

■ George Miller is associate director for National Ignition Facility Programs.

The National Ignition Facility Comes to Life

Successful commissioning shows that scientific vision, technical innovation, a talented team, and sheer hard work prevail.

"NIF-scale" runs the gamut from its facility the size of a football stadium and 192 beamlines (background) to an ignition target held inside the hohlraum (foreground).

FIRST conceived of nearly 15 years ago, the National Ignition Facility (NIF) is up and running and successful beyond almost everyone's expectations. During commissioning of the first four laser beams, the laser system met design specifications for everything from beam quality to energy output. NIF will eventually have 192 laser beams. Yet with just 2 percent of its final beam configuration complete, NIF has already produced the highest energy laser shots in the world.

In July, laser shots in the infrared wavelength using four beams produced a total of 26.5 kilojoules of energy per beam, not only meeting NIF's design energy requirement of 20 kilojoules per beam but also exceeding the energy of any other infrared laser beamline. In another campaign, NIF produced over 11.4 kilojoules of energy when the infrared light was converted to green light. And an earlier performance campaign of laser light that had been frequency-converted from infrared to ultraviolet really proved NIF's mettle. Over 10.4 kilojoules of ultraviolet energy were produced in about 4 billionths of a second. If all 192 beamlines were to operate at these levels, over 2 megajoules of energy would result. That much energy for the pulse duration of several nanoseconds is about 500 trillion watts of power, more than 500 times the U.S. peak generating power.

And how will that vast energy and power be used? Scientists interested in the behavior of materials at high temperatures and pressures will be able to explore entirely new states of matter and generate accurate data at extreme pressure. NIF can create temperatures—tens of millions of degrees—similar to those inside the Sun and stars. NIF's carefully controlled pulses can also drive experiments to pressures never before seen in a laboratory setting. NIF will achieve pressures higher than a billion times atmospheric pressure, which is over a million times the pressure at the deepest part of the oceans and equivalent to pressures at the center of the Sun. Some of the earliest experiments are designed to examine how various materials fail and demonstrate the behavior of planetary fluids such as those found inside Jupiter.

The sheer magnitude of the National Nuclear Security Administration's (NNSA's) $3.448-billion NIF is staggering. The building is the size of a football stadium, nearly 26,500 square meters and 10 stories high, with several adjacent support facilities. All that space is chock full. Commissioning Manager Bruno Van Wonterghem comments that this project has tested the limits of how much high-tech equipment can be squeezed into a given space.

The laser system is composed of more than 3,000 40-kilogram slabs of laser glass, 26,000 smaller glass optics, 3,000 laser mirrors and lenses, and over 1,000 crystalline optics. (See the figure on p. 6). More than 7,600 of the largest flashlamps ever built, each of them 2 meters long, power the laser system. When the full constellation of beams is operating in 2008, NIF will deliver more than 50 times the energy of Livermore's Nova laser, which was decommissioned in 1999, or the Omega laser at the University of Rochester Laboratory for Laser Energetics.

"But the most important thing about NIF," says Ed Moses, NIF project manager since 1999, " is not the parts count. It's how NIF is designed and integrated. Designing and commissioning any large project demands a systems approach. Putting together NIF's many systems has been like playing chess against a grand master. You can't win if you only look one move ahead at a small part of the board. We've had to look at the whole effort all at once and as far ahead as possible." Moses is quick to credit physicist Mary Spaeth, NIF's chief technical officer, and her systems engineering team for delivering a fully integrated and flexible target-shooting system as well as Ralph Patterson, NIF's chief operations officer, for managing the budget and schedule strategy.

Built-In Flexibility

Unprecedented flexibility has been designed into NIF to maximize its experimental capabilities. Changing the laser's energy or pulse shape is easy. Ultraclean modular optical systems simply plug in all along the beampath and can easily be removed for maintenance or upgrade. Diagnostic equipment at the target chamber is also designed for "plug-and-play" operation.

The activation of the first four beams, known as a quad, took place a year earlier than originally planned. This campaign, known as NIF Early Light, was designed to demonstrate NIF's capability to deliver high-quality energetic laser beams in support of experiments. Also, notes Co-Commissioning Operations Manager Gina Bonanno, "By validating virtually all representative parts of NIF with that first quad, we were able to untangle some unforeseen snags. We think that the rest of the beam commissioning can proceed smoothly."

Moses adds, "Because each NIF bundle—an upper and lower quad—is essentially independent from the others, NIF will be operational while the installation of additional beams proceeds."

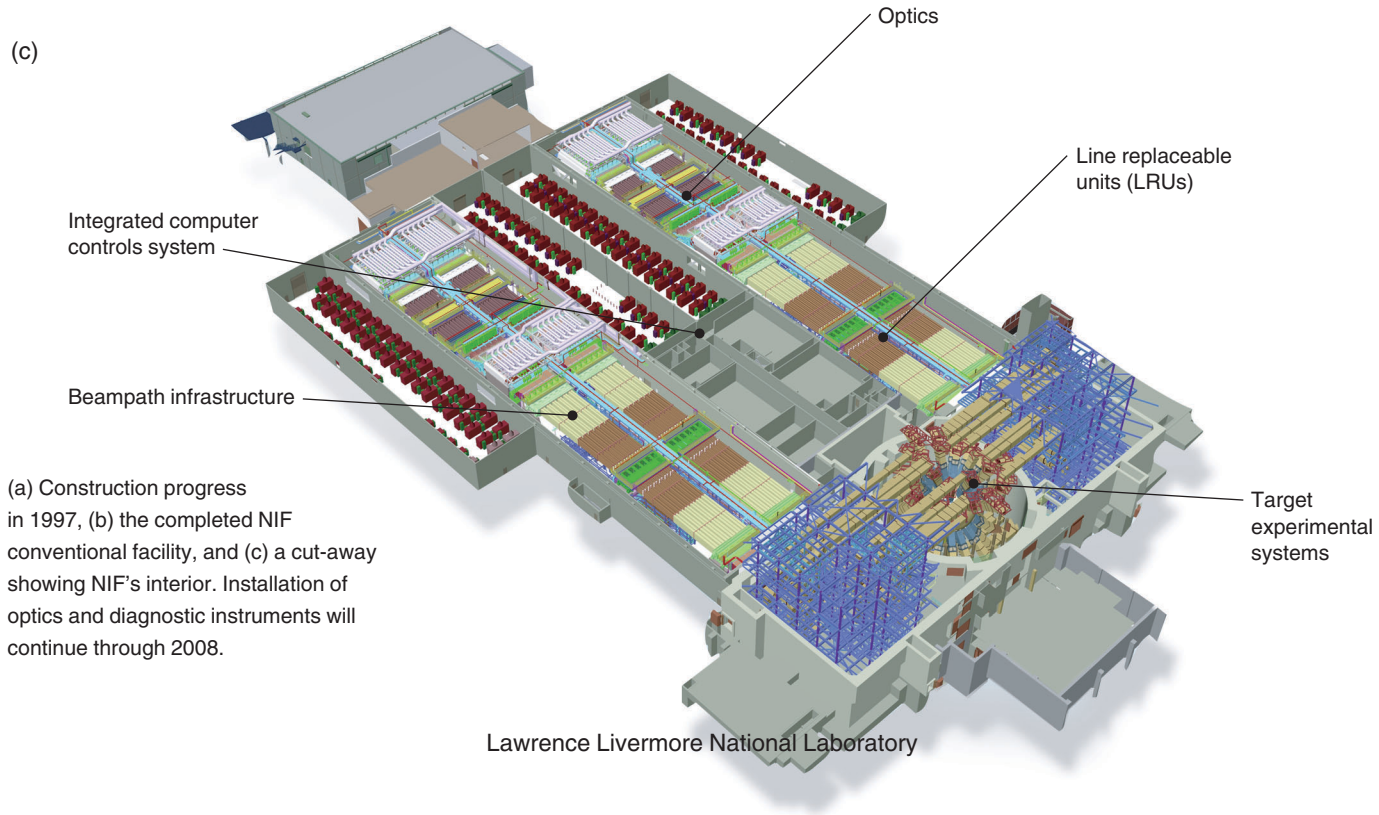
By June 2006, a total of 48 beams, a cluster, will be operational. After that,

the other clusters will be installed and commissioned at a much faster rate.

NIF, a cornerstone of NNSA's Stockpile Stewardship Program, will provide assurances of the performance and reliability of the U.S. stockpile. Even with just a few beams operational, NIF will make significant contributions to astrophysics, hydrodynamics, materials science, and plasma physics. By 2008, all 192 beams will be routinely firing in experiments that will create physical regimes never before seen in any laboratory setting—to benefit maintenance of the U.S. nuclear weapons stockpile, spur advances in fusion energy, and open up new vistas in basic science.

Building Success

Thousands of Livermore engineers, scientists, and technicians have been involved in NIF over the last 15 years, first in proposing that such a massive laser might even be possible and later in designing the specialized equipment housed inside, much of it the first of its kind. Hundreds more construction personnel, employees of equipment suppliers, and testing and



(a) Construction progress in 1997, (b) the completed NIF conventional facility, and (c) a cut-away showing NIF's interior. Installation of optics and diagnostic instruments will continue through 2008.

commissioning experts have brought the NIF dream to reality.

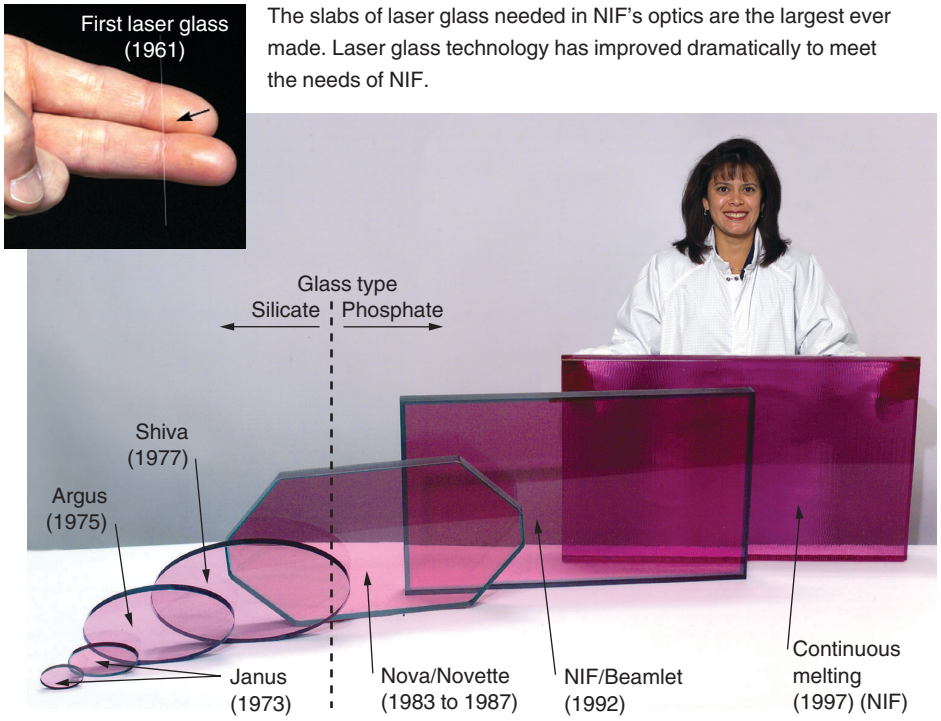
When Livermore broke ground for NIF's conventional facilities (the building and supporting infrastructure), Valerie Roberts was NIF's construction manager. Her team knew this phase of the project was the largest the Laboratory had ever attempted, and it had to be complete by the end of September 2001. But the construction schedule couldn't anticipate everything. In November 1997, El Niño rains flooded the NIF site. A month later, a backhoe uncovered the remains of a 16,000-year-old mammoth. Niffie, as local schoolchildren named him, had to be excavated by an archaeological team from the University of California at Berkeley.

Meanwhile, NIF's target chamber was being built. The spherical chamber is made from 6,800-kilogram, 10-centimeter-thick flat aluminum plates, each like a segment of a volleyball. The plates were cast in West Virginia, shaped in France, precision-edge machined in Pennsylvania, and then shipped to Livermore where they were fit together and welded. After assembly, 192 holes of various sizes were precisely located and bored for laser beams, diagnostic instruments, targets, and other equipment that will be put into the chamber. The completed chamber was hoisted onto a concrete pedestal inside the target building in June 1999.

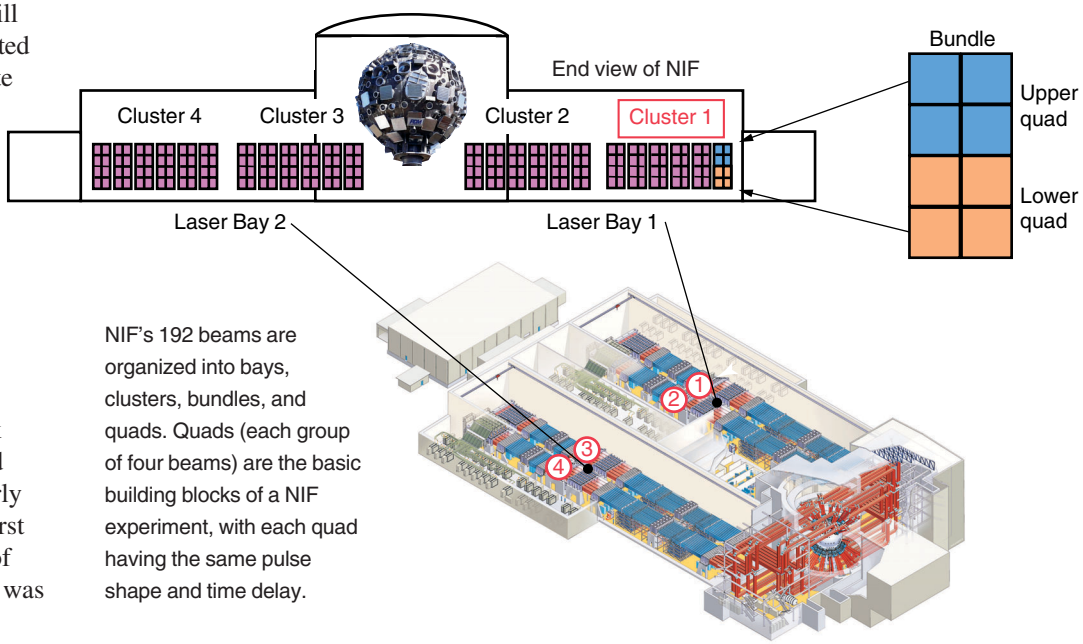
The chamber serves as an optical bench holding all of the frequency conversion and focusing optics. It is designed to withstand debris and neutron and gamma radiation from experiments and to maintain vacuum and cryogenic environments for experiments.

As the conventional facility took shape, the team developed a revised baseline plan to implement NIF Early Light. Its goal was to activate the first beamlines more than a year ahead of schedule. Thus, before the building was complete, workers were already beginning to install the laser beampath.

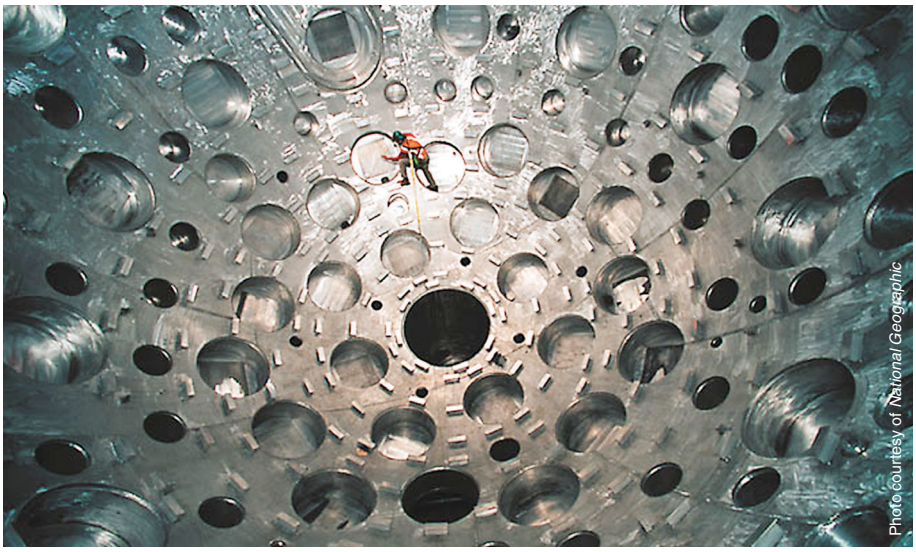
By the time construction of the conventional facility was completed in September 2001, the first modular line replaceable unit (LRU) had been installed and its cleanliness requirements measured and verified. Says Associate Project Manager Doug Larson, "The LRU engineering team designed over 20 different types of LRUs, successfully balancing cost with precision, stability, and cleanliness requirements. Although



The slabs of laser glass needed in NIF's optics are the largest ever made. Laser glass technology has improved dramatically to meet the needs of NIF.



NIF's 192 beams are organized into bays, clusters, bundles, and quads. Quads (each group of four beams) are the basic building blocks of a NIF experiment, with each quad having the same pulse shape and time delay.



Inside NIF's 10-meter-diameter target chamber.

some assemblies are the size of a phone booth, all must repeatably position optical surfaces to within a fraction of a millimeter." (See the box on p. 10 for more information on LRUs and other laser technologies.) A month later, the master oscillator, which provides the low-energy seed laser pulse for NIF, generated its first light.

By August 2002, the first Laser Bay 2 beamline was successfully aligned using a light source propagated through an entire beamline. The alignment provided the first test of the integrated operation of laser controls, safety, and utilities systems. "While this accomplishment may appear simple, it was actually quite remarkable," says

In April 2003, the NIF team celebrated 3 million hours without a lost workday injury. By July, the number of hours had grown to 3.3 million.

Why "Ignition" Is NIF's Middle Name

The idea for the National Ignition Facility (NIF) grew out of the decades-long effort to generate self-sustaining nuclear fusion reactions in the laboratory. Livermore's Director Emeritus John Nuckolls was among the first to conceive of the idea shortly after the laser was invented. Theorists, supported by years of experiments, have defined the conditions required to compress and heat a fuel of deuterium and tritium (isotopes of hydrogen) to temperatures and pressures that will ignite and burn the fuel to produce energy gain.

The energy and power of NIF's 192 beams will compress and heat a tiny fusion capsule to those extreme conditions. Unlocking the stored energy of atomic nuclei will produce about 10 times the amount of energy required to initiate the self-sustaining fusion burn. With ignition experiments, scientists can examine the conditions associated with the inner workings of exploding nuclear weapons, understand the processes that power the Sun and stars, and enhance our ability to eventually produce fusion energy for electrical power production.

Jeff Atherton, project manager for the beampath infrastructure system. “It validated the precision construction and surveys required to achieve NIF’s pointing accuracy over the length of its 300-meter beampath—which is like throwing a strike from Pac Bell Park in San Francisco to Dodger Stadium in Los Angeles.”

In September 2003, the construction team completed the three-year effort to build the beampath through which laser beams are transmitted, from the preamplifier system to the switchyard. Through these ultraclean enclosures, with their controlled temperature and humidity, 192 precision-aligned laser beams will eventually zoom to the switchyard in about one-millionth of a second.

“Perhaps the most beautiful part of NIF is being built right now,” adds Chief Engineer Rick Sawicki, who has been part of the NIF team since 1993. The mirror frames that redirect the linear arrangement of laser beams to the center of the spherical target chamber are creating “a forest of shining silver beamlines coming through the floor and ceiling of the target bay.”

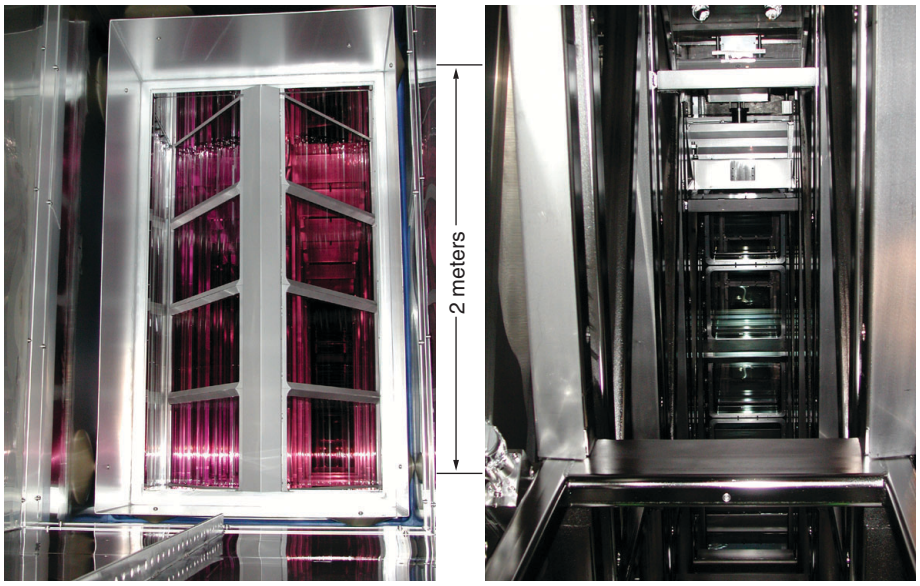
Throughout construction and commissioning, safety has been the number one priority. In July 2003, the construction team surpassed 3.3 million work hours in 950 consecutive days without any workdays lost to injuries. The National Safety Council honored NIF with Perfect Year awards for 2001 and 2002, and the project team received a Construction Industry Safety Excellence Award from the Construction Users Roundtable. Site Manager Vaughn Draggoo, Site Safety Manager Arnie Clobes, and NIF Safety Integrator George Stalnaker are justifiably proud of this outstanding safety record accomplished in a complex work environment.

Record-Setting Beam Quality

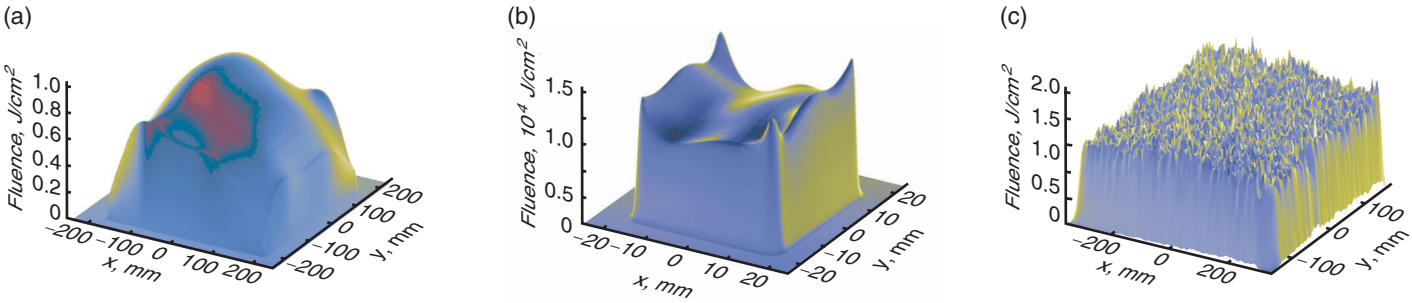
A key to NIF’s ultimate worth and ability to perform physics experiments is the quality of its laser light. To test and commission the laser, shot campaigns are carefully planned and modeled in advance.

In November 2002, commissioning teams completed a series of laser shots that verified the absence of parasitic oscillations within NIF’s main and power amplifiers. Parasitic oscillations are “renegade” light beams that divert from the main laser path. If present, they can degrade laser performance or even damage laser components. They can occur because of reflections all along the amplifiers’ “hall of mirrors.”

A few weeks later, in early December, the first amplified infrared laser light ran through Laser Bay 2 and



The interiors of NIF’s many laser components form a hall of mirrors. Parasitic oscillation paths that could degrade the laser’s performance have been mitigated.



Modeling that predicted (a) the gain profile (shape of the beam after amplification) was also used to design (b) a reciprocal intensity mask for the preamplifiers so the resulting beam would have uniform intensity. The result is shown in (c) an actual measurement of a NIF intensity profile. (J/cm^2 = joules per square centimeter; mm = millimeters.)

into Switchyard 2. This 43-kilojoule shot in four beams exceeded a NIF milestone of 10 kilojoules of amplified light per beam. Long before that first quad of beams was fired, extensive scientific modeling had characterized almost every facet of its performance: the shape of the beam, the distortions collected as the beam travels through the amplification system, and the shape of the pulse.

Modeling results were used in the engineering efforts to perfect all aspects of the laser beam. For example, modeling predicted the gain profile, that is, the intensity of the beam front after it has been fully amplified. Because a uniform beam is essential, an intensity mask installed in the preamplifiers compensated for the anticipated gain profile. Similarly, the deformable mirrors (described below) compensate for predicted beam distortion and allow the beam's focal spot in the target chamber to be nearly perfect. Calculations also indicated the need for modifications that smooth the temporal shape of the beam.

In April, when the commissioning team ran the infrared shot campaign that produced 83 kilojoules, reaching this energy milestone requirement of 20 kilojoules per beam was not a

The Technologies That Make NIF Possible

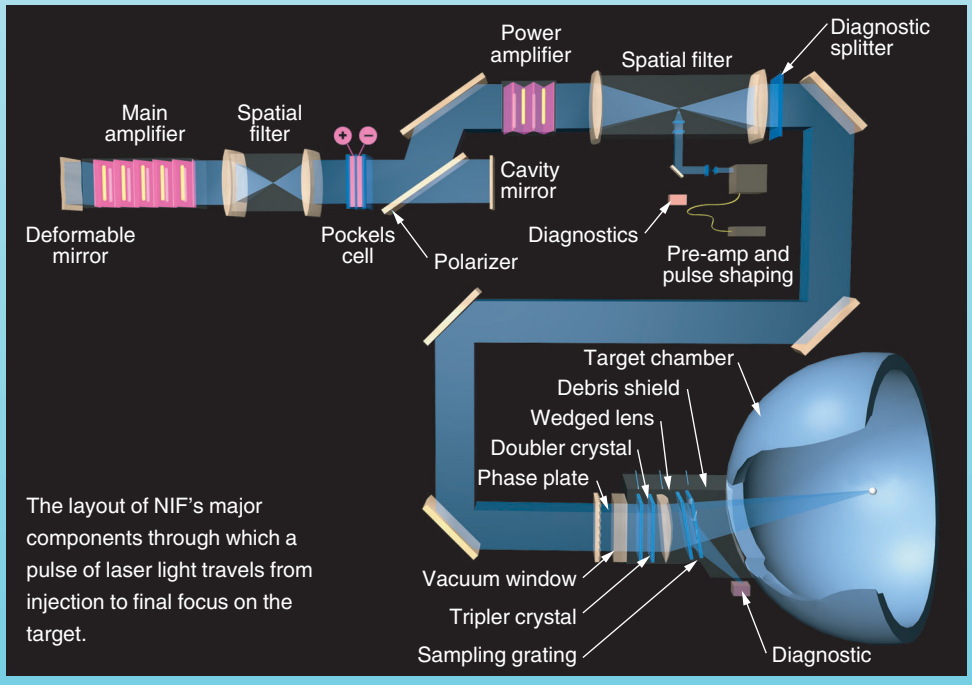
The National Ignition Facility's (NIF's) laser components shape and smooth the initial pulse, amplify it over a quadrillion times, and precisely direct it at a tiny target in the target chamber. Many components have required significant advances in laser technology, while others are entirely new. As subsystems were developed, most were tested on Beamlet, a scientific prototype that operated from 1994 to 1998. Project Manager Ed Moses refers to six of the laser's systems as the "six miracles of NIF," because without these breakthroughs, NIF would be far less capable or perhaps could not have been built at all.

The first miracle, at the beginning of the system, is the injection laser system. It makes the seed for the laser beams—a light pulse that contains all the spatial, temporal, and spectral information that the big laser glass systems amplify. All components of the injection laser system must operate in perfect harmony so that each quad of beams will have its specified energy and timing. The 48 injection laser systems are the most sophisticated lasers of their kind.

Next stop for the pulse is the main amplifier. For every bundle of eight beams, an amplifier module uses 128 slabs of neodymium-doped phosphate glass surrounded by flashlamps to amplify the beams many times over as they travel back and forth through the glass.

Amplifiers and other optical components have been made modular to reduce system downtime and enhance maintenance. Over the years, Livermore scientists learned of the need to maintain a clean environment around the path of the laser to avoid damaging the laser's optics and degrading the beam. The optical modules, known as line replaceable units (LRUs), are assembled in the Optics Assembly Building, a clean-room facility adjacent to the main building. Robotic assembly facilitates the handling of parts as heavy as 1,800 kilograms. LRUs are transported to the laser area via a portable clean room to maintain cleanliness all the way through installation and alignment. LRUs can easily be removed and refurbished or upgraded.

The neodymium-doped phosphate laser glass, the second miracle, is the result of a six-year joint research and development program with industrial partners Schott Glass Technologies and



The layout of NIF's major components through which a pulse of laser light travels from injection to final focus on the target.

surprise. By July, the team achieved energy of 26.5 kilojoules per beam, for a total of 106 kilojoules. Models predict that 30 kilojoules of infrared light per beam can be attained.

The result of this huge modeling and technology effort is the best beam quality ever demonstrated in a fusion-class laser system and the highest-energy infrared, green, and ultraviolet laser system operating anywhere in the world.

Controlling It All

Commissioning Operations Managers Gina Bonanno and Steve Johnson are working with Van Wonterghem to assure the facility's success. "Making sure everything works and works together," is how Johnson sums up his job.

"Because of the size of the project and with so much going on at once, little things come up every day that have to be dealt with," adds Bonanno. "We are constantly evaluating priorities, deciding on trade-offs. Some part isn't going to be here on time. How do you work around this challenge?"

Physicist Ralph Speck, 75 years old and mostly retired, is assisting with NIF commissioning, too. He has been involved in the commissioning of almost all of Livermore's lasers since Janus, and he led the commissioning

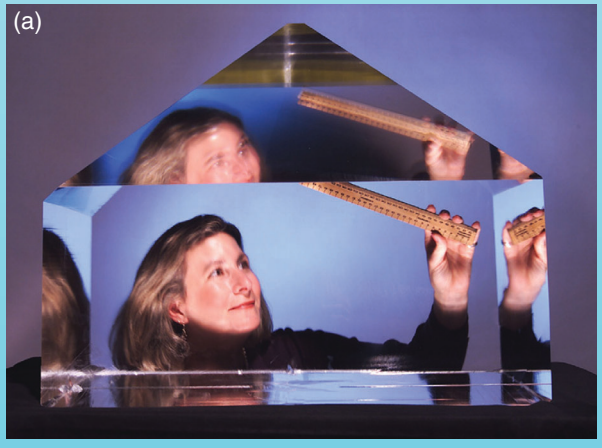
Hoya Corporation. This effort, led by Associate Project Manager Jack Campbell, developed a revolutionary process for manufacturing meter-size slabs of laser glass that is 10 times faster, 5 times cheaper, and with better optical quality than previous batch processes. The team won an R&D 100 Award and a Lawrence Livermore Science and Technology Award for developing this process.

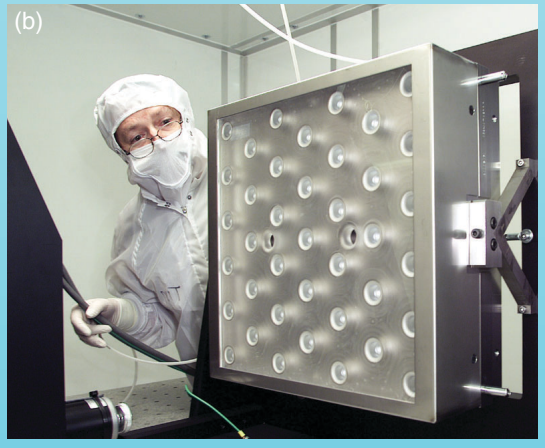
The next miracle is the plasma electrode Pockels cell (PEPC, pronounced like the soft drink) in the main amplification system. Each PEPC uses a thin slice of KDP (potassium dihydrogen phosphate) crystal measuring 40 by 40 centimeters and sandwiched between two gas-discharge plasmas. The plasmas are so tenuous that they have no effect on the laser beam passing through the cell, yet they serve as effective conducting electrodes. The PEPC is an optical switch, allowing the laser light to pass through the amplifiers four times. Says Moses, "As if NIF weren't big enough already, it would be almost 250 meters longer without the PEPC and probably could not have been built."

The fourth miracle was the development of technologies to quickly grow large, high-quality KDP crystals and to machine them to NIF's tight tolerances. KDP is used in the PEPCs to switch the polarization of the light and in the final optics to convert laser light from infrared to both green and ultraviolet light. About 600 large slices of KDP were needed, and growing big enough crystals by traditional methods would have taken years. A fast-growth method, pioneered in Russia and perfected at Livermore, produces crystal boules of the required size in just months. This team also won an R&D 100 Award. To machine and finish the crystal slices to NIF tolerances, the KDP crystal manufacturer is using methods developed by Livermore precision engineers.

As the NIF beams fly through the amplifiers, they accumulate wavefront aberrations from miniscule optical distortions in the amplifier glass and other materials. To compensate for the distortions, Livermore researchers developed a sort of "prescription lens," a 40-centimeter deformable (movable) mirror, another miracle. Each laser beamline incorporates a deformable mirror with 39 computer-controlled actuators on the back to adjust its surface. The mirror corrects distortions in the beam profile so that it can be focused to a submillimeter spot in the target chamber.

The sixth and final miracle is NIF's control system. "Without this system, NIF could not be the well-integrated system that it is," says Moses. As in all of NIF, flexibility is designed into the control system. After more than a decade of experience with Nova, Livermore designers know NIF will evolve over its projected 30-year lifetime.





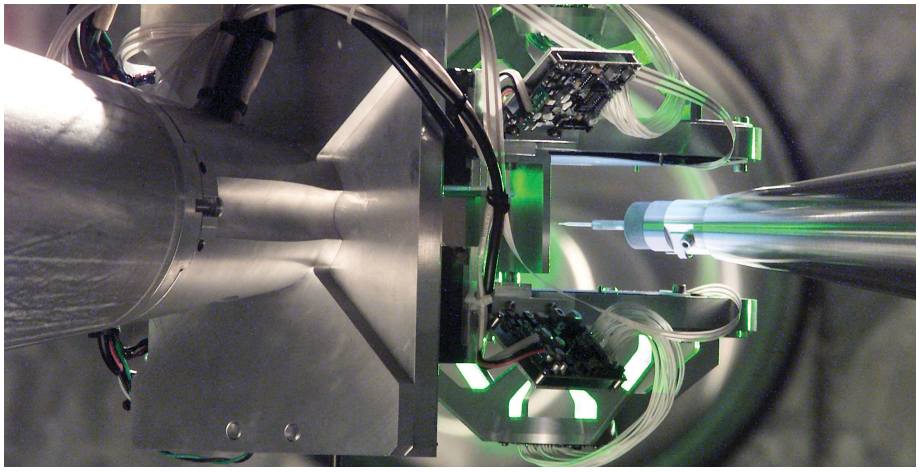
(a) A KDP crystal for NIF's optical system and (b) a deformable mirror to eliminate wavefront aberrations in the laser beam.

of Nova in the early 1980s. Speck says, "The engineering on NIF is better than on any big laser I've ever worked on before—and I've worked on almost all of them."

Today, laser shots to commission the laser and for the first physics experiments are running at up to three a day. None of them would be possible without NIF's control system. According to Associate Project Manager Paul Van Arsdall, the likes of the integrated computer control system have never before been seen on a laser. (See *S&TR*, November 1998, pp. 4–11.)

NIF's control system will eventually handle the computerized monitoring and control of some 60,000 elements throughout the system, including safety interlocks, alignment systems, mirrors, lenses, motors, sensors, cameras, amplifiers, capacitors, and diagnostic instruments. Twenty-four hours a day, the system supervises shot setup and countdown; oversees machine interlocks to protect hardware, data, and personnel; generates reports on system performance; provides operators with graphical interfaces for control and system status displays; performs alignment, diagnosis, and control of power conditioning and electro-optic subsystems; and monitors the health of all subsystems and components.

NIF's control system handles the computerized monitoring and control of 60,000 elements throughout the system.



Inside the target chamber, the target alignment sensor positioner (at far left) is being used to align a tiny target, which would be at the tip of the target positioning system entering from the right. The green light illuminates objects within the chamber.

NIF's Reason for Being

Exploring the world of high-energy-density physics is NIF's entire reason for being. Using NIF's unique capabilities, scientists will delve into the inner workings of nuclear weapons, astrophysical phenomena such as supernovae, and materials under extreme conditions.

Physicist Brian MacGowan is the program manager for the facility diagnostics that collect information during each experiment. He notes that because the first quad of beams is highly efficient in delivering energy to the target, NIF can create energetic laser pulses with the longest duration and most precisely tailored shape ever achieved on a large glass laser system. NIF also has the flexibility to generate a range of pulse shapes and durations with varying power and energy. Tailored pulses will be key for all experiments on NIF, providing the capability to drive materials and complex targets to states of high energy density.

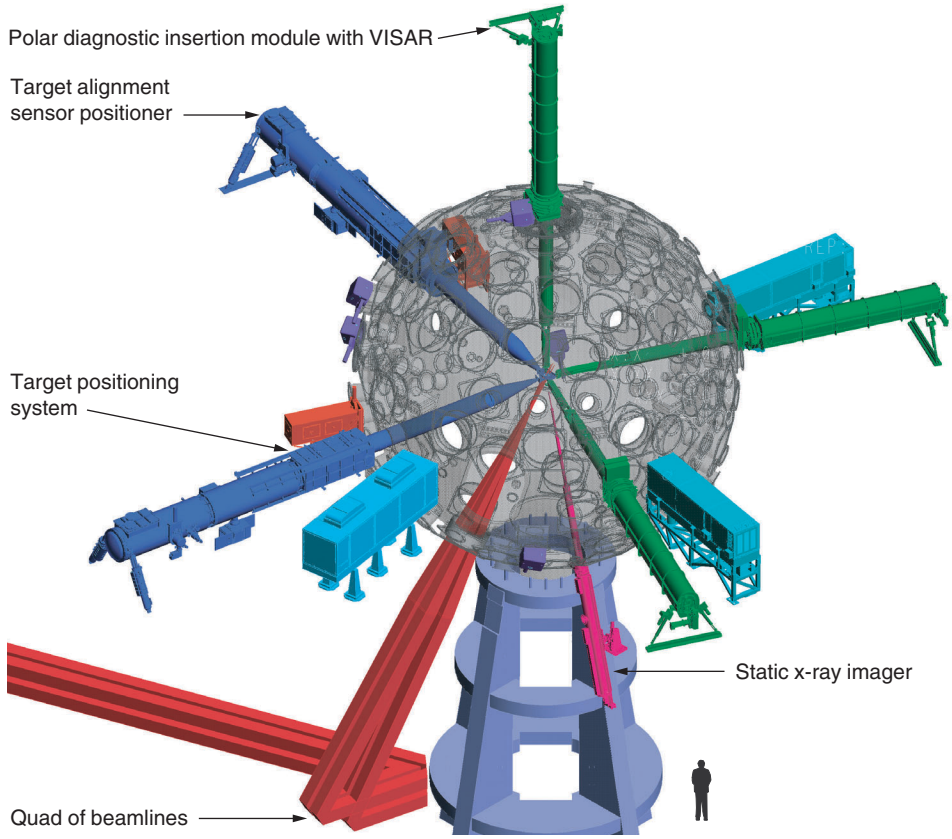
Permanent facility diagnostics in NIF's target area include x-ray imaging systems, high-speed framing cameras, and the largest-ever VISAR laser interferometer, which measures the velocity of shock waves. Eventually, as many as 40 diagnostic tools can be installed, either permanently or

temporarily, on the target chamber. Also in place is the full-aperture backscatter detector under the target chamber. Characterizing the light backscattered from experiments provides information about laser–plasma interactions that is critical for future fusion experiments.

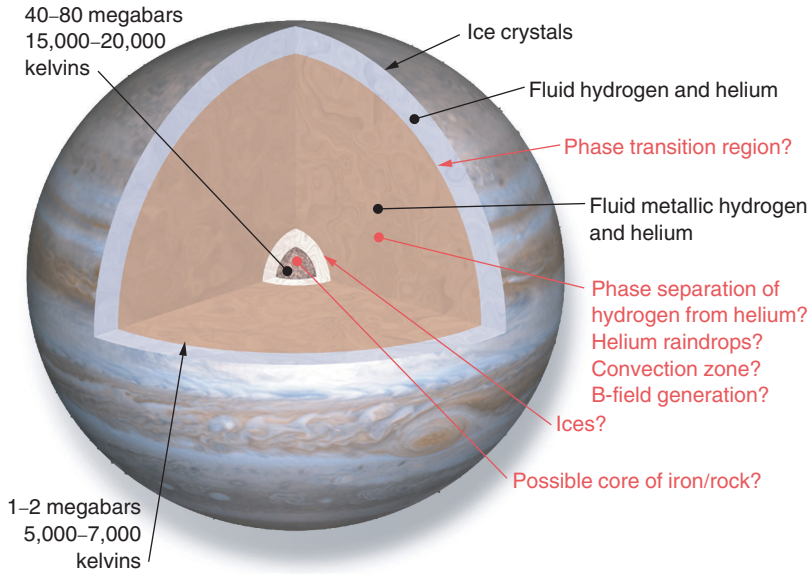
With NIF's tailored pulses, physicists can generate the longest lasting high-density plasmas ever produced. A set of early experiments will use special gas-filled targets, whimsically called gas bags, to produce large-scale plasmas that approach the conditions expected to be found in later gas-filled hohlraum fusion experiments.

Hydrodynamics—the behavior of fluids of unequal density as they mix—is an important issue for stockpile stewardship and for understanding the behavior of stellar evolution and supernovae. Weapons use solid materials, but solid materials driven to states of high energy density tend to behave as if they were fluids. The hydrodynamic behavior of mixtures of heavy and light materials is also key to understanding astrophysical phenomena such as supernovae. Even in the first hydrodynamic experiments using four beams, in which one beam backlights the experiment, the remaining three offer a major increase in capability over that available at other experimental facilities.

NIF-scale cryogenic ignition targets, placed inside a hohlraum, are expected to be ready for use in 2006. When they are combined with more laser beams, increasingly sophisticated fusion experiments will begin. And when even more beams are firing on a target, NIF will approach the high temperatures seen inside exploding nuclear weapons. As ignition and higher-energy-density experiments become possible, additional diagnostics will be commissioned to detect neutrons, gamma rays, and other phenomena



The first quad of beams is shown entering the target chamber. Thus far, four instruments mounted on diagnostic instrument manipulators have been commissioned to take measurements during physics experiments.

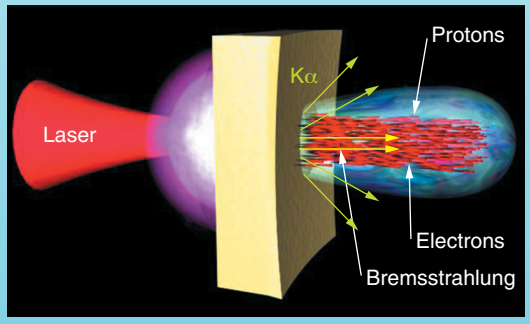


A series of experiments planned for NIF will help scientists answer questions about the structure of Jupiter. NIF will be able to re-create the dense conditions inside Jupiter.

NIF into the Future

Laboratory scientists are working independently of the NIF project to find ways to increase NIF's flexibility and improve its experimental capabilities in the future.

Researchers at the Laboratory are exploring how to operate NIF's lasers at two colors instead of one, allowing even higher energies and longer pulse lengths. Larry Suter, winner of the 2003 Edward Teller Award for his contributions to inertial confinement fusion research, has proposed that a high-energy green laser system could provide more robust and higher-gain ignition. Studies have shown that these conditions could also be advantageous for experiments on equations of state and strength of materials. Simply removing one of the crystals in the final optics and changing the focusing lens allow a single beamline or even all beamlines to operate as green instead of ultraviolet. A quad of NIF beamlines will be available for experiments designed to study these options in the next two years.



A high-energy, short-pulse petawatt laser will act as a novel source of hard x rays, electrons, and protons that can be used for radiography and heating of matter.

Another goal of current research is to explore the benefits for some NIF beamlines to function as petawatt lasers. The pulse of an extremely high-power petawatt laser lasts for just a few trillionths of a second—a thousand times shorter than NIF's usual pulses—to deliver highly intense light onto targets. (See *S&TR*, October 2001, pp. 13–15.) With a modification to the master oscillator and a change to the final optics, individual NIF beamlines can operate as petawatt lasers that will allow experimentalists both to improve the high-energy and high-intensity backlighting for experiments and to explore physics processes not accessible with the baseline NIF system. The ability to generate a high-energy petawatt laser will revolutionize NIF's already unparalleled scientific capabilities.

"NIF has been designed to be a platform for cutting-edge science in the decades ahead," says Project Manager Ed Moses. "NIF's flexible beamline architecture and plug-and-play LRU configuration ensure that NIF can continually respond to the needs of the experimental community, serving us today and the young scientists of tomorrow."

important for the Stockpile Stewardship Program.

Expectations Are High

Well before 2008 and completion of construction, experiments on NIF will make significant contributions to stockpile stewardship, fusion energy, and basic science.

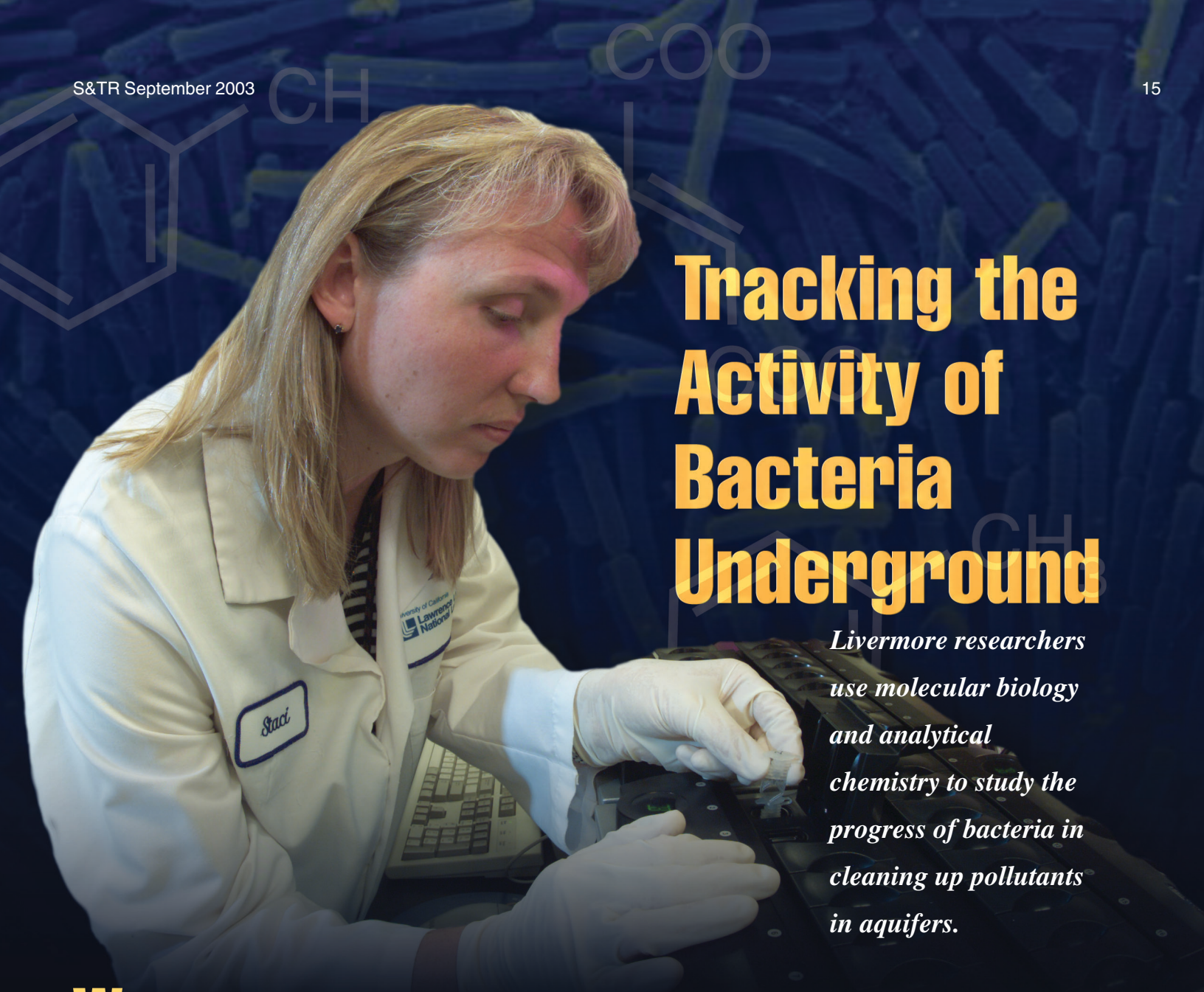
NIF Programs Associate Director George Miller has noted that big facilities are seldom known for the thing that they were originally designed to do. As people learn to use the facility, they come up with ideas and inventions that were never conceived of by those who designed it.

Lawrence Livermore Director Emeritus Dr. Edward Teller provides further wisdom on NIF's future. He is certain that we cannot know now what NIF will accomplish because the greatest scientific achievements are not expected.

—Katie Walter

Key Words: control system, inertial confinement fusion, KDP (potassium dihydrogen phosphate) crystals, line replaceable units (LRUs), National Ignition Facility (NIF), neodymium-doped phosphate laser glass, plasma electrode Pockels cell (PEPC), Stockpile Stewardship Program, systems engineering.

For further information contact Ed Moses (925) 423-9624 (moses1@llnl.gov).



Tracking the Activity of Bacteria Underground

Livermore researchers use molecular biology and analytical chemistry to study the progress of bacteria in cleaning up pollutants in aquifers.

WITH the recent focus on biological warfare agents that can cause diseases such as anthrax or plague, the myriad ways that bacteria can benefit people are easily overlooked. In the area of cleaning up pollution, researchers are discovering the extraordinary capabilities of some bacteria to grow on and degrade substances, such as chlorinated solvents and benzene, that are quite toxic to humans. Many of these bacteria have been found in contaminated aquifers, leading to the discovery that naturally occurring bacteria can actually promote groundwater cleanup.

At Lawrence Livermore, environmental microbiologists Harry Beller and Staci Kane are interested in the natural role of bacteria in breaking down compounds of environmental concern. They head up an applied research team that is part of the Environmental Protection Department's efforts to understand how these unusual bacteria can naturally degrade the compounds that escape from leaking underground fuel tanks (LUFTs). To get a better handle on how these bacteria work in the subsurface, researchers are using two advanced techniques for rapidly and reliably detecting the bacterial degradation of toxic compounds in soil and groundwater samples collected at LUFT sites.

One technique, real-time polymerase chain reaction (PCR), is widely used in biomedical research and has also been applied at Livermore to detect bioterrorism agents. The other technique, liquid chromatography/tandem mass spectrometry (LC/MS/MS), is also used to detect chemical warfare agents and in the biomedical and pharmaceutical industries. Both techniques show great promise for monitoring the activity of bacteria that are cleaning up groundwater naturally.

What Lurks Below the Surface

Groundwater contamination at LUFT sites is a pervasive problem at federal and commercial facilities throughout the U.S. By 2002, more than 427,000 releases from LUFTs had been confirmed nationwide, and according to the U.S. Environmental Protection Agency, the cleanup backlog totaled more than 142,000 sites. Among the compounds in gasoline that are of greatest regulatory concern are benzene, toluene, ethylbenzene, and the three xylene isomers. (Isomers are compounds that have the same atomic composition but differ in structural arrangement.) BTEX is the acronym for this mixture of hydrocarbons. BTEX are among the most toxic and water-soluble constituents of gasoline.

Bioremediation is one of several accepted methods for restoring BTEX-contaminated aquifers to environmentally satisfactory conditions. Intrinsic bioremediation (also called natural attenuation) relies on indigenous bacteria to degrade contaminants in place and is a cost-effective approach favored by the LUFT owners responsible for cleanup. However, regulatory agencies and the public are sometimes skeptical of intrinsic bioremediation, viewing it as a "do nothing" approach.

The key to acceptance of intrinsic bioremediation at a given LUFT site is the ability to demonstrate in a substantial, scientifically credible manner that biodegradation of the contaminants is occurring. As Beller notes, "One of the roadblocks to the widespread acceptance of intrinsic bioremediation in groundwater is the difficulty of proving that measured decreases in BTEX concentrations are due to bacterial degradation and not to nondestructive processes such as dilution or dispersion. The monitoring methods that we have developed are designed to be capable of providing incontrovertible evidence of the biodegradation of BTEX compounds."

How Bacteria Remediate Naturally

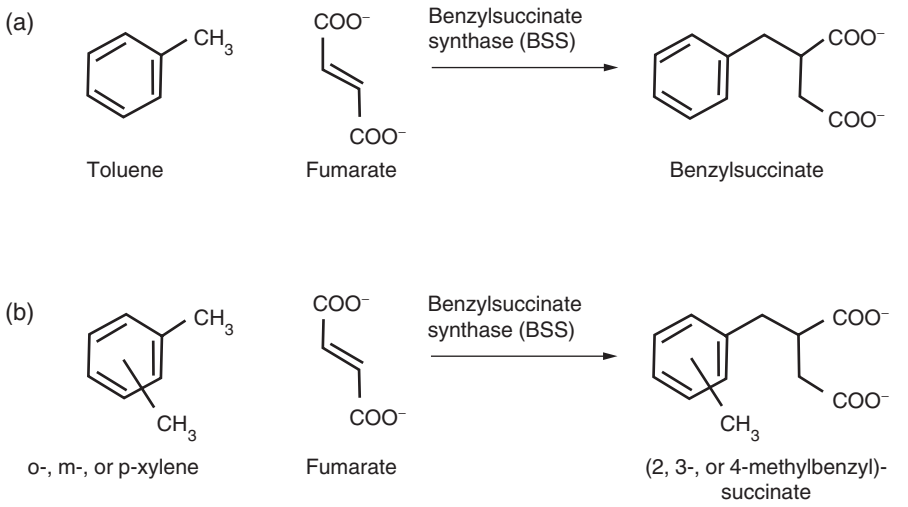
Groundwater underlying LUFT sites is typically oxygen-depleted (anaerobic) because oxygen-respiring (aerobic) bacteria rapidly use up the available oxygen. Once the oxygen in the groundwater environment is depleted, intrinsic bioremediation can only work if anaerobic bacteria are present that can degrade BTEX. As recently as 15 years ago, notes Beller, conventional wisdom held that anaerobic BTEX-degrading bacteria didn't exist because degradation of BTEX compounds in the absence of oxygen was an insurmountable biochemical challenge.

Groundbreaking research in the past seven years not only showed that such bacteria exist, but it also identified the key enzyme, benzylsuccinate synthase (BSS) that carries out the first step of anaerobic degradation of toluene and xylenes. During this time, researchers discovered the gene sequences that lead to the production of this enzyme. The BSS reaction (see the figure below) is found in diverse anaerobic, toluene-degrading bacterial cultures that represent the range of bacteria one would expect to find in aquifers under LUFT sites.

Beller and Kane decided to leverage this new understanding of anaerobic BTEX degradation to develop methods that would unequivocally demonstrate whether intrinsic BTEX bioremediation was occurring at a given LUFT site. Their methods focus on two aspects of the metabolic process.

The first monitoring method focuses on the *bssA* gene. This method gives scientists a tool for counting the bacteria that harbor a gene specific to anaerobic toluene and xylene degradation. The second method focuses on the unique metabolic products of the BSS reaction, which are benzylsuccinate and methylbenzylsuccinates. This method sensitively detects these metabolites, which have no known sources other than the anaerobic degradation of toluene or xylenes.

Beller explains, "The power of these so-called signature metabolites is that their mere presence in groundwater definitively demonstrates the degradation of specific compounds. There is no other way that these compounds could appear in the groundwater."



The benzylsuccinate synthase (BSS) reaction, which anaerobic bacteria use to attack (a) toluene and (b) xylenes as the first step of the biodegradation process. The BSS enzyme catalyzes the addition of toluene or xylene to fumarate, a compound that is typically present in many bacteria.

Monitoring Bacteria Genetically

The first method quickly and accurately counts the number of copies of a specific bacterial gene, *bssA*, in samples of aquifer sediment. Because each bacterial cell typically contains only one copy of the *bssA* gene, the number of gene copies is equivalent to the population of bacteria that contain *bssA*. Thus, this method quantifies the number of bacteria that are genetically capable of anaerobic toluene or xylene degradation in a given sample.

"Because the BSS pathway is the only one to date that has been identified with anaerobic toluene degradation, measuring populations of bacteria containing *bssA* probably is inclusive of most anaerobic toluene- and xylene-degrading bacteria," says Kane.

How does counting the copies of *bssA* relate to intrinsic bioremediation? Kane explains that if anaerobic bacteria at a LUFT site are metabolizing BTEX and proliferating, it is reasonable to expect that the populations of these bacteria should be higher within BTEX-contaminated areas than in nearby, uncontaminated areas. "This method allows us to compare bacterial populations containing *bssA* over distance or time," she adds.

The researchers use analysis based on the real-time PCR—also known as quantitative PCR or TaqMan® PCR—to quantify copies of the *bssA* gene by targeting DNA sequences that are unique to this gene. The same technology has been used extensively by scientists at Livermore to develop real-time PCR methods for targeting specific bioterrorist agents such as *Bacillus anthracis*, which causes anthrax. (See the box, p. 18.)

The team, including microbiologist Tina Legler, began by comparing the *bssA* genes in four different toluene-degrading bacterial strains. At the time this study started, *bssA* sequences were only available for two strains, so *bssA* sequences were determined for two additional strains to provide a better assessment of the diversity of *bssA* sequences among toluene-degrading bacteria. In this and later studies, the team found a high degree of similarity

Region of predicted bssA sequence that includes a conserved glycine* residue

GM GS-15bssA		N	I	D	H	V	Q	F	N	C	V	S	T	A	E	M	K	A	A	Q	K	E	P	E	K	H	Q	D		
TA_K172bssA	792	N	I	D	H	V	Q	F	N	V	V	S	T	E	E	M	K	A	A	Q	R	E	P	E	K	H	Q	D	818	
TA T1tutD	795	N	I	D	H	V	Q	F	N	V	V	S	T	D	E	M	R	A	A	Q	R	E	P	E	K	H	H	D	821	
Asp_TbssA	795	N	I	D	H	V	Q	F	N	V	V	S	T	D	E	M	R	A	A	Q	R	E	P	E	K	H	S	D	821	

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GM_GS-15bssA		L	I	V	R	V	S	G	F	S	A	R	F	V	D	I	P	T	Y	G	Q	N	T	I	I	A	R	N	E	Q	A	F
TA_K172bssA	819	L	I	V	R	V	S	G	F	S	A	R	F	V	D	I	P	T	Y	G	Q	N	T	I	I	A	R	N	E	Q	N	F
TA_T1tutD	822	L	I	V	R	V	S	G	Y	S	A	R	F	V	D	I	P	T	Y	G	Q	N	T	I	I	A	R	Q	E	Q	D	F
Asp TbssA	822	L	I	V	R	V	S	G	Y	S	A	R	F	V	D	L	P	T	Y	G	Q	N	T	I	I	A	R	Q	E	Q	D	F

Region of predicted bssA sequence that includes a conserved cysteine* residue

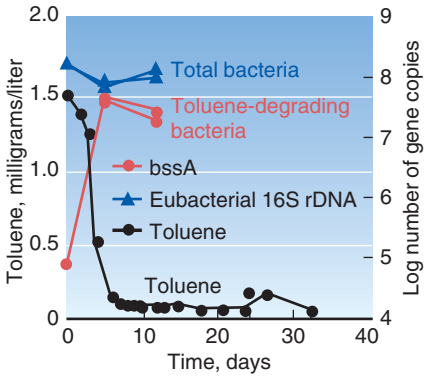
GM_GS-15bssA		P	S	I	K	H	D	V	I	G	T	E	Q	L	K	Y	Y	S	Q	F	S	K	N	N	N	G	A	T	D	D
TA K172bssA	451	P	S	I	K	H	N	E	L	G	V	Q	Q	M	L	E	M	A	K	Y	S	R	N	G	N	G	A	T	P	E	479
TA_T1tutD	454	P	S	I	K	H	D	E	I	G	T	E	Q	M	K	E	Y	A	K	F	S	L	N	G	N	G	A	T	D	E	482
Asp TbssA	454	P	S	I	K	H	D	E	I	G	T	A	Q	M	K	E	Y	A	K	F	S	L	N	G	N	G	A	T	D	E	482

										*																						
GM_GS-15bssA		E	A	H	Y	W	G	L	V	L	C	M	S	P	G	V	C	G	R	R	K	T	H	K	T	R	S	E	G	G	G	S	I	F
TA_K172bssA	480	E	A	H	Y	W	V	N	V	L	C	M	A	P	G	L	A	G	R	R	K	A	Q	K	T	R	S	E	G	G	S	A	I	F
TA T1tutD	483	E	A	H	N	W	V	N	V	L	C	M	S	P	G	I	H	G	R	R	K	T	Q	K	T	R	S	E	G	G	G	S	I	F
Asp TbssA	483	E	A	H	N	W	V	N	V	L	C	M	S	P	G	L	H	G	R	R	K	T	Q	K	T	R	S	E	G	G	S	S	V	F

GM_GS-15bssA Geobacter metallireducens strain GS-15, bssA
TA_K172bssA Thauera aromatica K172, bssA
TA_T1tutD Thauera aromatica T1, tutD
Asp_TbssA Azoarcus sp. strain T, bssA

Evidence of the similarity of bssA gene sequences in four different bacterial strains. This figure shows the genetic code as "translated" into amino acids, which make up the enzyme. Only selected portions of the benzylsuccinate synthase enzyme are shown, specifically, portions of the largest of three subunits that make up the enzyme. Among the different bacterial strains, yellow indicates identical amino acids, and green indicates similar amino acids.

in this gene sequence among different organisms. (See the figure on p.17.) After aligning four DNA sequences chosen from their studies, the researchers focused on a stretch of DNA—about 130 base pairs—for development of their real-time PCR method. To target this region, they designed degenerate primers that corresponded to sequences from all four strains and an internal probe that complemented *bssA* from all four strains.



Real-time PCR of *bssA* successfully tracked toluene-degrading bacteria under denitrifying conditions. The relationship between toluene degradation and increases in numbers of *bssA* copies is apparent.

To test the technique, the team took samples from four sites with different histories of BTEX exposure, including three LUFT sites and an uncontaminated site. They spiked the sediments with BTEX, incubated them in the laboratory under various conditions, and monitored the BTEX degradation activity.

For real-time PCR analysis, they extracted and purified the total DNA from more than 100 5-gram sediment samples of these laboratory incubations. Using real-time PCR, the researchers successfully tracked bacterial population trends that were consistent with observed anaerobic toluene degradation activity.

They also discovered that, of all the environments studied, the ones with denitrifying conditions—that is, where nitrate was being respired by bacteria in the degradation process—had the most rapid toluene degradation and the largest abundance of *bssA*. In the samples with the most rapid toluene degradation, the numbers of *bssA* copies increased 100- to 1,000-fold during the first 4 days of incubation, the time when most of the toluene was being consumed. (See figure at left.) The team validated its method by comparing its results with those produced by traditional hybridization-based methods that do not use PCR amplification and by analyzing the sequences of PCR products to confirm the method's specificity.

The real-time PCR technique, Kane notes, has many advantages over other bacteria-counting methods that require cultivating the bacteria in the laboratory and then calculating the original populations. "Cultivating anaerobic bacteria can be a difficult, sometimes seemingly impossible, task. Because they reproduce slowly, cultivation is also time-consuming," she says. "Getting results can take from days to months, whereas the real-time PCR method does the job in less than an hour."

Basics of the Real-Time Polymerase Chain Reaction

Developing a way to rapidly identify DNA by the real-time polymerase chain reaction (PCR) was a breakthrough event in the mid-1990s that launched Livermore's biodefense program. At the time, PCR was a well-established technique for identifying specific regions of DNA. PCR works by making multiple copies of a particular segment (referred to as the amplicon) of the DNA in the sample. When the sample is heated, the double-helix of DNA separates into two single complementary strands. When the sample is cooled, single, short (18- to 25-nucleotide) strands of DNA called primers attach to the ends of the target region to be amplified. Subsequently, a heat-stable enzyme (*Taq* DNA polymerase from *Thermus aquaticus*, a bacterium isolated from hydrothermal vents) replicates the region of DNA bracketed by the primers. With each heating–cooling cycle, the amount of DNA doubles. Eventually, after 20 cycles, a single target would be amplified a millionfold.

A dramatic advance in PCR technology was the development of real-time PCR, which allows for rapid quantification of specific genes. In addition to the specific primers used in conventional PCR, real-time PCR also includes a probe (typically 20 to 35 nucleotides long) that specifically binds to a region of the target DNA that is bracketed by the primers. The probe is labeled with fluorescent dyes at each end. One dye quenches the fluorescence of the other when the probe is intact. The real-time PCR method relies on the exonuclease activity of *Taq* DNA polymerase that cleaves the probe, resulting in fluorescence. The amount of fluorescence is proportional to the amount of replication, which in turn is proportional to the number of initial target DNA copies. By performing real-time PCR with specific DNA standards, a calibration curve is obtained to calculate the amount of target DNA in the environmental DNA extract.

The real-time PCR technique is fundamental to the Livermore-developed Handheld Advanced Nucleic Acid Analyzer (HANAA) and Biological Aerosol Sentry and Information System (BASIS), which are used to identify microorganisms that present a biological threat.

For more information about PCR and its biodefense applications, see *S&TR*, January/February 2002, pp. 24–26, and June 1998, pp. 4–9.

Another plus is the method's sensitivity. PCR can detect as few as five copies of a gene per analysis. It is also highly selective—an important quality, since it must avoid false-positive results.

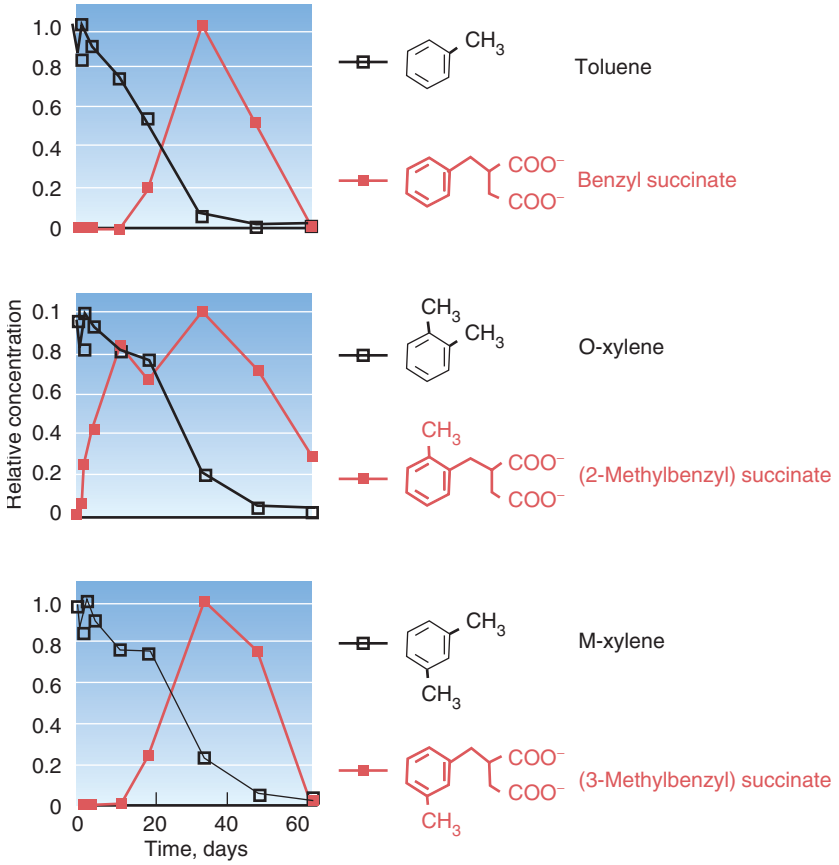
Detecting Key Signatures

The second method for tracking intrinsic bioremediation of BTEX in groundwater was developed by Beller, using LC/MS/MS to detect signature metabolites of BTEX degradation.

Instead of counting the populations of bacteria harboring a gene associated with BTEX degradation, this method measures distinctive metabolites (benzylsuccinate and methybenzyl-succinate isomers) that are uniquely associated with anaerobic toluene and xylene degradation.

Beller successfully used the signature metabolite approach in a controlled-release field study before coming to work at Livermore. (See the figure at right.) However, he didn't have access to LC/MS/MS then, and the more traditional analytical methods he used were labor-intensive and time-consuming. Traditional methods for such analysis typically involve extraction of a large (1-liter) water sample with organic solvent, concentration of the solvent to a small volume, chemical treatment called derivatization that makes the benzylsuccinates more amenable to further analysis, and gas chromatography/mass spectrometry analysis.

Using the isotope-dilution LC/MS/MS method, Beller can skip the extraction, concentration, and derivatization steps and analyze a groundwater sample in less than 10 minutes. The method is highly sensitive, accurate, and precise, and it requires modest samples—less than 1 milliliter of groundwater. The detection limits for the LC/MS/MS technique are about 0.3 microgram of benzylsuccinate or methylbenzylsuccinate per liter (roughly the equivalent of a thimbleful of water in an Olympic-size swimming pool).



Concentrations over time of selected BTEX hydrocarbons and their corresponding benzylsuccinate metabolites in groundwater from a site in Seal Beach, California. In this experiment, BTEX and bromide were added to the groundwater at the sampling site. All concentrations are normalized to bromide (an inert tracer that corrects for the effects of dilution) and to the maximum concentrations of the compounds themselves. (Copyright 1995 by the American Chemical Society. Reused with permission from *Environmental Science and Technology*, 1995 **29**, 2869.)

To test this method, Beller turned to a fuel terminal with contaminated groundwater. Since 1911, the terminal has been in the business of blending and distributing petroleum products, such as gasoline and diesel fuel. The team collected groundwater samples quarterly for a year from 12 wells located in the highly anaerobic aquifer. Methylbenzylsuccinates were detected in the three wells with the highest BTEX concentrations. The methylbenzylsuccinate concentrations ranged from less than 0.3 to 205 micrograms per liter. Beller found a strong and consistent correspondence between concentrations of methylbenzylsuccinates and their parent compounds, xylenes, throughout the most contaminated portion of the aquifer. (See figure on p. 20.)

Overall, the LC/MS/MS method proved to be a rapid, selective, and sensitive method for detecting benzylsuccinates, which are prime indicators of anaerobic bacteria hard at work degrading hydrocarbons.

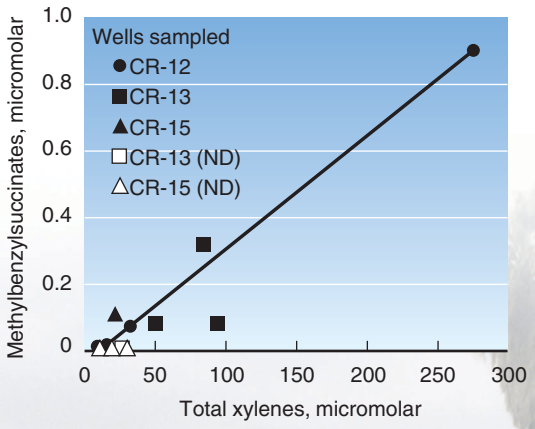
Future of "Natural" Bioremediation

A major challenge for the regulatory acceptance of intrinsic bioremediation is to provide evidence that decreases in the concentrations of groundwater contaminants truly represent biological metabolism of these contaminants rather than nondestructive, natural processes such as dilution. Beller and Kane have developed two independent methods to meet that challenge. They applied these techniques to contaminants at LUFT sites and are extending their use to other classes of contaminants, such as nitrate and high explosives.

Despite the significant strides that researchers have made in developing new methods for monitoring intrinsic bioremediation, a remaining challenge is to progress from qualitative evidence (is biodegradation occurring?) to quantitative evidence (what is the rate of in situ biodegradation, and what proportion of contaminant decreases can be attributed to biodegradation?). Beller and Kane are investigating ways to adapt their methods to yield more quantitative data.

An additional long-term goal of this research is to gain a better understanding of how ethanol—which is a strong contender to replace MTBE in gasoline—could affect the population of anaerobic BTEX-degrading bacteria and, therefore, the rates of intrinsic BTEX biodegradation in the subsurface. Before this project, notes Kane, researchers had no way to quickly assess the populations of anaerobic BTEX-degrading bacteria in a given environment. The real-time PCR technique, with its ability to quantify the abundance of the *bssA* gene, provides a tool for doing just that.

—*Ann Parker*



Highly correlated concentrations of methylbenzylsuccinates (signature metabolites of xylenes) versus xylenes in groundwater from three different wells at four sampling times at a contaminated, fuel-distribution terminal. (Copyright 2002 by the American Chemical Society. Reused with permission from *Environmental Science and Technology,* 2002 **36**, 2727.)

Key Words: benzene, toluene, ethylbenzene, xylene (BTEX); biodegradation; groundwater; hydrocarbons; intrinsic bioremediation; leaking underground fuel tank (LUFT); liquid chromatography/tandem mass spectrometry (LC/MS/MS); natural attenuation; polymerase chain reaction (PCR).

For further information contact Harry Beller (925) 422-0081 (beller2@llnl.gov) or Staci Kane (925) 422-7897 (kane11@llnl.gov).

Additional Reading

Harry R. Beller, Staci R. Kane, Tina C. Legler, and Pedro J. J. Alvarez (2002), "A Real-Time Polymerase Chain Reaction Method for Monitoring Anaerobic, Hydrocarbon-Degrading Bacteria Based on a Catabolic Gene," *Environmental Science and Technology* **26**, 3977–3984.

Harry R. Beller (2002), "Analysis of Benzylsuccinates in Groundwater by Liquid Chromatography/Tandem Mass Spectrometry and Its Use for Monitoring In Situ BTEX Biodegradation," *Environmental Science and Technology* **36**, 2724–2728.

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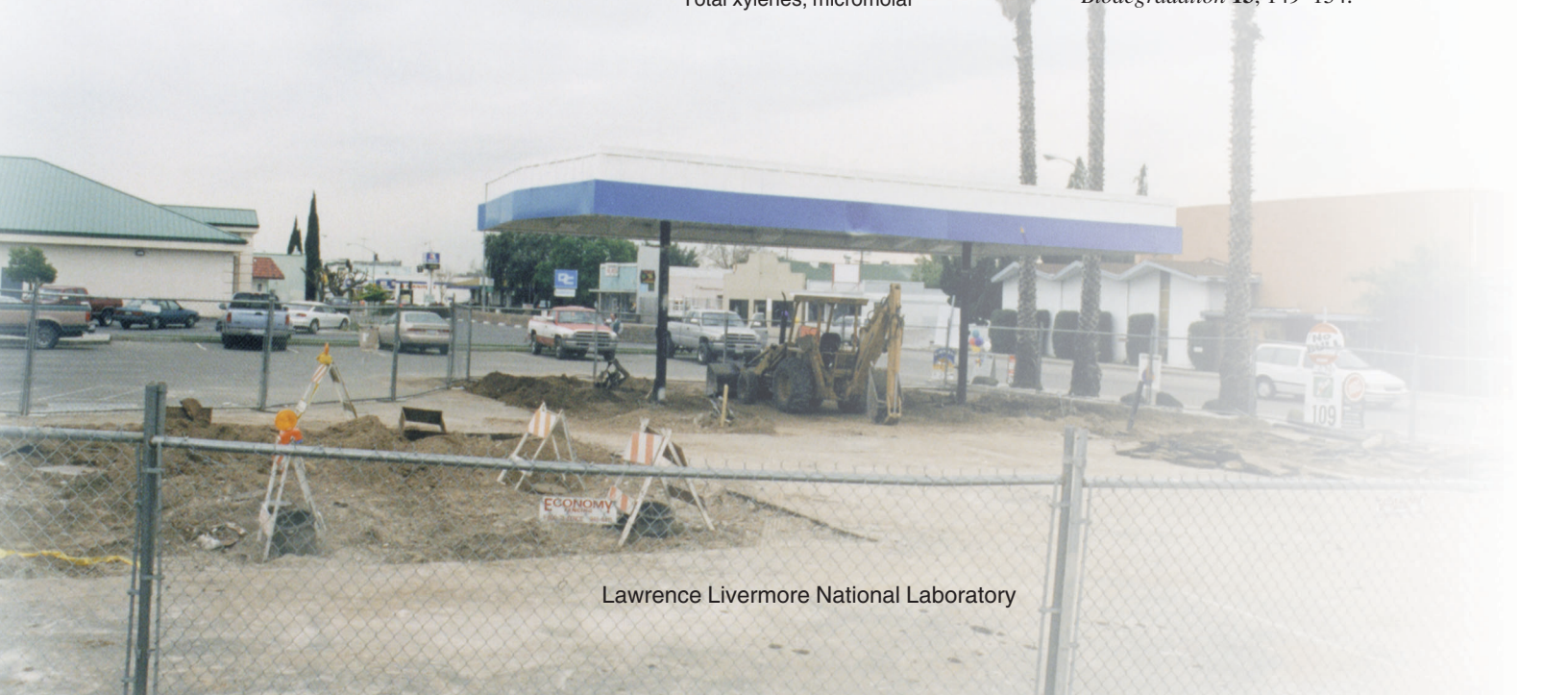


When Every Second Counts
Pathogen Identification in Less than a Minute

WHEN there's anthrax in the air—or indeed, any pathogen—the sooner one knows, the better. Ideally, a detector would identify the pathogen in time to take action, an interval referred to as detect-to-warn, which is generally considered to be a minute or less.

Commercial systems exist that can identify airborne pathogenic spores, but they take days or, at best, hours to produce results. Far too long to hold one's breath.

A system being developed by Lawrence Livermore to identify such spores—the bioaerosol mass spectrometry (BAMS) system—recently broke that critical 1-minute time barrier. Livermore chemist Eric Gard heads up a team developing this mass-spectrometry technique, which can successfully distinguish between two related but very different spore species. It can also sort out a single spore from thousands of other particles—both biological and nonbiological—with no false positives.

The biomedical aspects of this work are funded by the Laboratory Directed Research and Development (LDRD) at Livermore, and the biodefense aspects are funded by the Technical Support Working Group and Defense Advanced Research Project Agency of the Department of Defense.

When Time Is of the Essence

The premise of a detect-to-warn system is to allow time to react. "A minute gives people enough time to put on masks, leave the room, hold their breath. The challenge was to actually make a device that could provide answers in less than a minute," explains Gard.

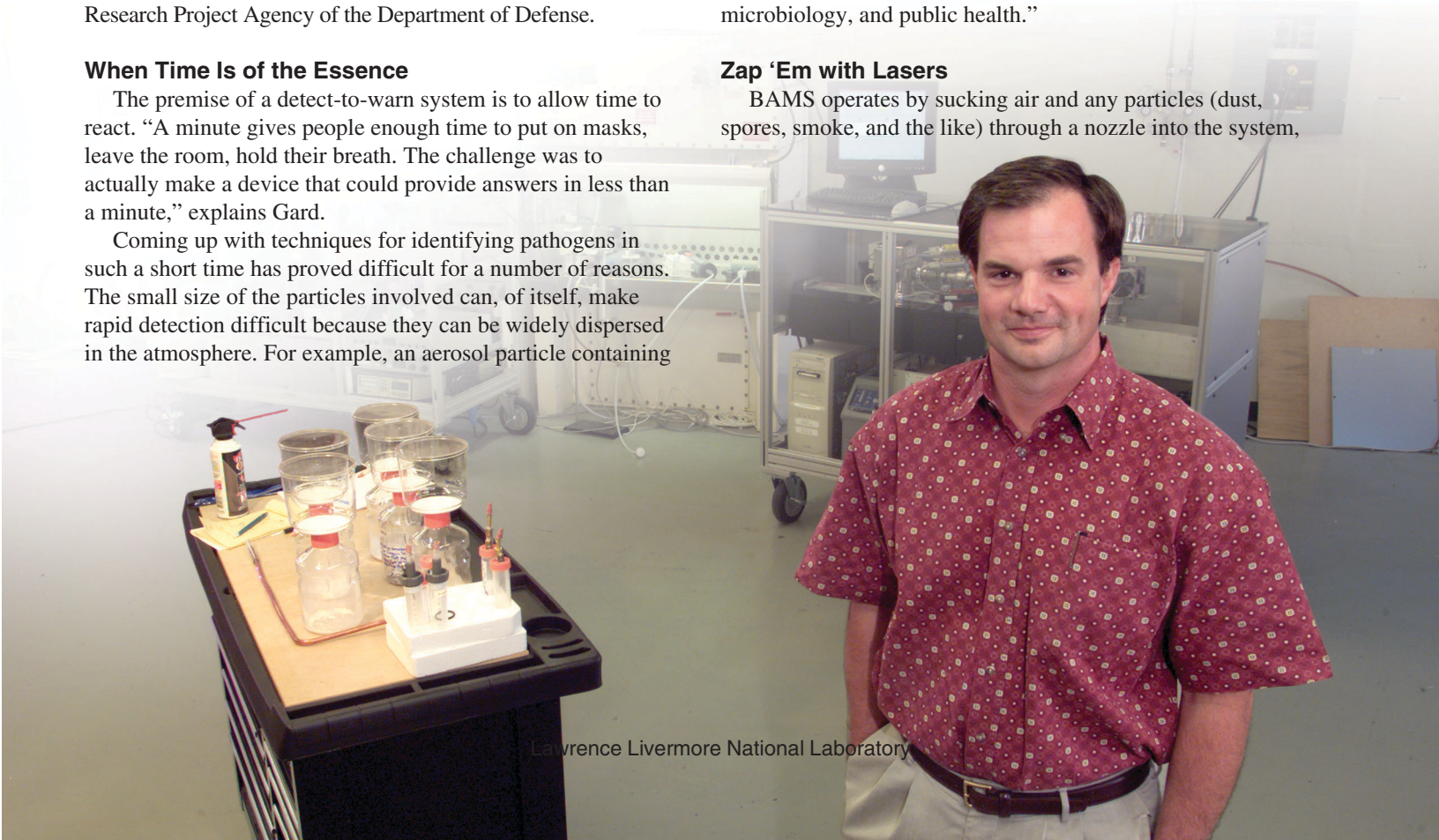
Coming up with techniques for identifying pathogens in such a short time has proved difficult for a number of reasons. The small size of the particles involved can, of itself, make rapid detection difficult because they can be widely dispersed in the atmosphere. For example, an aerosol particle containing a single *Bacillus anthracis* spore has a mass of approximately one-trillionth of a gram. Of the methods available to detect anthrax and other airborne uglies, most take hours, even days, to yield results, making timely actions impossible.

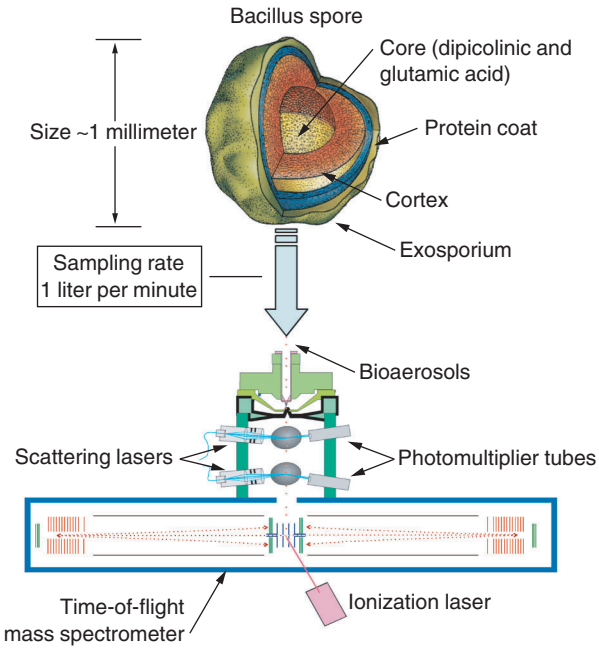
The issue of false alarms is also critical—some techniques have difficulty separating organisms that are benign from those that are pathogenic but very similar. The situation becomes even more complicated because some pathogens, such as smallpox, are highly contagious, requiring just a few organisms to infect a person. The system should ideally be sensitive enough to find and identify a single particle among other naturally occurring background particles, which could be present at concentrations thousands of times higher.

The BAMS technique, which Gard and others have been working on for nearly five years, can successfully identify a single airborne particle in about 100 milliseconds. This technique has other applications as well, Gard notes. "In the future, BAMS could also be used as a medical diagnostic to, for instance, track small subpopulations of cancerous cells that deviate from their normal development cycle. As such, BAMS may make far-reaching contributions in the fields of oncology, microbiology, and public health."

Zap 'Em with Lasers

BAMS operates by sucking air and any particles (dust, spores, smoke, and the like) through a nozzle into the system,

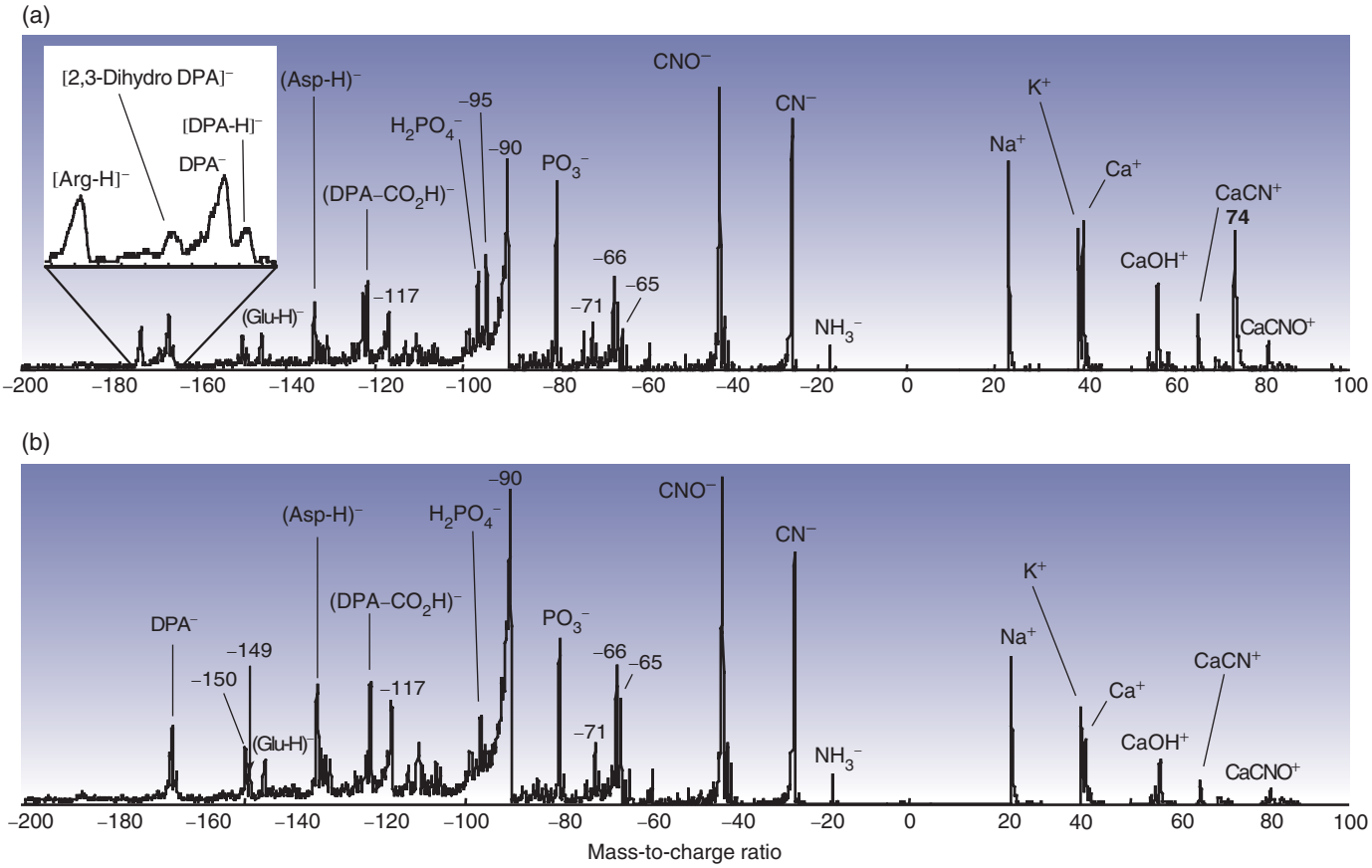




A schematic of a bioaerosol mass spectrometry (BAMS) system being used to analyze a bacterial spore. BAMS has the potential to identify bioagents, such as anthrax, from only a single spore or cell and to clarify the molecular changes that occur in normal and cancerous cells.

which is under a vacuum. While entering the vacuum, each particle accelerates to its own specific terminal velocity—a velocity that depends on a particle's size and shape but averages about 300 meters per second. The particles then pass, one at a time, through two continuous scattering laser beams, which are set serially in the path of the particles. Each particle scatters laser light as it passes through each beam. The time between the two scattering events provides information on a particle's velocity and size. Each particle continues on, zipping into the path of a third, pulsed ionization laser. The pulsed laser fires, desorbing and ionizing the particle and producing both negative and positive ions. The particle's journey—from entering the nozzle to annihilation by the ionizing beam—takes about 100 milliseconds. (See the figure at left.)

Spectra from these resulting ions are collected simultaneously by separate mass spectrometers. The spectra for each type of material are as unique as snowflakes. The spectra from one spore species differ in varying degrees from those of other *Bacillus* spores and are even more different from the spectra from a smoke particle, for instance. The spectra are first analyzed and categorized using real-time



Spectra of (a) *Bacillus subtilis var. niger* and (b) *Bacillus thuringiensis*, showing the peaks of greatest difference.

pattern recognition software developed at Livermore. Then, in a two-stage process, they are compared with spectra in a database of various substances gathered previously.

In the first stage, nonmicrobial (nonliving) particles such as smoke and flour are identified and removed from further analysis, while spectra of bacterial spores proceed to the next stage. In this second stage, the spectra of the bacterial spores are analyzed and classified by species. "A lot of data come in very quickly," says Gard. "We need to be accurate, first time out. For instance, a natural insecticide containing spores of *Bacillus* is similar in chemical structure to the anthrax pathogen. We need to be able to differentiate between them the first time, every time."

Tests Show the Difference

To test their system, the team used surrogates of anthrax (*Bacillus subtilis var. niger*) and a commonly used organic pesticide (*Bacillus thuringiensis*) that differs from *B. anthracis* in two short sections of its DNA. One technical reality the team had to work around is that the fast-traveling microorganism may encounter the ionizing laser beam at any point in the beam field. Because irregularities in the beam field exist—even in a beam of specific wavelength, pulse length, and fluence—this inhomogeneity results in the particle fragmenting into slightly different ions, depending on what part of the beam field it hits. The variation in the resulting ions makes it more difficult to identify the original material. Even so, subtle differences between the spectra of *B. subtilis var. niger* and *B. thuringiensis* can be detected. (See the lower figure at left.) In recent tests, the BAMS systems success rate was 93.2 percent.

A prototype of the system was taken to Florida in 2001 to help screen the overwhelming number of suspicious powders sent to the Florida Department of Health shortly after the anthrax exposures in the U.S. Postal Service. "The Department of Health was using methods that took three days to turn around a single sample. At the time, we wanted to see if we could do the analysis with our system in a few seconds," says Gard.

In earlier tests at a biosafety level 3 facility in Florida, the system detected *B. anthracis* spores from nonmicrobial background particles. These proof-of-principle experiments showed how *Bacillus* spores could be detected when mixed with biological and nonbiological materials. Some of the other materials included white powders, such as aspartame, medicated foot powder, gelatin, growth medium, baking soda, and powdered sugar as well as cigarette and wood smoke. In all these cases, the BAMS system was easily able to detect spores from all other materials.

The team is working on the next-generation system, with which they hope to improve the rate of detection by focusing on specific optical properties of particles of interest.

Identifying Cancer, Tracking Tuberculosis

The ideal method for identifying bioagents would be instantaneous and absolute. BAMS is heading in that direction.

The technique also holds great promise in the arena of public health. The team is in the final year of an LDRD project, headed by Matthias Frank and Eric Guard. The goal is to develop the BAMS technique primarily for biomedical applications, such as detecting cancer by analyzing individual cells in clinical biopsies or identifying the bacteria that cause tuberculosis.

"Some day, when the system is perfected for field use, BAMS could be smaller than a breadbox and detect particles in about a millisecond," says Gard. "A person would breathe into a mask. BAMS could sample the particles from the lungs and then identify and characterize the particles—instantaneously."

—Ann Parker

Key Words: anthrax, bioaerosol mass spectrometry (BAMS), bioterrorism, airborne pathogens.

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The bioaerosol mass spectrometry (BAMS) team includes (left to right) in the front row: Maurice Pitesky, Herb Tobias (aerosol science), Joanne Horn, David Ferguson (data analysis), and Eric Guard (team leader); middle row: Jim Birch, Vincent Riot, Matthias Frank (laser–particle interactions) and Bruce Woods; and back row: Paul Steele, Norm Madden, and Keith Coffee (next-generation system).

Portable Radiation Detector Provides Laboratory-Scale Precision in the Field

In CryoFree/25, a hermetically sealed germanium gamma-ray detector is coupled to a small, low-power cooler that is available commercially. The unit weighs 4.5 kilograms and can operate for 7 to 8 hours on two rechargeable lithium-ion batteries.

UNTIL recently, the U.S. relied on large oceans and friendly bordering countries to provide security against a terrorist attack. It was believed that an attack would most likely arrive in the form of missiles launched from land, air, or sea.

The terrorist threat now lies much closer to home. Experts believe that a possible method of weapon delivery will be a suitcase concealing contraband radioisotopes hidden in a car or plane's luggage compartment. Or a seemingly harmless shipment of medical or industrial radioisotopes could mask potent radioisotopes destined for a dirty bomb—an ordinary explosive laced with radioactive material. To counter such threats, security agencies are looking for a new generation of portable radiation detection devices that will allow military, law-enforcement, public-health, and medical personnel to easily and quickly identify radioactive materials and distinguish among them.

Devices that detect x and gamma rays have been available for a few decades. However, precision energy-resolution detection devices, which unambiguously identify radioisotopes, are large and power-intensive and require a consumable liquid cryogen, all of which make them difficult to use in the field. A Lawrence Livermore team has developed a portable, handheld germanium radiation detector called CryoFree/25 that can duplicate the energy resolution and efficiency of a laboratory gamma-ray spectrometer. Physicist John Becker and engineers Norman Madden, Lorenzo Fabris, and Chris Cork are collaborating on the project. Begun in 1998, the project is sponsored by the Department of Energy's Office of Nonproliferation Research and Engineering, which is part of the Office of Defense Nuclear Nonproliferation.

"The team's goal," says Madden, "was to create the smallest possible handheld, mechanically cooled gamma-ray spectrometer with the largest amount of germanium. The more germanium, the higher the detection efficiency." As part of Livermore's Measurements Science Team, originally formed at Lawrence Berkeley National Laboratory and now part of the Physics and Applied Technologies Directorate, the team had previously developed technology for a radiation detector that is onboard a NASA spacecraft. Becker thought it would be worthwhile to explore terrestrial applications for the radiation detector.

Powerful and Lightweight

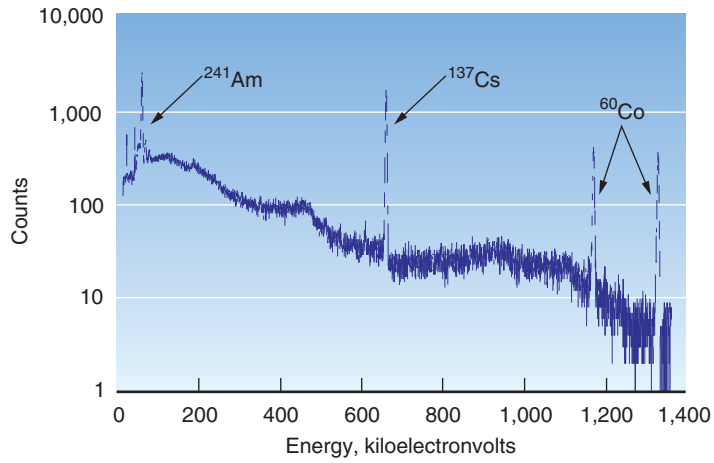
Developed under the name Cryo3 but now dubbed CryoFree/25, this technology makes a quantum leap forward in portable radiation detection. The detector system features a handheld, gamma-ray spectrometer and book-size auxiliary equipment, such as a portable computer, power supply, and conditioning units. The gamma-ray spectrometer nearly replicates the precision energy resolution found in the larger, less-portable laboratory units used for unambiguous radioisotope identification.

The unit weighs less than 4.5 kilograms and can run for 7 to 8 hours on two rechargeable lithium-ion batteries. CryoFree/25 operates on only 16 watts of dc power and can operate continuously for more than 6 months before the unit's cooling mechanism needs a short recycling period. "The beauty of CryoFree/25 is that the device can deliver the level of gamma-ray energy resolution associated with laboratory germanium spectrometers in a portable, lightweight, germanium detector without liquid nitrogen and with long field life," says Becker.

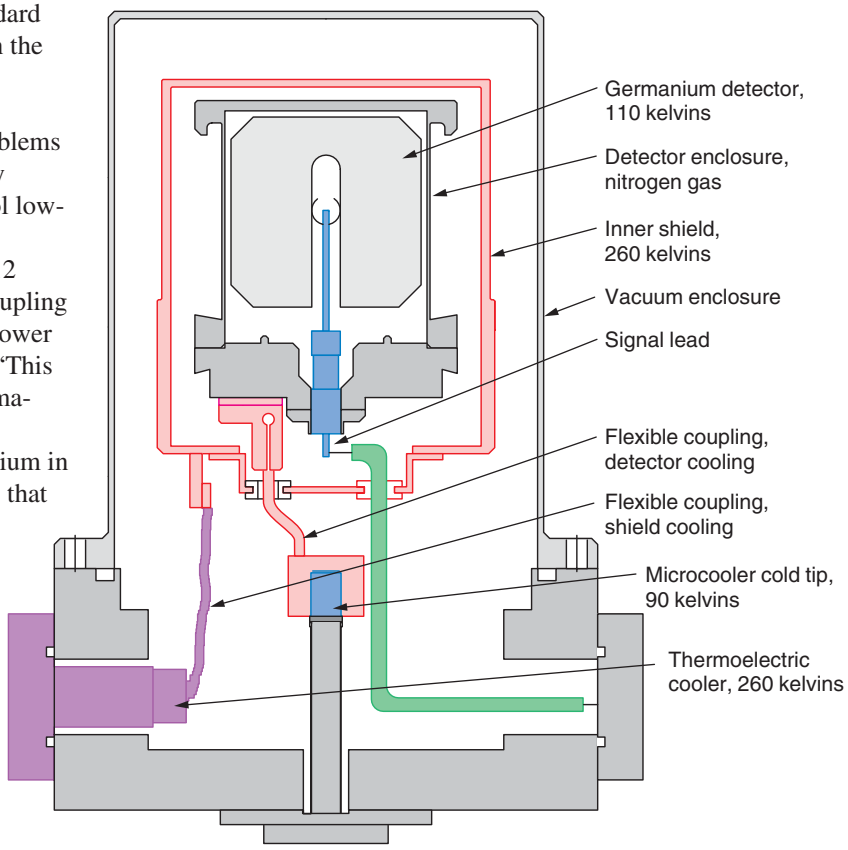
Germanium has long been the detector material of choice for precision gamma-ray spectroscopy. Compared with other semiconductor materials used in detectors, such as silicon or cadmium telluride, germanium provides better detection efficiency, line-shape characteristics, and precision energy resolution, which are needed to produce the detailed x- or gamma-ray spectra for identifying radioactive materials. The germanium crystals must be cooled to approximately 90 kelvins (about –300°F) to operate. Liquid nitrogen has been the cryogen of choice, but more than 10 liters per week of liquid nitrogen are required to cool an average laboratory-size detector. This cooling requirement makes standard detectors awkward to transport, store, and handle in the field. Access to liquid nitrogen is a requirement for routine use.

Becker's team overcame the size and access problems by joining the germanium crystal to a commercially available mechanical device commonly used to cool low-noise cell-phone antennas. The device, originally designed for the aerospace industry, requires only 12 watts to cool the germanium. "Our innovation is coupling a germanium radiation detector with a small, low-power cryogenic cooling mechanism," explains Madden. "This combination offers extremely high-resolution gamma-radiation analysis in a portable package."

As gamma-ray photons interact with the germanium in CryoFree/25, their energy is converted into charges that can be measured and recorded. Every radioisotope has a unique gamma-ray signature, which can be inferred by measuring the magnitude of the charge created in the detector and processed by the detector's electronics. Unlike many other detectors, CryoFree/25 can identify all of the gamma rays originating from the known radioisotopes.



As gamma-ray photons illuminate the CryoFree/25 detector, their energy is converted to electrical signals that can be measured and recorded. Every radioisotope has a unique signature. Shown are the combined characteristic fingerprints of americium-241, cobalt-60, and cesium-137 radioisotopes.



The germanium detector is hermetically encapsulated within a thin layer of aluminum that contains a nitrogen blanket. An external metal "getter" and a miniature ion pump are used to maintain the utility vacuum.

Adaptable for Multiple Applications

"CryoFree/25 is a forensics science tool for gamma-ray detection," says Madden. "The resolution of the CryoFree/25 is so precise that it provides a unique fingerprint of the sample. For example, the detector can reveal not only

what radioisotope is present but also the history of the radioisotope—whether, for instance, it came from a spent fuel rod or another source and how long ago the chemical alteration to the radioisotope occurred. The device might even reveal approximately where the alteration occurred."

In addition to finding a cooling mechanism for the portable unit, the Livermore team added signal-processing electronics to minimize electronic noise that would otherwise obscure the detector's energy resolution. A readout that shows detector pulse height with sharp, defined peaks accurately depicts the types and amounts of radiation present.

The Livermore team is working with the Coast Guard to adapt the unit for use on shipping vessels. "The Coast Guard needs the least obtrusive, most rugged and lightweight unit with proven reliability," says Madden. CyroFree/25's small size makes it particularly attractive for applications where small spaces may obscure field use of other detectors, such as at border crossings, airport terminals, and cargo ports.

The group is applying the same detector technology used in CryoFree/25 for space applications. Last year, an expanded team from Lawrence Livermore and the Space Science Laboratory at the University of California at Berkeley, delivered a flight detector to Johns Hopkins Applied Physics Laboratory for research on a NASA spacecraft designed to retrieve radioisotope data on the geochemistry of Mercury. CryoFree/25 technology may also prove valuable for the Department of Energy's work in monitoring the nation's nuclear weapons stockpile and protecting the weapons and nuclear energy facilities from terrorists.

The team is hopeful that government agencies will take advantage of the portable unit's technology, which can be adapted to many applications. In emergencies, where time and power outages may limit the ability of laboratories to process radiation samples, CryoFree/25 provides the unambiguous radioisotope identification that is required to protect vital resources.

—Gabriele Rennie

Key Words: counterterrorism, CryoFree/25, portable germanium radiation detector.

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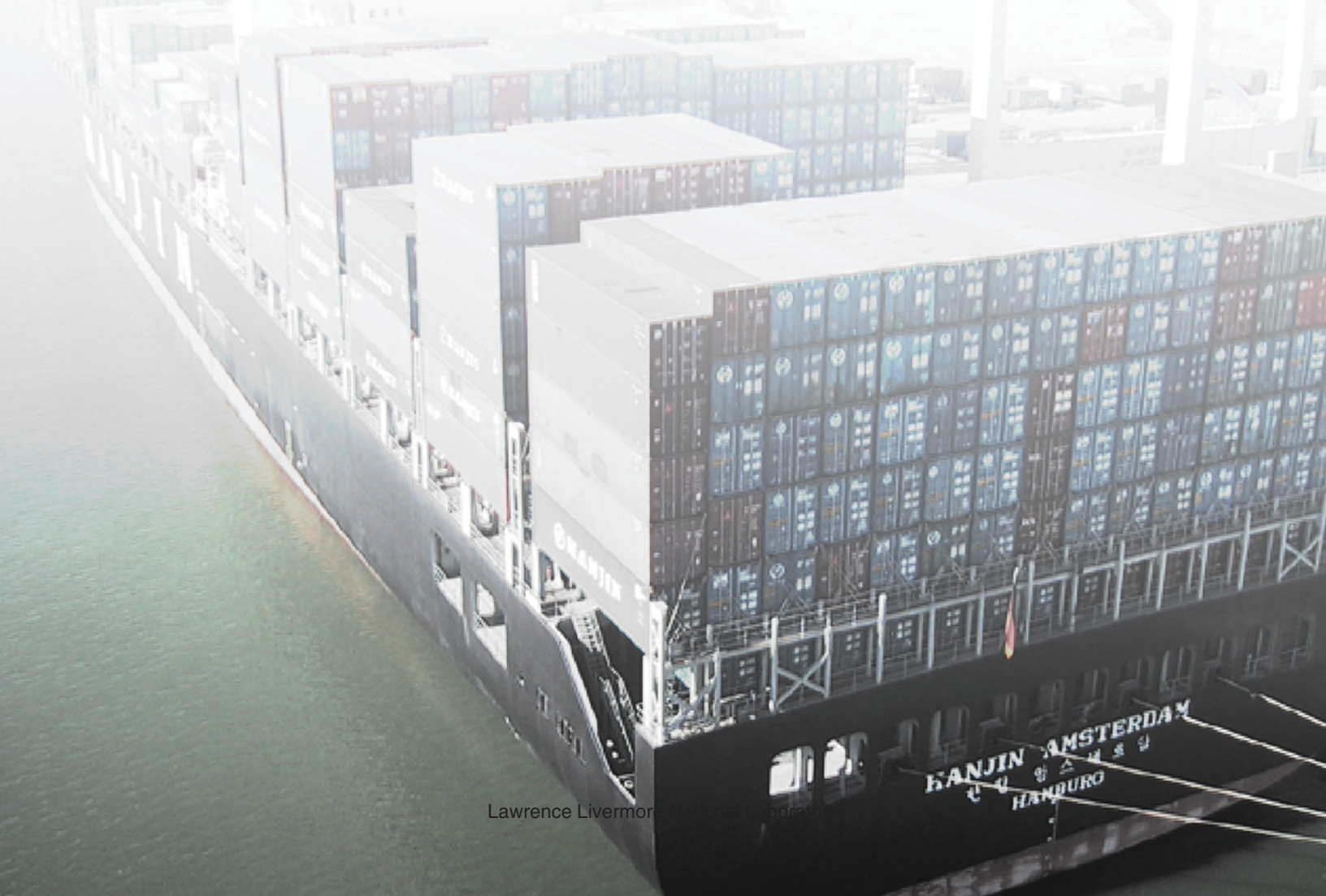

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Proton Radiography Based on Near-Threshold Cerenkov Radiation

Karl A. van Bibber, Franck S. Deitrich
U.S. Patent 6,518,580 B1
February 11, 2003

A Cerenkov imaging system for charged-particle radiography that determines the energy loss of the charged particle beam passing through an object. This energy-loss information provides additional detail on target densities when used with traditional radiographic techniques such as photon or x-ray radiography. In this invention, a probe beam of highly charged (800-megaelectronvolt to 50-gigaelectronvolt) particles traveling at the speed of light is passed through an object to be imaged and then through an imaging magnetic spectrometer to a silicon aerogel Cerenkov radiator, where the charged particles emit Cerenkov light proportional to their velocity. At the same beam focal plane, a particle scintillator produces a light output proportional to the incident beam flux. Optical imaging systems relay the Cerenkov and scintillator information to charge-coupled devices on other measurement equipment. A ratio between the Cerenkov and scintillator is formed, which is directly proportional to the line density of the object for each pixel measured. Rotating the object permits tomographic radiography to be performed. Discrete time-step movies of dynamic objects may be made by applying pulses of beam to the object.

Beam Converter

Peter Poulsen
U.S. Patent 6,560,314 B2
May 6, 2003

An apparatus and method for converting electron energy to irradiative energy. The converter is made of a high-electron-energy material such as, but not limited to, tantalum in the form of foil or foam.

Magnetron Sputtered Boron Films for Increasing Hardness of a Metal Surface

Daniel M. Makowiecki, Alan F. Fankowski
U.S. Patent 6,569,293 B1
May 27, 2003

A method for producing thin boron and titanium–boron films by magnetron sputter deposition. The amorphous boron films, unlike those made with various physical vapor deposition processes, contain no morphological growth features. Magnetron sputter deposition method requires the use of a high-density crystalline boron sputter target, which is prepared by hot isostatic pressing. Thin boron films prepared by this method are useful for producing hardened surfaces and surfacing machine tools and for making ultrathin-band pass filters. They also can be used to produce low-electron-energy elements in low-electron-energy/high-electron-energy optical components, such as mirrors, which enhance reflectivity from grazing to normal incidence.

Optical Distance Measurement Device and Method Thereof

Mark W. Bowers
U.S. Patent 6,570,646 B2
May 27, 2003

A system and method for efficiently obtaining distance measurements of a target. A modulated optical beam may be used to determine the distance to the target. A first beam splitter may be used to split the optical beam, and a second beam splitter may be used to recombine a reference beam with a return ranging beam. An optical mixing detector may be used in a receiver to efficiently detect distance measurement information.

Antiguided Fiber Ribbon Laser

Russel B. Wilcox, Ralph H. Page, Raymond J. Beach, Michael D. Feit, Stephen A. Payne
U.S. Patent 6,570,702 B2
May 27, 2003

A ribbon of an optical material with a plurality of cores that run along its length. The cores include cores doped with lasing impurity spaced alternately with cores doped with index-modifying impurity. The ribbon comprises an index of refraction that is substantially equal to or greater than the indices of refraction of the array of cores doped with lasing impurity. Cores doped with index-increasing impurity promote antiguiding and leaky modes, which provide more robust single supermode operation.

Medical Devices Utilizing Optical Fibers for Simultaneous Power, Communications, and Control

Joseph P. Fitch, Dennis L. Matthews, Karla G. Hagans, Abraham P. Lee, Peter Krulevitch, William J. Benett, Robert E. Clough, Luiz B. DaSilva, Peter M. Celliers
U.S. Patent 6,575,965 B1
June 10, 2003

A medical device in the form of a catheter having a distal end for insertion into and manipulation within a body and a proximal end by which a user can control the manipulation of the distal end within the body. A fiber-optic cable within the catheter connects the distal end to the proximate end of the catheter where it can be coupled to an external source of laser light energy. A converter of laser light to mechanical power is connected to receive light from the distal end of the fiber-optic cable and may include a photovoltaic cell and an electromechanical motor or a heat-sensitive photothermal material. An electronic sensor is connected to receive electrical power from the distal end of the fiber-optic cable, provide signal information about a particular physical environment, and communicate externally through the fiber-optic cable to the proximal end thereof. A mechanical sensor is attached to the distal end of the fiber-optic cable and connected to provide light signal information about a particular physical environment and communicated externally through the fiber-optic cable.

Hybrid Joule Heating/Electro-Osmosis Process for Extracting Contaminants from Soil Layers

Charles R. Carrigan, John J. Nitao
U.S. Patent 6,576,116 B2
June 10, 2003

Joule (ohmic) heating and electro-osmosis are combined in a hybrid process for removal of both water-soluble contaminants and nonaqueous-phase liquids from contaminated, low-permeability soil formations that are saturated. Central to this hybrid process is the partial desaturation of the formation or layer using electro-osmosis to remove a portion of the pore fluids by inducting a groundwater flow to extraction wells. Joule heating is performed on a partially desaturated formation. The joule heating and electro-osmosis operations can be carried out simultaneously or sequentially if the desaturation by electro-osmosis occurs initially. Joule heating of the desaturated formation results in an effective transfer or

partitioning of liquid contaminants to the vapor phase. The heating also substantially increases the vapor-phase pressure in the porous formation. As a result, the contaminant-laden vapor phase is forced out into soil layers of a higher permeability where other conventional removal processes, such as steam stripping or groundwater extraction, can be used to capture the contaminants. This hybrid process is more energy efficient than joule heating or steam stripping for cleaning low-permeability formations and can share electrodes to minimize facility costs.

Sample Preparation and Detection Device for Infectious Agents

Robin R. Miles, Amy W. Wang, Christopher K. Fuller, Asuncion V. Lemoff, Kerry A. Bettencourt, June Yu
U.S. Patent 6,576,459 B2
June 10, 2003
A sample preparation and analysis device incorporating both immunoassays and polymerase chain reaction assays in one compact, field-portable microchip. The device provides new capabilities in fluid and particle control, so a fluidic chip can be built with no moving parts, thus decreasing fabrication cost and increasing the robustness of the device. The device can operate in a true continuous (not batch) mode. The device incorporates magnetohydrodynamic pumps to move the fluid through the system, acoustic mixing and fractionation, dielectrophoretic sample concentration and purification, and on-chip optical detection capabilities.

Optical Electric-Field Pattern Generator

Eddy A. Stappaerts
U.S. Patent 6,577,428 B2
June 10, 2003
The amplitude of an input laser beam is modulated by a two-dimensional array of Michelson interferometers composed of a phase spatial light modulator, a mirror, and a 50/50 light beamsplitter. The array of Michelson interferometers is calibrated by adjusting the path length of one of the interferometer arms. The calibration is maintained with the aid of feedback. The amplitude-modulated beam is then directed successively through a field imaging telescope, a polarization beamsplitter, and a quarter-wave plate before impinging a second phase spatial light modulator. The second modulator is adjusted to apply the desired phase profile. The beam, which at this point has the desired amplitude and phase profiles, is again directed through the quarter-wave plate and subsequently reflected off the polarization beamsplitter, out of the apparatus, and into free space.

Awards

Pedro Luis "Pete" Estacio is part of a team that recently received the **Secretary's Award for Distinguished Service** from U.S. Secretary of Health and Human Services Tommy Thompson in Washington, D.C. Estacio and 23 other members of the Bioterrorism State and Local Preparedness Coordination Group were presented with this top award.

A physician and senior scientist in the Chemical and Biological National Security Program, Estacio serves as an adviser to Thompson's Office of Public Health Emergency Preparedness.

"You were selected to receive this award not only because of your diligence and dedication, but also because of the impact of your personal contributions to the citizenry of our nation," Thompson wrote to Estacio.

As a member of the Bioterrorism State and Local Preparedness Coordination Group, Estacio assisted with the evaluations of state grant applications for bioterrorism preparedness in 2002. He is performing similar work in 2003.

National Nuclear Security Administrator Linton Brooks interrupted a program briefing by **National Ignition Facility Project Manager Ed Moses** in Washington, D.C., on June 10, 2003, to present him with **NNSA's Award of Excellence**.

The commendation praises Moses for his "vision, planning, and leadership" and "extraordinary record of sustained accomplishments."

Moses said that he was surprised and humbled. "This award is shared with everyone in TeamNIF. It was their talent and hard work that made our successes possible," he said.

Abstracts

The National Ignition Facility Comes to Life

With only 4 of its 192 beamlines in operation, the National Ignition Facility has already set world records for energy. When the full constellation of beams is operating in 2008, NIF will deliver more than 50 times the energy of Livermore's recently decommissioned Nova laser and the Omega, the University of Rochester's laser that is currently the world's highest-energy laser system. NIF, the world's largest experimental laser facility, is a cornerstone of the National Nuclear Security Administration's Stockpile Stewardship Program, which is designed to ensure the safety and reliability of the U.S. stockpile in an era of no full-scale nuclear testing. Even with just a few beams operational, NIF will also make significant contributions to astrophysics, hydrodynamics, materials science, and plasma physics.

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Ed Moses (925) 423-9624 (moses1@llnl.gov).

Tracking the Activity of Bacteria Underground

A team of environmental microbiologists at Lawrence Livermore is clarifying the natural role of bacteria in breaking down compounds of environmental concern. Some bacteria have the ability to grow on and degrade substances, such as chlorinated solvents and benzene, that are toxic to humans. Many of these bacteria have been found in contaminated aquifers where they are actually promoting groundwater cleanup. To get a better understanding of how these bacteria work in the subsurface, the researchers have turned to two advanced techniques for rapidly and reliably detecting the bacterial degradation of these components in field-collected samples from leaking underground fuel tank sites. One technique, real-time polymerase chain reaction, has also been applied at Livermore to detect biothreat agents and is widely used in the biomedical field. The other technique, liquid chromatography/tandem mass spectrometry, is also used to detect chemical agents and in the biomedical and pharmaceutical industries. Both techniques show great promise for monitoring the activity of bacteria that are cleaning up groundwater naturally.

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This Year's R&D 100 Awards

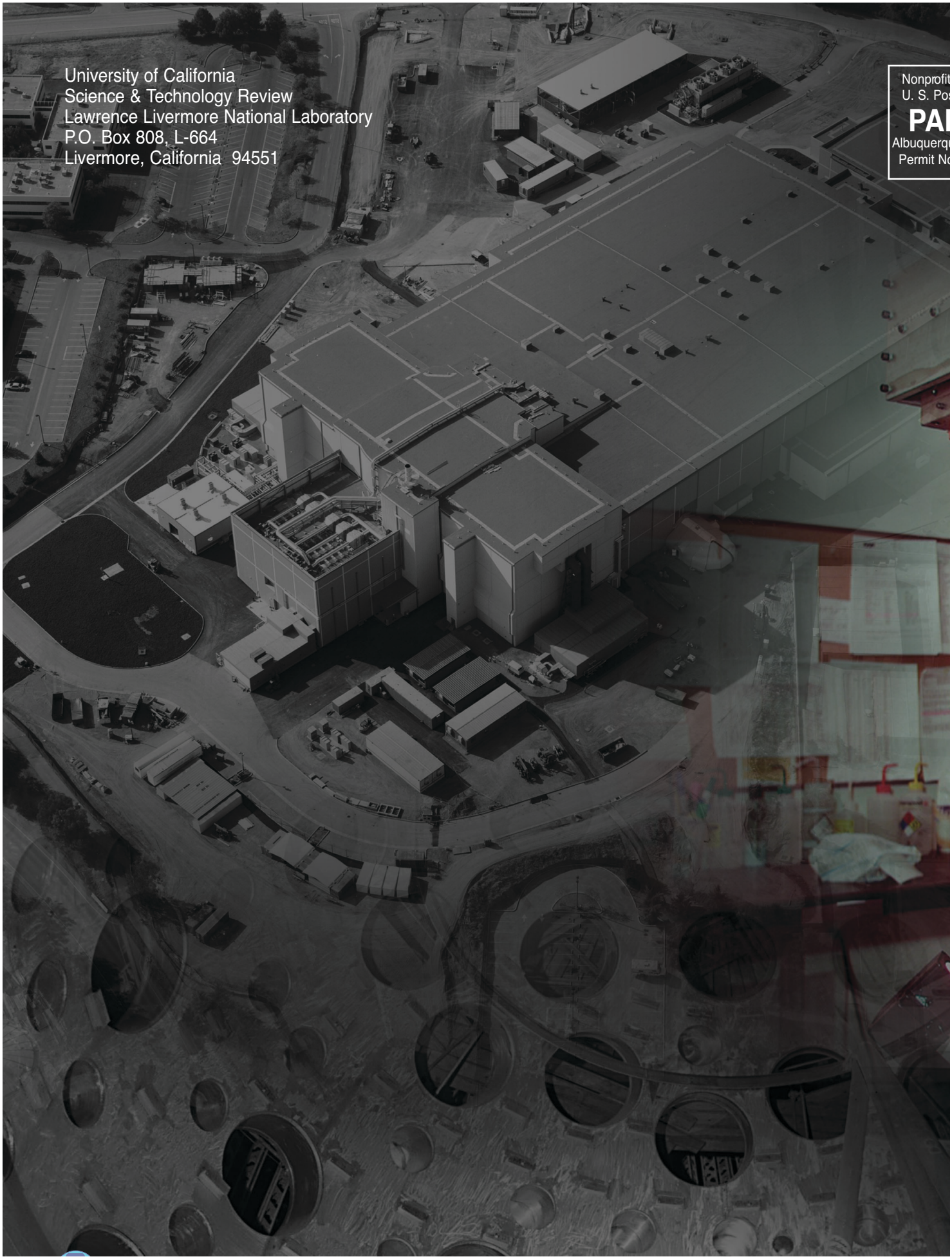
Livermore won six awards in *R&D Magazine*'s annual competition for the 100 most significant technological products and processes:

- High-Average-Power Electro-Optic Q-Switch.
- Ion-Beam Thin-Film Planarization Process.
- Lasershot[SM] Precision Metal Forming.
- BASIS, the Biological Aerosol Sentry and Information System.
- Extreme Ultraviolet Lithography Full-Field Step-Scan System.
- MEMS-Based Adaptive Optics Phoropter.

Also in October

- ***Livermore researchers are developing nondestructive techniques for characterizing materials in the mesoscale—where millimeter-size objects are measured in micrometers.***

Coming Next Month



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