Lawrence Livermore National Laboratory

Science & Technology REVIEW

April/May 2010

Ignition on Target

Also in this issue:

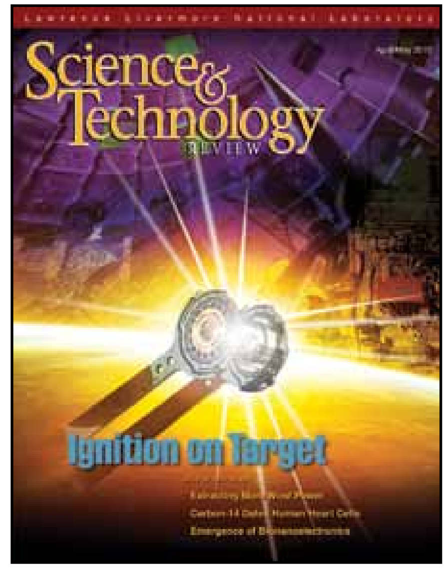
Extracting More Wind Power

Carbon-14 Dates Human Heart Cells

Emergence of Bionanoelectronics

About the Cover

All of the energy produced by the National Ignition Facility's (NIF's) 192 laser beams is directed inside a dime-size gold cylinder called a hohlraum (cover center) precisely positioned in the laser system's 10-meter-diameter target chamber (background). A tiny deuterium–tritium capsule inside the hohlraum fuels the ignition process. As the article beginning on p. 4 describes, a series of shots with the laser system over the last several months has enabled scientists to obtain critical data on key physics parameters required to control ignition performance. Tests demonstrating how the laser can be "tuned" to optimize these parameters have met or exceeded performance requirements. In December 2009, NIF set a world record by firing more than 1 megajoule of ultraviolet energy into a target—more than 30 times the energy previously delivered to a target by any laser system.



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About *S&TR*

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

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

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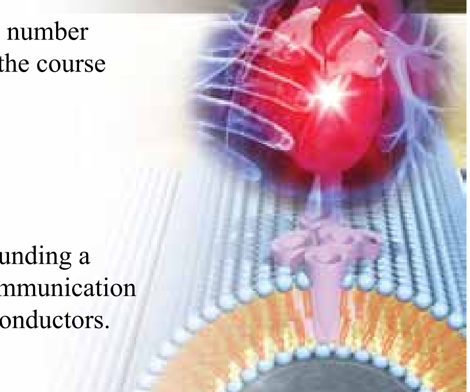
Feature

Research Highlights

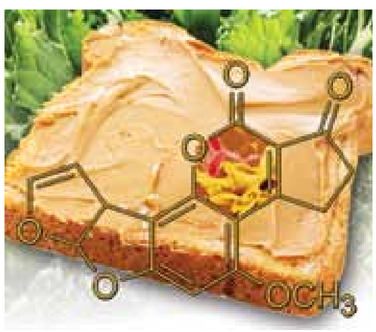


Departments

Leafy Greens Help Fight Toxins

Laboratory researchers Graham Bench and Ken Turteltaub found that giving an individual a small dose of chlorophyll or chlorophyllin—found in green leafy vegetables such as spinach, broccoli, and kale—could reverse the effects of aflatoxin poisoning. Aflatoxin is a potent, naturally occurring carcinogenic mycotoxin that is associated with the growth of two types of mold: *Aspergillus flavus* and *Aspergillus parasiticus*. Food and food crops most prone to aflatoxin contamination include corn and corn products, cottonseed, peanuts and peanut products, tree nuts, and milk. Bench and Turteltaub, working with colleagues from Oregon State University and industrial partner Cephalon, Inc., also found that green leafy vegetables have chemopreventive potential.

The team initially gave each of three volunteers a small dose of carbon-14 labeled aflatoxin (less than the amount found in a peanut butter sandwich). In subsequent experiments, the patients received a small amount of chlorophyll or chlorophyllin concomitantly with the same dose of carbon-14-labeled aflatoxin. Then using Livermore's Center for Accelerator Mass Spectrometry, the team measured the amount of aflatoxin in the volunteers after each microdosing regimen and determine whether the chlorophyll or chlorophyllin reduced the amount of aflatoxin absorbed.



"The chlorophyll and chlorophyllin treatment each significantly reduced aflatoxin absorption and bioavailability," says Bench. Lower blood and urine levels of aflatoxin following these interventions are presumptive reflections of diminished carcinogen absorption and likely reduced DNA damage in liver cells and other target cells. "This study was unique among prevention trials because we could administer a microdose of radio-labeled aflatoxin to assess the pharmacodynamic actions of the carcinogen directly in humans," says Turteltaub. The research appeared in the December 2009 issue of *Cancer Prevention Research*.

Contact: Graham Bench (925) 423-5155 (bench1@llnl.gov) or Kenneth Turteltaub (925) 423-8152 (turteltaub2@llnl.gov).

Researchers Garner Early Career Awards

Lawrence Livermore's Greg Bronevetsky of the Center for Applied Scientific Computing and Vsevolod Soukhanovskii of the Fusion Energy Program have both won an Early Career Research Program Award from the Department of Energy (DOE). Bronevetsky and Soukhanovskii are among 69 scientists nationwide from a pool of about 1,750 applicants who will receive research grants in the amount of $500,000 per year for five years. The grants are funded under the American Recovery and Reinvestment Act. The DOE program is designed to bolster the nation's scientific workforce by providing support to exceptional researchers during the crucial early career years, when many scientists do their most formative work.

Bronevetsky will focus his research on reliable high-performance peta- and exascale computing. He is dedicating his early scientific career to ensuring that the increasing power, size, and complexity of the supercomputers critical to national security research do not come at the expense of their reliability. Soukhanovskii will conduct research in the Advanced High Heat Flux Diverter Program on the National Spherical Torus Experiment at Princeton Plasma Physics Laboratory. Soukhanovskii's research is part of a collaboration between Princeton and the Laboratory's Fusion Energy Program that is funded by DOE's Office of Fusion Energy Sciences.

Contact: Greg Bronevetsky (925) 424-5756 (bronevetsky1@llnl.gov) or Vsevolod Soukhanovskii (609) 243-2064 (soukhanovskii2@llnl.gov).

First Measurement of the Age of Cometary Material

Although comets are thought to be some of the oldest, most primitive bodies in the solar system, new research on the comet Wild 2 indicates that inner solar system material was transported to the comet-forming region at least 1.7 million years after the formation of the oldest solar system solids. The research by Laboratory geochemist Jennifer Matzel and colleagues provides the first constraint on the age of cometary material from a known comet.

The National Aeronautics and Space Administration's Stardust mission to Wild 2, which launched in 1999, was designed around the premise that comets preserve pristine remnants of materials that helped form the solar system. In 2006, the Stardust spacecraft ejected a capsule that parachuted down to the Utah desert, delivering the first samples from a comet. New analyses of comet remnants show that most of the material formed close to the Sun and then migrated outward to be captured by the comet millions of years after the solar system began taking shape. The comet remnants captured by Stardust consist of materials formed at high temperatures, including calcium–aluminum inclusions (CAIs), the oldest objects formed in the solar nebula. Matzel and her team dated the formation of a small particle called Coki by searching for decay products of a radioactive isotope of aluminum.

"The inner solar system material in Wild 2 underscores the importance of radial transport of material over large distances in the early solar nebula," says Matzel. The team's findings are published in the February 25, 2010, edition of *Science Express*. Livermore team members include Matzel, Hope Ishii, Ian Hutcheon, John Bradley, Peter Weber, and Nick Teslich. Colleagues include scientists from the University of Washington, the University of California at Los Angeles, and the Smithsonian Institution.

Contact: Jennifer Matzel (925) 422-0051 (matzel2@llnl.gov).

Commentary by Edward I. Moses

Fifty Years of Stellar Laser Research

THE National Ignition Facility (NIF) at Lawrence Livermore is the world's largest and highest energy laser system. Since completion in March 2009, NIF's 192 beams have produced more than 1 million joules of ultraviolet light and completed over 170 target experiments. NIF illustrates what the Laboratory does best: bring together multidisciplinary teams to solve big science and engineering challenges. Over the past decade, NIF scientists and engineers have overcome technical obstacles with ingenuity, determination, and hard work to deliver a facility for the ages.

NIF's principal goals are to achieve ignition of a deuterium–tritium fuel capsule and to explore high-energy-density physics regimes needed for experiments in national security, fusion energy, and frontier scientific discovery. In addition to supporting the National Nuclear Security Administration's Stockpile Stewardship Program, success in achieving controlled thermonuclear fusion will position NIF as the world's preeminent facility for the study of inertial fusion energy and the physics of matter under extreme temperature, density, and pressure. In fact, ignition and net energy gain on NIF will be a major step toward developing inertial fusion energy as a baseload energy source.

NIF is the most recent laser in a long and successful laser program at the Laboratory. It seems fitting to celebrate the Laboratory's laser program in this issue of *S&TR* because May 16, 2010, marks the 50th anniversary of the demonstration of the laser. With its highly coherent and focusable light, the instrument caught the attention of Livermore scientists. In particular, physicist John Nuckolls immediately began to study the possibility of using powerful, short laser pulses to compress and ignite a small quantity of fusion fuel composed of tritium and deuterium, two isotopes of hydrogen, in a process called inertial confinement fusion.

These original calculations revealed that heating the fusion fuel with only laser energy would not be enough to generate net energy gain, even with lasers producing as much as 1 million joules. To achieve energy gain, the laser would have to compress the fuel to 1,000 times its liquid density. Scaling up existing lasers was a daunting and high-risk task both scientifically and financially.

Over four decades, the Laboratory designed and built a series of ever bigger, more complex, and more powerful lasers. In 1974, Livermore completed the one-beam, 10-joule Janus laser and used it in fusion experiments to demonstrate for the first time a thermonuclear reaction in laser-imploded fuel capsules. Next, a two-beam Janus laser was used to gain a better understanding of laser–plasma and thermonuclear physics. In 1975, the one-beam Cyclops became the prototype for the future Shiva laser.

The next year, the two-beam Argus came online, which increased knowledge about laser–target interactions and laser propagation limits. Argus was the first laser with spatial filters, enabling the beam to be relayed from one amplifier to another while eliminating intensity fluctuations that led to optical damage.

In 1977, the 20-beam Shiva became the world's most powerful laser delivering 10.2 kilojoules of energy in less than a billionth of a second in its first full-power firing. In June 1979, Shiva compressed fusion fuel to a density 50 to 100 times greater than its liquid density. Even more important, Shiva experiments showed that infrared laser light had too long a wavelength to reach fusion energy gain, as energetic suprathermal electrons generated by infrared light in the target's plasma absorb the laser light and inhibit compression.

Novette, which began operation in 1983, was the first laser to be engineered with optical frequency converters made of potassium dihydrogen phosphate (KDP) crystals, which converted the infrared light to shorter wavelengths. Novette was a test bed and interim target facility between Shiva and the 10-beam Nova, the next system in line. Ten times more powerful than Shiva, Nova produced the largest laser fusion yield to date in 1986, a record 11 trillion fusion neutrons. The following year, Nova compressed a fusion fuel target to about one-thirtieth of its original diameter, close to that needed for ignition and fusion gain.

Work on Nova prepared Livermore to begin construction of NIF. Beamlet, the prototype of NIF, was also essential to demonstrating the viability of the new laser system. Operated at the Laboratory between 1994 and 1998, Beamlet showed that the multipass laser architecture conceived for NIF was capable of meeting the fluence (energy per unit area) requirements prescribed by the National Academy of Sciences, a necessary milestone to proceed with NIF.

Ground was broken for the stadium-size NIF in May 1997, and the facility was formally dedicated on May 29, 2009. NIF is designed to deliver a total energy of 1.8 million joules of ultraviolet light to the center of a 10-meter-diameter target chamber. The article beginning on p. 4 describes how NIF's laser system has demonstrated the precision, flexibility, and reliability required for repeated ignition experiments and the ability to become an international user facility.

■ Edward I. Moses is principal associate director for NIF and Photon Science.

A Stellar Performance

Recent experiments at the National Ignition Facility are demonstrating the laser's robust capabilities for bringing star power to Earth.

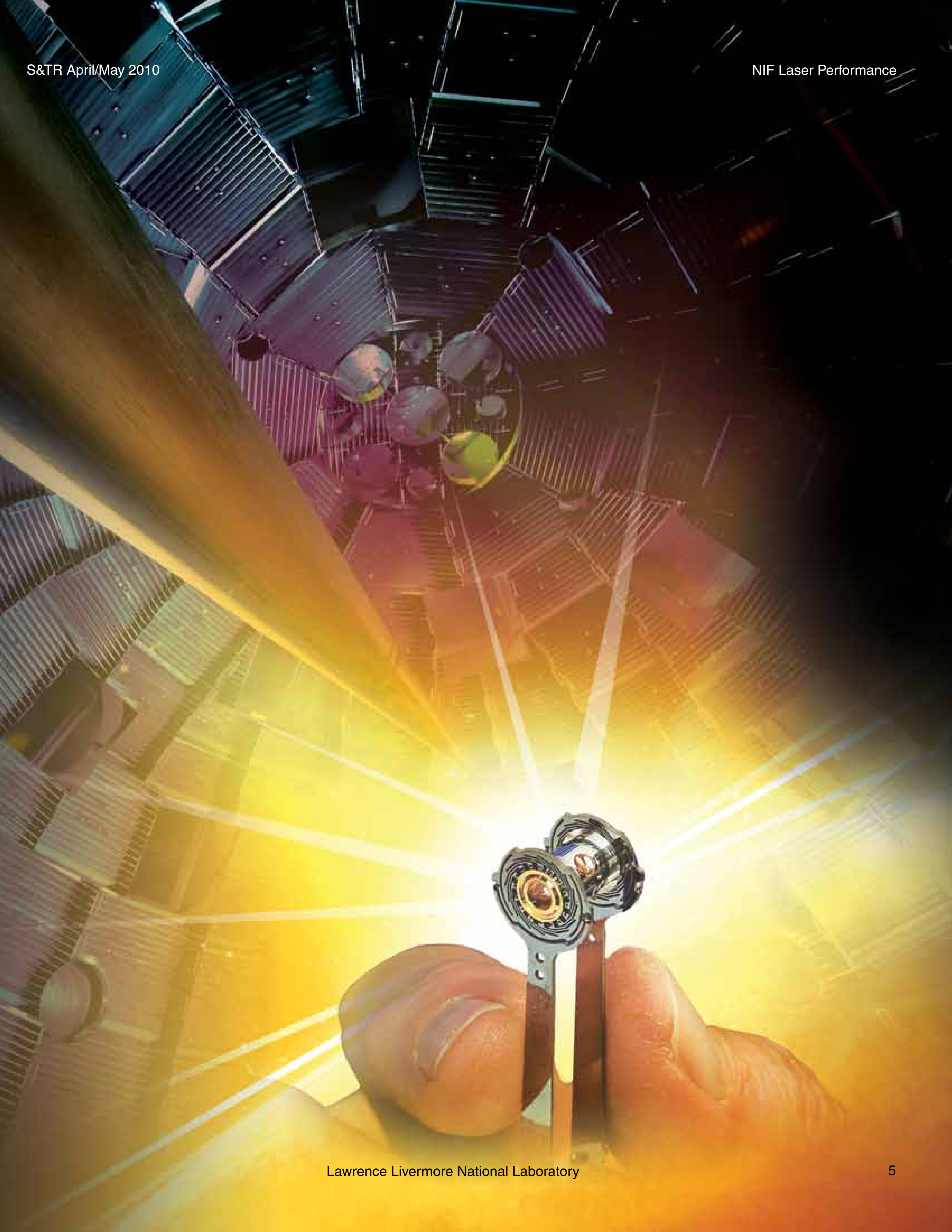
FIFTY years ago, Theodore Maiman first demonstrated a laser, the design of which was originally articulated by Nobel prize winning physicist Charles Townes. At that time, how the laser would evolve and its many applications were unknown. Almost simultaneously, Livermore's John Nuckolls and colleagues invented the idea of inertial confinement fusion (ICF), but they needed a powerful energy source to implode the fuel and create fusion. Scientists at Livermore began pursuing innovative research using lasers with ICF in mind. In 1972, the Laboratory officially formed a laser program to step up efforts to develop large lasers with the goal of achieving fusion in a laboratory setting. Recent experiments at the National Ignition Facility (NIF) move scientists even closer to achieving this goal.

Soon after the NIF dedication in May 2009, scientists ramped up an experimental campaign geared toward creating the necessary environment for ignition and overcoming any challenges associated with the task. Subsequent tests have shown how researchers can fine-tune the laser system to create the necessary conditions for ignition and have yielded valuable data on the timing, pulse shape, energy, and power requirements for ignition experiments.

The first step in obtaining ignition was commissioning the laser. To date, shot results have met or exceeded the laser performance criteria established by the Department of Energy's National Nuclear Security Administration (NNSA). The initial experimental results have not only shown a robust laser but also established the hohlraum design necessary for ignition experiments. "This accomplishment is a major milestone that demonstrates both the power and reliability of NIF's integrated laser system," says Ed Moses, principal associate director of NIF and Photon Science.

NIF is designed to produce well-controlled, precise, repeatable, and flexible shots that provide enhanced capabilities for a variety of applications. Since its completion, the laser system has been used in basic science research for studying the hydrodynamic processes in supernovae and for critical national security programs such as stockpile stewardship.

The National Ignition Facility (NIF) is a 192-beam laser system designed for high-energy-density science research. (opposite page) Inside the target chamber, scientists aim to create ignition and energy gain for the first time in a laboratory setting. A tiny metallic case called a hohlraum holds the fuel capsule for NIF experiments. The target positioner (top left) helps center the hohlraum.



In December 2009, NIF set a world record by firing more than 1 megajoule of ultraviolet energy at a target—more than 30 times the energy previously delivered to a target by any laser system. This shot combined with data from the experimental campaign suggest that NIF is on track to be the first facility in history to create self-sustaining nuclear burn in a laboratory setting, which is the initial step toward making ICF a feasible source of carbon-free, sustainable energy.

Infrared In, Ultraviolet Out

NIF's 192 individual beamlines are designed to simultaneously fire onto a 2-millimeter-diameter deuterium–tritium target capsule to create ignition and energy gain—where more energy is produced by the reaction than was put into it. (See the box below.) To achieve ignition, scientists calculate that the beams must simultaneously deliver about 1.3 megajoules of 351-nanometer (3-omega, ultraviolet) light with a peak power of about 400 terawatts (trillion watts) using the current target design.

Thousands of optics and diagnostics, as well as sophisticated mechanical and computer hardware, need to operate perfectly and in proper sequence to create the necessary conditions for ignition. It all begins at the NIF master oscillator, which generates an initial infrared laser pulse containing a few nanojoules of energy. This initial laser pulse is shaped specifically for each experiment and

The Art of Implosion

The National Ignition Facility (NIF) at Lawrence Livermore is leading the nation's effort to achieve ignition and energy gain for the first time inside a laboratory setting. This feat will require using the world's largest, most energetic laser to create extreme temperatures and pressures that for the time being occur only in the interiors of stars and in exploding nuclear weapons. Using NIF's 192 beamlines, scientists aim to deliver up to 1.8 megajoules of ultraviolet light, with a power of up to 500 trillion watts, onto a target about the size of a pea. The hot, intense conditions within the target capsule are expected to cause the fuel inside it to "ignite," producing more energy from the reaction than was used to initiate it. The target is a 2-millimeter-diameter capsule filled with a deuterium–tritium (DT) gas, which is surrounded by a few-nanometer-thick layer of DT ice.

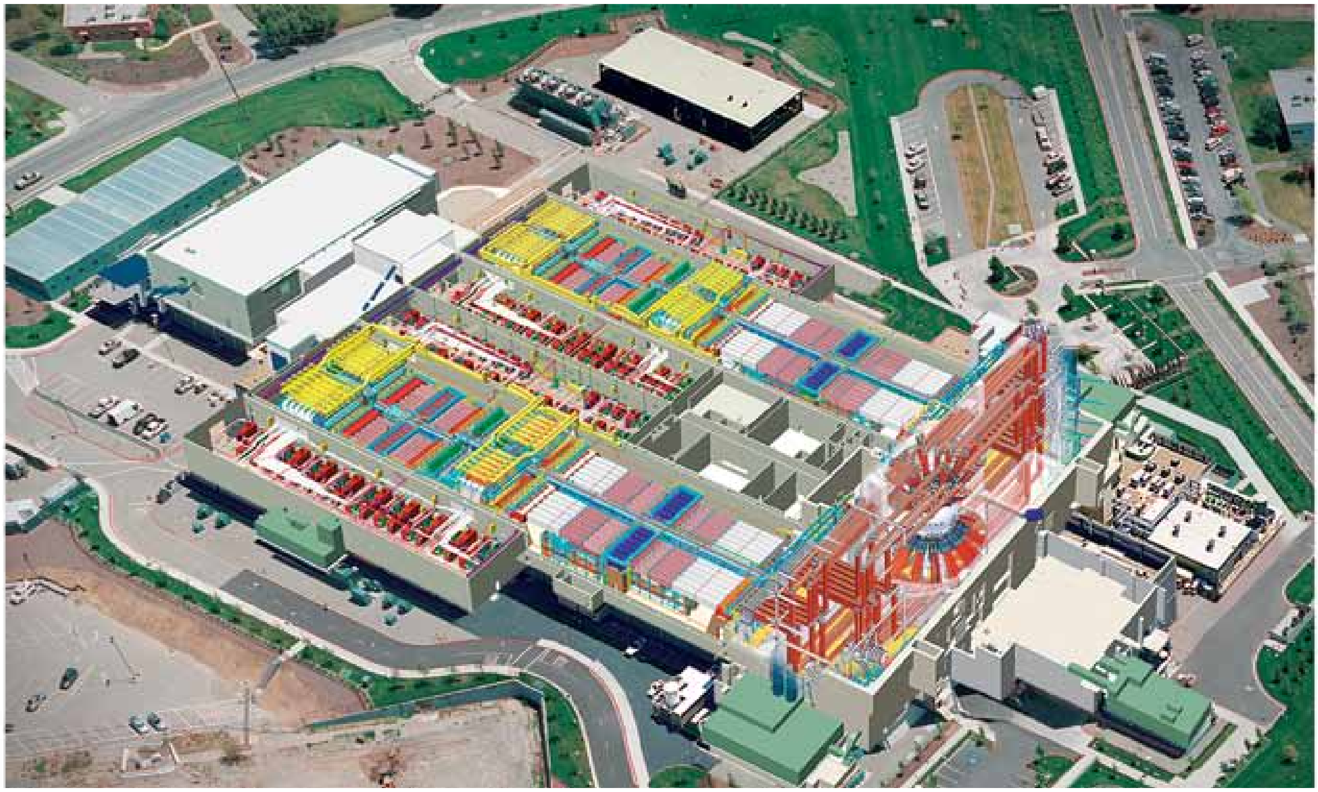
The entire capsule is housed in a cylindrical gold case called a hohlraum. Two openings, one on either side of the several-millimeter-long hohlraum body, are the entry points for the laser beams. A sophisticated target positioner and an automated alignment system place the target at the center of the 10-meter-diameter target chamber with an accuracy of less than the thickness of a human hair.

The 192 laser beams enter the target chamber from 48 points symmetrically positioned around the chamber's top and bottom sections and are directed into the entrance holes of the hohlraum. The lasers heat the hohlraum's inside walls, creating x rays that heat and vaporize the surface of the capsule. Based on Newton's third law of motion that states every force has an equal and opposite force, the vaporizing surface pushes on the central portion of the capsule, causing it to implode. As the fuel is compressed, it produces a shock wave that heats the fuel to its core. The heat is so intense—100 million degrees—that fusion reactions occur, creating thermonuclear burn and ultimately ignition. The entire process takes just 20-billionths of a second.

The ignition process requires that each of NIF's 192 beamlines be precisely positioned and timed to reach the target at exactly the same moment. The beams must also be spatially uniform and of equivalent energy so that the power (up to 500 terawatts) delivered to the target is balanced. From the moment the ignition pulse is generated at the master oscillator to when it reaches the target, the laser must perform flawlessly to produce the right conditions for ignition.

Decades of research have been devoted to creating fusion in the laboratory. With NIF operational and demonstrating its one-of-a-kind capabilities, the laser is on its way to helping scientists finally achieve their goal.

This polished capsule designed for inertial confinement fusion experiments is just 2 millimeters in diameter.



(above) The building housing the 192-beam laser and its target chamber is the size of three football fields. (below) Each of NIF's two identical laser bays has two clusters of 48 beamlines, one on either side of the utility spine running down the middle of the bay.

A technician assembles and aligns the components in a preamplifier module.

can vary in length and overall energy. The pulse is then split into 48 separate beams, which are directed into individual preamplifier modules that increase the beams' energies by billions of times—up to a few joules. The beams are then further split to create 192 beams.

Subsequently, each beam passes several times through its own series of glass amplifiers. By the time the beams are redirected to the switchyard, each one contains more than 4 megajoules of 1,053-nanometer-wavelength (1-omega, infrared) light. In the switchyard, mirrors merge the parallel array of beams into 48 groups of 4. Before entering the target chamber, these "quads" pass through 48 final optics assemblies that are symmetrically positioned around the top and bottom halves of the target chamber to precisely orient the beams onto the target.

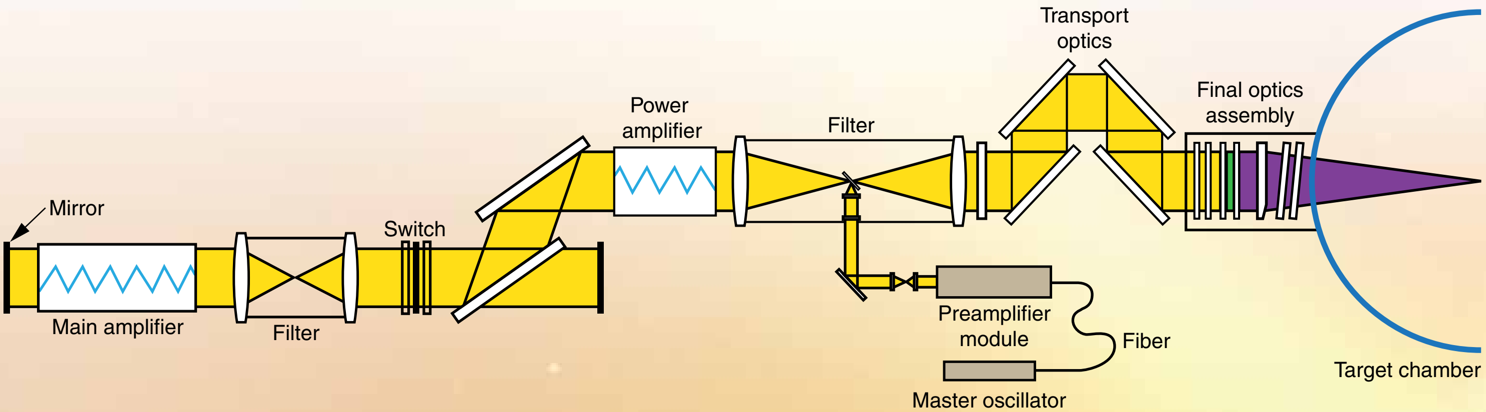
Inside the optics assemblies, potassium dihydrogen phosphate crystals convert the beams from 1-omega infrared light into the desired 3-omega ultraviolet light. This high-frequency, short-wavelength light improves the coupling of the energy into the target. Several other optics focus the light onto the target.

In total, a NIF laser beam travels approximately 1,500 meters within 5 millionths of a second from its birth at the master oscillator to when it reaches the target chamber. When the beams arrive at the target, they are aligned within 60 micrometers root mean square, less than the width of a human hair. Bruno Van Wonterghem, operations manager for NIF, says, "The precision NIF is designed to achieve is similar to throwing a dime from Livermore to San Francisco [a distance of about 64 kilometers] and landing it perfectly inside the coin slot of a parking meter."

Tuned to Perfection

One challenge of ignition is creating the perfect mix of physical conditions at a precise moment in time so that the target implodes uniformly. Recently, multiple test shots were fired to demonstrate how certain laser parameters can be manipulated to produce those conditions. "The laser is one of the main tools used to tune the ignition capsule," says Chris Haynam, manager of NIF's Laser Performance Integrated Experiment Team.

All shots are modeled, set up, and analyzed through a computational system called the Laser Performance Operation Model (LPOM). LPOM provides real-time information on the system requirements for meeting a specific set of laser energy, pulse length, and power goals. It defines the configuration for the master oscillator and preamplifier hardware, determines the



Every NIF beam starts at the master oscillator. The low-energy beam is amplified in the preamplifier module and then in the power amplifier, the main amplifier, and again in the power amplifier before the beam is run through the final optics assembly and into the target chamber.

diagnostic settings for a particular shot, and analyzes shot data. With LPOM, the team can compare predicted shot values with actual data and adjust the settings as necessary for later shots. The data are derived from the many instruments surrounding the target chamber—detectors, oscilloscopes, interferometers, streak cameras, and other diagnostics—that measure the system's performance and record experimental results.

More than a dozen laser parameters are "tuned" to control and optimize key physics parameters related to ignition capsule performance. For example, in ignition experiments, the master oscillator must produce a pulse consisting of four shocks that are timed to collapse the capsule in a precise sequence. Sudden amplitude (peak power) transitions in the pulse create these shocks, and the timing of them must be exact to create the ignition "hot spot"—which starts fusion burn—at the center of the compressed fuel. The amplitude, duration, timing, and energy of each shock can be manipulated by producing the desired pulse shape from the laser system.

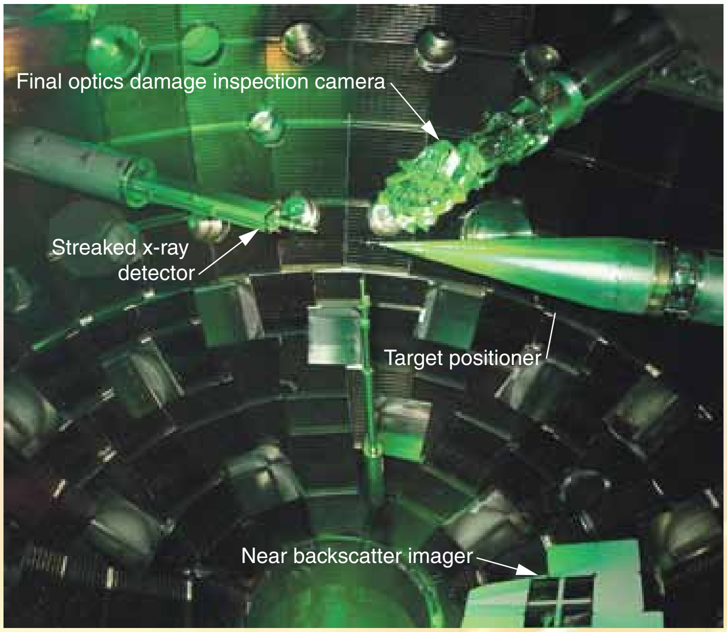
To show how the laser parameters could be adjusted to meet the shock-timing requirements needed for ignition, the team tested a single beamline in a separate unit known as the Precision Diagnostic System (PDS). The team fired 16 shots, then increased the amplitude of the pulse and delayed it by 100 picoseconds, before firing an additional 12 shots. "A comparison of the test data showed that the laser could make the precise changes in amplitude and timing required to tune the capsule to achieve ignition," says Haynam.

A Powerful, Shapely Spot

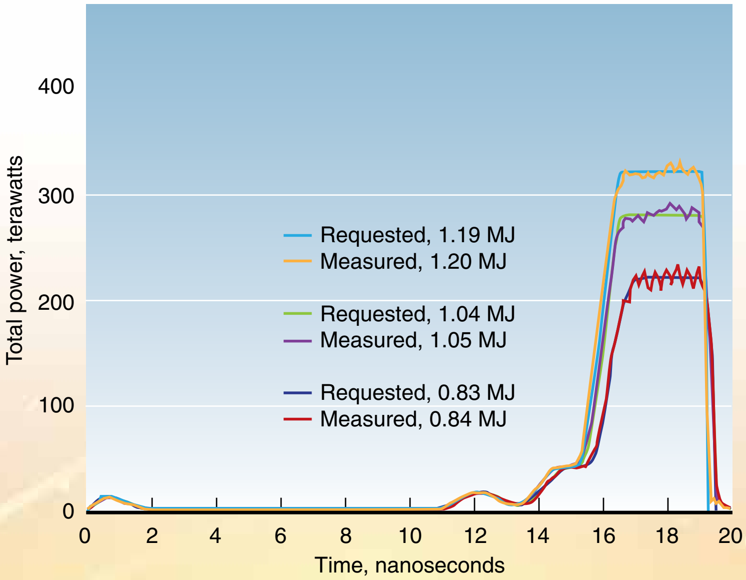
The amplitude and energy of the final shock produced by the laser pulse controls the velocity of capsule implosion and the ignition process. However, the uniformity of this velocity depends on the size and spatial uniformity of each focal spot inside the hohlraum. Haynam's team uses the sophisticated optics and lenses inside the final optics assembly to manipulate the focal spot size. For example, large-aperture diffractive optics, called continuous phase plates, adjust and fine-tune the laser beam to a prescribed size and shape, while maintaining the coherent properties of the laser light. (See *S&TR*, October 2007, pp. 12–13.) These continuous phase plates are combined with a wedged focusing lens to precisely control the focal spot size and uniformity of the beams as they enter the target chamber.

Focal spot size was also tested in PDS. Inside PDS, a beam's energy can be effectively attenuated while still providing accurate measurements. PDS includes an integrated optics module that converts 1-omega infrared light redirected from the switchyard into 3-omega ultraviolet light and then focuses the pulse in precisely the same way as NIF hardware.

Beam-smoothing techniques are used to reduce the intensity of the energy



Detectors, oscilloscopes, interferometers, streak cameras, and other diagnostics surround the target chamber to measure the laser system's performance and record experimental results.



The ability to reliably produce the desired laser pulses provides a stable experimental platform. This graph compares the requested and measured energy produced by three ignition pulses between 0.84 and 1.2 megajoules (MJ).

spikes, lower the contrast of the beam, and spatially shape the beam in a manner that meets target-size and irradiance requirements. A 17-gigahertz frequency modulator in the master oscillator first adjusts the beam's bandwidth. Then, a grating inside each preamplifier module creates a corresponding high-bandwidth pointing variation that promotes smoothing by spectral dispersion.

The team measured focal spot and beam-smoothing parameters for 1.1- and 1.8-megajoule shots inside PDS. "Both shots simultaneously met ignition requirements for beam conditioning, energy, temporal profile, and peak power," says Haynam. Using all the necessary smoothing techniques, the team then fired one NIF quad at 3 omega to the target chamber center. This shot demonstrated that the beam-smoothing and pulse-shaping requirements could be met on the main laser system at full energy and power (1.8 megajoules and 500 terawatts when scaled to 192 beams). In December 2009, the energetics shot series culminated in a shot where all of NIF's beams were fired simultaneously on an ignition-like target at 1.2 megajoules, meeting the beam-smoothing and pulse-shaping requirements for the entire laser.

The Balancing Act

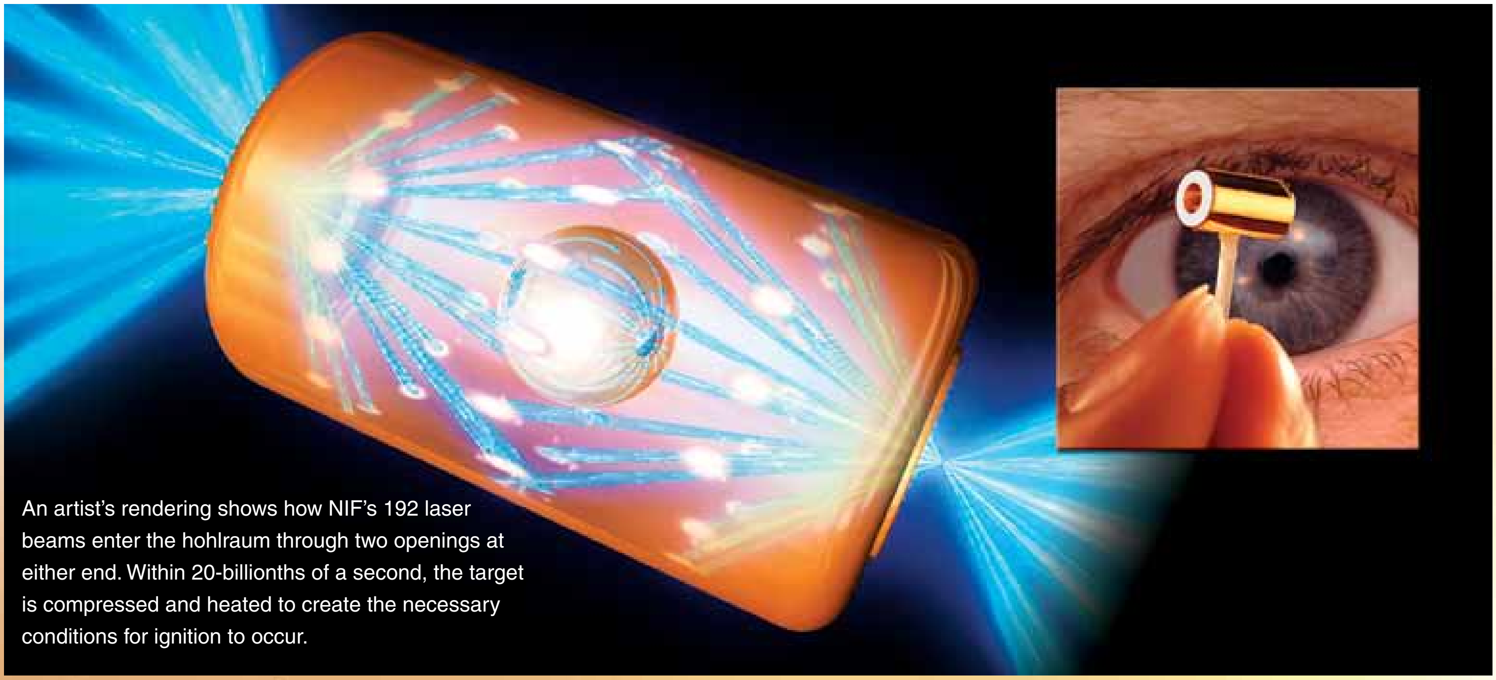
NIF's 192 beams are configured to form an inner and outer cone when they enter the hohlraum. (See the figure below.) The inner cone contains 16 quads (64 beams), and the outer cone contains 32 quads (128 beams). The wavelength separation of these beams affects the shape of the implosion. When beams at the entrance holes of the hohlraum interact with the hot plasma initiated from the x-ray bath occurring inside the hohlraum, energy can transfer between the beams as a result of laser–plasma interactions. In 2009, scientists effectively tuned the wavelength of beams in the outer cone to control this energy transfer, thus transforming a pancake-shaped implosion into a round one.

Power balance and synchronization of the beams are also key to achieving this optimal implosion shape. Balancing the power allows the x rays created inside the hohlraum to uniformly compress the target. "The process is analogous to pressing on a balloon," says Jeff Atherton, director of experiments for the National Ignition Campaign, currently under way. "Unless the balloon is pressed on evenly all the way around, it will bulge out in different directions. The same is true for compressing an ignition capsule. We analyzed the power balance at the start and the peak of the pulse, and it was well within the design requirements."

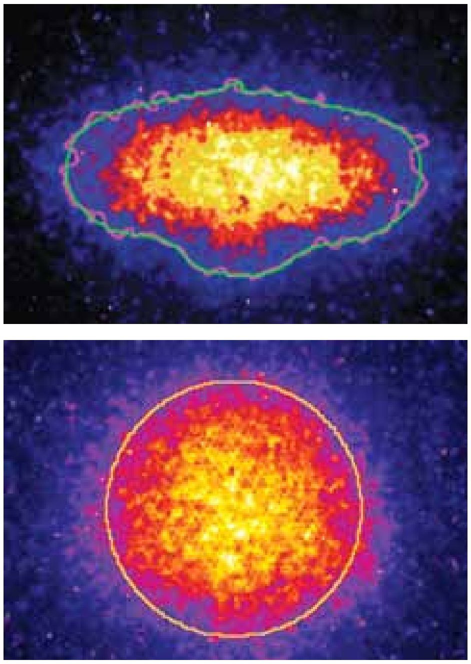
Haynam and his team's efforts are primarily geared toward demonstrating the laser's flexibility and how it can be tuned to create the conditions needed to occur inside the hohlraum for ignition. However, creating the perfect conditions for ignition also requires the right target. Another group of NIF scientists and engineers is studying target energetics and design requirements. Together, the laser and target experiments will provide the data needed so that operational processes and system components can be designed and engineered to meet optimal performance standards.

A Facility for the Ages

The National Ignition Campaign is dedicated to taking the necessary steps to achieve ignition and to developing a robust ignition platform. The campaign is



An artist's rendering shows how NIF's 192 laser beams enter the hohlraum through two openings at either end. Within 20-billionths of a second, the target is compressed and heated to create the necessary conditions for ignition to occur.



Using a new wavelength-tuning technique, scientists can control the direction and amount of energy transfer between laser beams, greatly improving the implosion symmetry of a target. Shown here is (top) an asymmetrical target implosion before tuning and (bottom) a spherical one after tuning.

More than 3,500 guests attended the formal dedication of NIF on May 29, 2009, 12 years to the day of the facility's groundbreaking ceremony.

a partnership of NNSA with members from Lawrence Livermore, Los Alamos, and Sandia national laboratories; the University of Rochester's Laboratory for Laser Energetics; General Atomics in San Diego, California; and numerous other national laboratories and universities including the Massachusetts Institute of Technology.

The first set of experiments demonstrated that NIF is a robust platform for the campaign. "The 173 target shots at 3 omega with 97-percent reliability provide high confidence of the laser and the ability to achieve ignition," says Van Wonterghem. "Over the next few years, we plan to continuously improve the laser to further increase performance, reliability, and shot rate." Ignition experiments will begin later this year, with the goal of creating a reproducible ignition platform by end of fiscal year 2012.

Scientists are also experimenting with NIF's capabilities for other high-energy-density research. For example, using a foil backlighter, they apply NIF's 1-omega light for x-ray radiography. These experiments allow researchers to see through and analyze materials in greater detail. Additionally, Haynam's team has demonstrated in PDS that NIF can operate using 527-nanometer-wavelength (2-omega, green) light equal to 3.4 megajoules of energy when scaled to the full NIF equivalent of 192 beams. "These results are exciting because 2-omega operation allows us to go up to higher energy while significantly extending the life of the optics," says Haynam.

The experimental work being performed at NIF is surpassing the expectations of many people. After a recent tour of the facility, Charles Townes said, "When I was inventing the laser and hoping to build the first one, I was hoping to get milliwatts of power with a small laboratory device. I just never imagined anything like this coming out of it." Fifty years later, advances in laser technology have brought us closer than ever before to achieving ignition and, with it, the potential to produce a secure, reliable source of limitless energy for future generations.

—*Caryn Meissner*

Key Words: energy gain, hohlraum, ignition, inertial confinement fusion (ICF), laser performance, pulse shape, National Ignition Campaign, National Ignition Facility (NIF), wavelength tuning.

For further information contact Trish Damkroger (925) 422-5816 (damkroger1@llnl.gov).

Extracting More Power from the Wind

WIND power use in the U.S.—and worldwide—is expanding rapidly. In 2008, more than 40 percent of our nation's newly installed electricity-producing plants involved wind power. Currently, wind energy plants produce enough electricity on a typical day to power nearly 7 million American homes. The Department of Energy (DOE), which is supporting research at Lawrence Livermore and other facilities to improve the performance and efficiency of wind turbines, calculates that wind power could provide 20 percent of U.S. electricity needs by 2030, up from about just 1 percent in 2009.

To help DOE meet this ambitious goal, Livermore researchers are working to achieve a better understanding of how wind speed variability—in particular with relation to height—and atmospheric turbulence can affect power production. The researchers are also building advanced numerical models to aid in designing wind turbines, siting wind farms, and integrating wind power into the electrical grid. The Livermore effort is supported by DOE's Energy Efficiency and Renewable Energy Program, the Laboratory Directed Research and Development (LDRD) Program, and a cooperative research and development agreement (CRADA) with Siemens Energy, Inc.

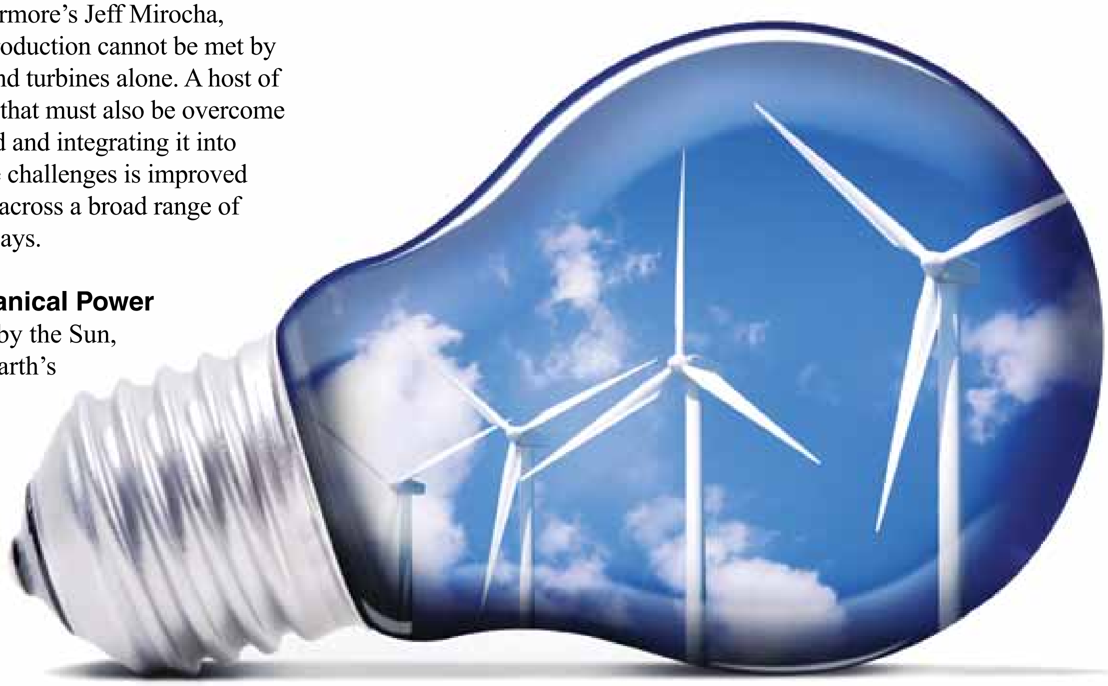
Wind power offers significant advantages over other energy technologies. For example, wind farms can be developed and linked to the electrical grid more rapidly and cheaply than other energy technologies. Also, wind power generates almost no carbon emissions. However, according to Livermore's Jeff Mirocha, significant expansion of wind power production cannot be met by installing a massive number of new wind turbines alone. A host of technological and scientific challenges that must also be overcome involve extracting power from the wind and integrating it into the electrical grid. "At the core of these challenges is improved understanding and prediction of winds across a broad range of spatial and temporal scales," Mirocha says.

Converting Wind Flows to Mechanical Power

Uneven heating of the atmosphere by the Sun, irregularities of Earth's surface, and Earth's rotation all contribute to wind flows. Wind turbines are used to convert the kinetic energy from the wind into mechanical power. Most turbines have either two or three blades, and the wind blowing over these blades causes them to lift and rotate. As the blades rotate, they spin a shaft, which connects to an electrical generator. Wind turbines are complicated devices that include a sophisticated gearbox for increasing a spinning shaft's speed from about 30 to 60 revolutions per minute (rpm) to the 1,000 to 1,800 rpm required by most generators to produce electricity. Utility-scale turbines can produce from 100 kilowatts to several megawatts of power each and are grouped together into wind farms to provide power to the electrical grid.

The power available in wind is proportional to the cube of the wind speed. That is, doubling the wind speed provides eight times the power. For example, a 20-kilometer-per-hour wind has eight times the energy of a 10-kilometer-per-hour wind. However, wind is rarely constant; its speed and variability depend on many factors such as time of day, topography, and changes in temperature with height. Turbulence variability with height is more complicated. In general, wind increases with altitude and becomes more turbulent at higher altitudes.

Modern land-based wind turbines are typically 60 to 100 meters tall (measured from the ground to the centerline of the turbine rotor) but can be as tall as 135 meters. Rotor blade diameters can exceed 120 meters. (See the figure on p. 13.) Because of a turbine's operating altitude and rotor diameter, wind speeds can vary significantly at opposite ends of the blades. This difference may cause the blades to twist and deform, resulting in reduced power output and often in blade and gear failures.



Mirocha, the technical lead of Livermore's growing number of wind energy projects, says the effects of turbulence have been underestimated by both wind turbine manufacturers and wind farm operators. Livermore's research aims to help the industry improve power-generation efficiency and reliability as well as turbine longevity by better understanding winds and building a forecasting mechanism.

Livermore postdoctoral researcher Sonia Wharton recently analyzed an unusually extensive data set from a West Coast wind farm with modern wind turbines. The data were generated over 12 months by meteorological instruments not typically used at wind farms. The instruments collected information every 10 meters up to 200 meters, well above the wind turbines, yielding a high-resolution vertical profile of wind speed, direction, and turbulence.

The data were invaluable because most wind farms record only intermittent measurements of wind speed and direction at a small number of locations about 10 meters aboveground and sometimes isolated measurements at turbine hub height. As a result, manufacturers must make assumptions about the conditions turbine blades experience as they slice through the air at much higher altitudes.

Wharton analyzed the yearlong data set to determine the effect of atmospheric stability on power production of tall turbines. She calculated detailed power curves, which show the relation between wind speed (in meters per second) and power (in kilowatts). The data showed that in unstable atmospheric conditions (high turbulence) turbines generated less power than expected, while in stable conditions (low turbulence) they generated more power than expected. This finding is important because it allows wind farm operators to better predict the amount of power they will supply to the grid over a wide range of meteorological conditions.

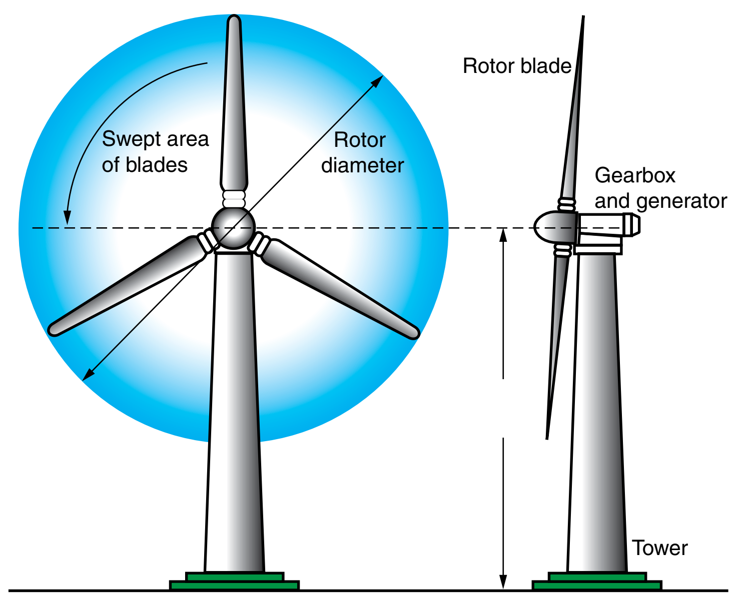
Building a Wind Forecast Capability

The project's second phase builds on this wind farm data set. Using Livermore supercomputers, researchers will simulate wind flow through the same West Coast wind farm during different weather patterns, seasons, and times of day. The project has a special focus on "ramping events," which are sudden changes in wind speed that can either significantly decrease or increase the generative capacity of the wind farm. Wharton says ramping events are of particular interest to the wind power industry because they challenge the ability of the grid to absorb unexpectedly large amounts of wind power or, in the opposite case, generate power from other sources when winds rapidly drop.

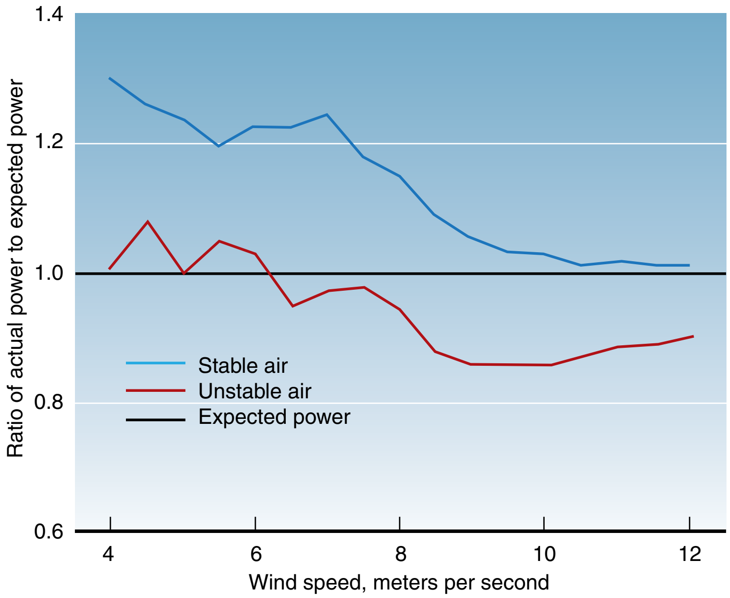
Wharton, along with university collaborators, is using the yearlong data set together with different versions of the Weather Research and Forecasting Model (a supercomputer code collectively maintained and refined by atmospheric researchers worldwide) to determine how to better predict wind patterns and therefore improve the extraction process. The scales of interest vary from the mesoscale (1 to 4 kilometers) for weather fronts to the turbulence scale (10 meters) for much smaller areas of swirling, chaotic winds.

Mirocha notes that energy experts have traditionally used simplified numerical models based on a sparse number of atmospheric measurements. As a result, these models have not fully taken into account turbulence and rapid changes in wind speed and direction. With the wind farm data, the Livermore researchers are confident they can build a better numerical model of wind turbulence that will improve short-term wind forecasting and therefore short-term power forecasting for wind farms. Because atmospheric stability plays such an important role in power production, power predictions may be improved with accurate weather forecasting models.

The forecasting effort partners Livermore scientists with colleagues at University of Colorado at Boulder, Colorado School of Mines, and University of California at Berkeley. Former Livermore scientist Julie Lundquist is leading the University of Colorado's participation in the project. While at Livermore, Lundquist worked on advanced atmospheric turbulence simulations with LDRD and DOE support. Livermore scientists have been incorporating turbulence more accurately in atmospheric forecasting models for the National Atmospheric Release Advisory Center. Lundquist focused on how topography affects winds and realized how the research could be useful for advancing wind energy.



As wind turbine blades rotate, they spin a shaft, which is connected to an electrical generator. Wind turbines include a gearbox to increase the spinning shaft's speed from about 30 to 60 revolutions per minute (rpm) to the 1,000 to 1,800 rpm required by most generators to produce electricity. The hub height of most land-based turbines ranges from 60 to 100 meters. Rotor diameters can exceed 120 meters.



Results from the Livermore wind study show that more power is produced than expected during stable atmospheric conditions (low turbulence) and less power is produced than expected during unstable atmospheric conditions (high turbulence) over a wind speed range of 4 to 12 meters per second.

The importance of wind forecasting was underscored last year, when Lawrence Livermore signed a $2.3 million, two-year CRADA with Siemens Energy, Inc., to provide high-resolution atmospheric modeling capabilities for improving the efficiency of turbine design and wind farm siting and operations. This agreement with a major wind turbine manufacturer is an outgrowth of informal conversations beginning in early 2007 about how winds affect turbines and why wind farms generate more power than expected on some days and less power on other days. The LDRD research on high-resolution atmospheric modeling led directly to Livermore's ability to propose the CRADA to Siemens.

Under the CRADA, the Livermore team, led by Lee Glascoe, is combining its atmospheric turbulence modeling capabilities with complex databases of topography and atmospheric conditions supplied by Siemens for its wind farms in Europe and the U.S. The goal is to merge real-time meteorological data streams with a high-resolution numerical weather prediction model to develop a tool for wind forecasting.

Mirocha is confident that improved models will help wind farms operate more efficiently and thereby provide more power to electrical grids. Many U.S. wind farms are generating up to 20 percent less energy than predicted because of uncertain wind forecasts. More accurate predictions would help farm operators know hours or even days ahead of time how wind conditions will likely affect power generation.

The Livermore research should also ensure more reliable integration of large amounts of renewable energy into power grids, which are not designed for large fluctuations of power input. For example, if electrical utility operators are aware that an impending ramping event is likely to significantly decrease power production at a wind farm, they can prepare to fill the gap with power from other sources such as nuclear, natural gas, or coal plants. Improved model accuracy could also reduce the investment risks in large wind power projects and eventually improve the design of wind turbines to better withstand high-turbulence conditions. A more complete understanding of wind patterns for a specific area should also provide better siting of wind farms and individual turbines to take advantage of maximal wind speeds and minimal turbulence. Finally, understanding how to optimize turbine performance could help the nation more quickly reduce its dependence on foreign oil.

—Arnie Heller

Key Words: cooperative research and development agreement (CRADA), energy efficiency, renewable energy, weather forecasting, wind power, wind turbine.

For further information contact Jeff Mirocha (925) 422-4627 (mirocha2@llnl.gov).

Date for a Heart Cell

WITHOUT the steady, rhythmic beating of our hearts, we die. Thanks to Livermore research, scientists now know that a significant number of cells in the human heart, which may continue to beat for nearly a century, are regenerated over the course of our lives. The finding that the adult human heart retains the capacity to generate new cells could lead to regenerative therapies for heart diseases.

In 2004, scientists at Sweden's Karolinska Institutet in Stockholm began work to establish definitively whether cardiomyocytes, a type of cell in the human heart muscle, are generated later in life. To measure the age of these cells, they sought out Livermore's Bruce Buchholz and his team at the Center for Accelerator Mass Spectrometry (CAMS). The team had earlier pioneered a method for dating plaques in brain tissue samples from Alzheimer's victims. The heart cell collaboration ultimately included not only researchers from Karolinska and Livermore but also other scientists in Sweden and France.

Isolating DNA

As described in the box on p. 16, CAMS researchers have developed unique capabilities for applying carbon-14 dating to biological research. Almost every project has required developing new processes for preparing samples, and the heart cell project was no different.

While brain plaques are fairly simple structures, heart cells are full of proteins that are continually being produced and degraded. "The Karolinska researchers decided that determining the true age of a cell depended on measuring the carbon-14 in its DNA," says Buchholz. "DNA is the one thing that is formed at the moment of a cell's birth and remains unusually stable throughout its life."

Karolinska and Livermore researchers developed a method for isolating DNA from the cardiomyocyte cell. "That work took us a couple of years," says Buchholz. "Each cell has just small amounts of DNA. Existing kits for DNA separation were not adequate because they tended to contaminate the DNA with minute quantities of specious carbon such as petroleum-derived products." Ultimately, Karolinska personnel used fluorescent-activated flow cytometry, a cell-sorting technique earlier invented at Livermore, to separate the nuclei of cells. Solubility chemistry was used to isolate the DNA from the rest of the nucleus.

Using the "Bomb Pulse"

Work then moved to Livermore where multiple DNA samples from 14 cadavers were carbon dated. For AMS, DNA samples are freeze-dried, then burned (or "combusted") to carbon dioxide,

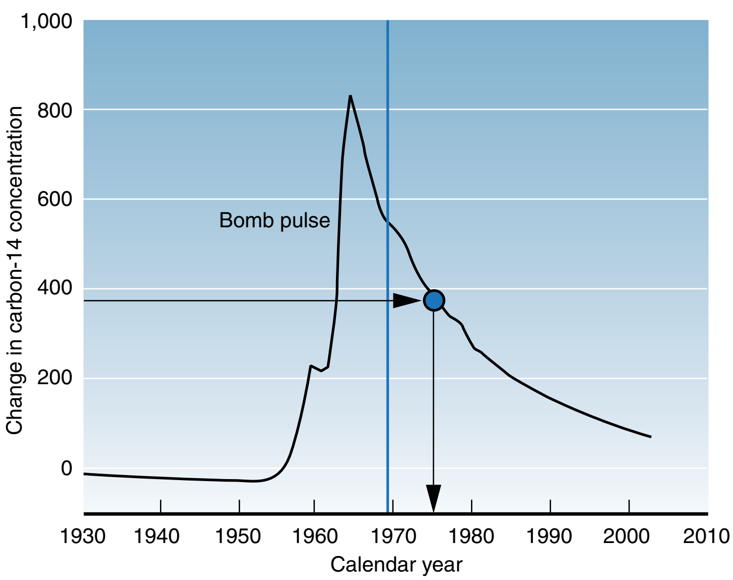
The Old Meets the New

Carbon-14 dating prompts most people to think of objects that are thousands of years old—petrified wood, archeological artifacts, or ancient glaciers. Heart cells from a 20-year-old human would seem far too young to be dated using carbon-14.

Livermore's Center for Accelerator Mass Spectrometry (CAMS) has refined the process of carbon-14 dating to a precision seen nowhere else, allowing researchers to accurately measure extremely small samples and very low doses of carbon-14 and other isotopes in various materials. CAMS researchers can thus examine not only ancient bones and DNA that naturally contain carbon-14 but also other biological materials that have been "tagged" with extremely small amounts of hydrogen-3 (tritium) and other long-lived radioisotopes.

Carbon-14 dating works because every carbon-containing molecule on Earth mirrors the level of carbon-14 in the atmosphere at the time that molecule was created: in glacial ice, tree rings, mammoth bones, and DNA. CAMS uses a huge accelerator as part of its sophisticated method for counting the very rare carbon-14 atoms among the more common carbon-12 and carbon-13. Instruments can detect one carbon-14 atom among up to a quadrillion atoms of carbon-12.

The National Institutes of Health has named CAMS a National Resource for Biomedical Accelerator Mass Spectrometry. This designation makes the facility available to biomedical scientists whose research requires measurements of very low levels of carbon-14 or hydrogen-3. AMS has been used to study human metabolism of vitamins and other substances and to identify areas of the body that absorb drugs and toxic compounds. (See related News Brief on p. 2.)



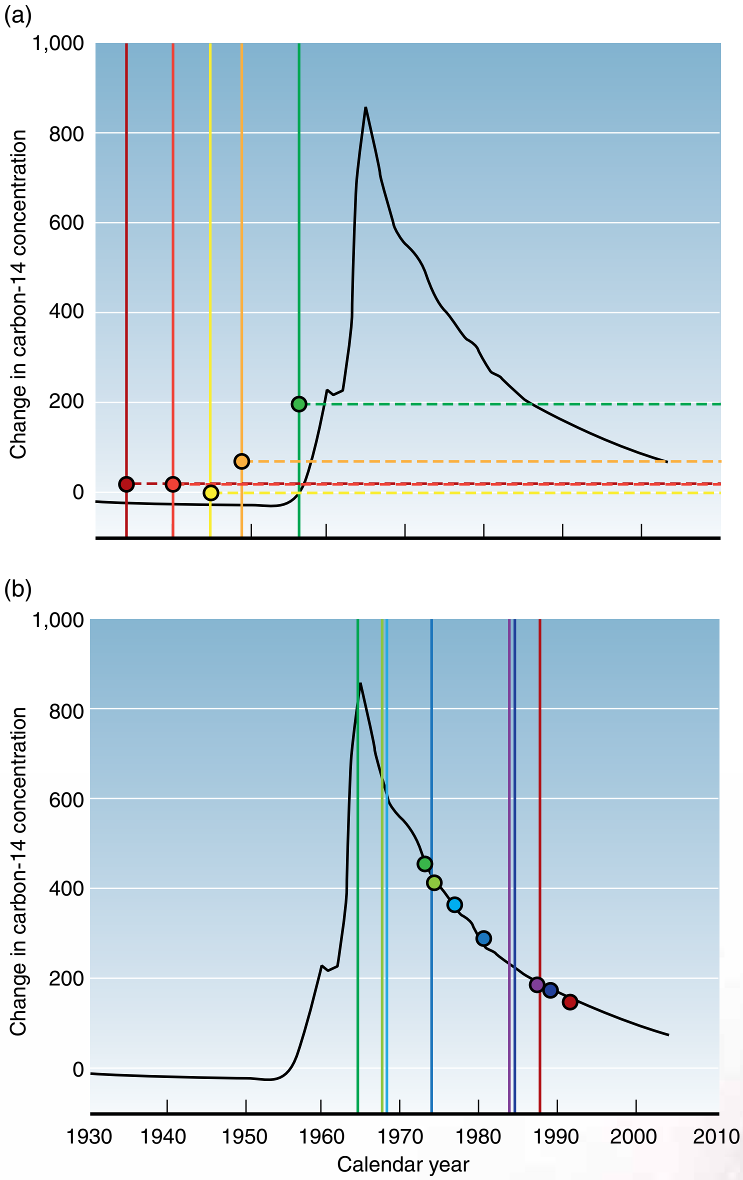
This graph shows how researchers determine the age of cardiomyocyte heart cells using carbon-14 dating. The curve is the atmospheric concentration levels of carbon-14 since 1930, and the blue vertical bar indicates the date of an individual's birth. The measured cellular carbon-14 concentration (horizontal arrow) is compared to established atmospheric carbon-14 concentration over time. The time at which the cellular and atmospheric concentrations correspond (data point) is the inferred birth date (vertical arrow) for the cells tested.

and lastly reduced to tiny graphite pellets. AMS was performed "blind," that is, the identity of each sample was unknown.

Carbon dating was first performed on general heart muscle cells, including cardiomyocytes and other cell types from the left ventricle. That was the easier task. Later, after the team worked out the technique for isolating cardiomyocyte DNA alone, they dated those cells in 12 of the cadavers. Carbon-14 dating is based on using the known decay rate of carbon-14 for long-dead samples. For this project, the dating process took advantage of an atmospheric carbon-14 phenomenon called the "bomb pulse."

Carbon-14 concentrations in the atmosphere remained relatively stable until the Cold War, when aboveground testing of nuclear weapons increased the amount of atmospheric carbon-14. Plants incorporate carbon-14 into their cells, animals eat the plants, and people eat both, absorbing the isotope into their own cells at the same level as is in the atmosphere. Aboveground testing, which started the pulse of carbon-14, began in 1955 and ceased with the 1963 Limited Test Ban Treaty. Although atmospheric nuclear testing took place in only a few locations, carbon-14 was rapidly equalized in the atmosphere around the world following each test. Since 1963, carbon-14 has diffused from the atmosphere into Earth's biosphere.

CAMS researchers found that in the five subjects born before the onset of the nuclear bomb tests, the carbon-14 concentrations in cardiomyocyte genomic DNA were higher than the prebomb atmospheric concentrations, demonstrating DNA synthesis



(a) The carbon-14 concentrations in cardiomyocyte DNA from individuals born before the time of the "bomb pulse" correspond to time points after the birth of all individuals. Vertical bars are years of test subjects' birth, and the corresponding colored data points indicate the change in the carbon-14 value. (b) Carbon-14 concentrations in cardiomyocyte DNA from individuals born after the time of nuclear bomb tests also indicate postnatal synthesis of cardiomyocytes.

after 1955. Similarly, in the seven subjects born near or after the time of the nuclear bomb tests, the carbon-14 concentrations in cardiomyocyte DNA corresponded to the atmospheric concentrations several years after their birth, indicating postnatal cardiomyocyte DNA synthesis. (See the figure at left.) The ages at death for the individuals studied ranged from 20 to 73 with dates of birth from 1987 to 1933.

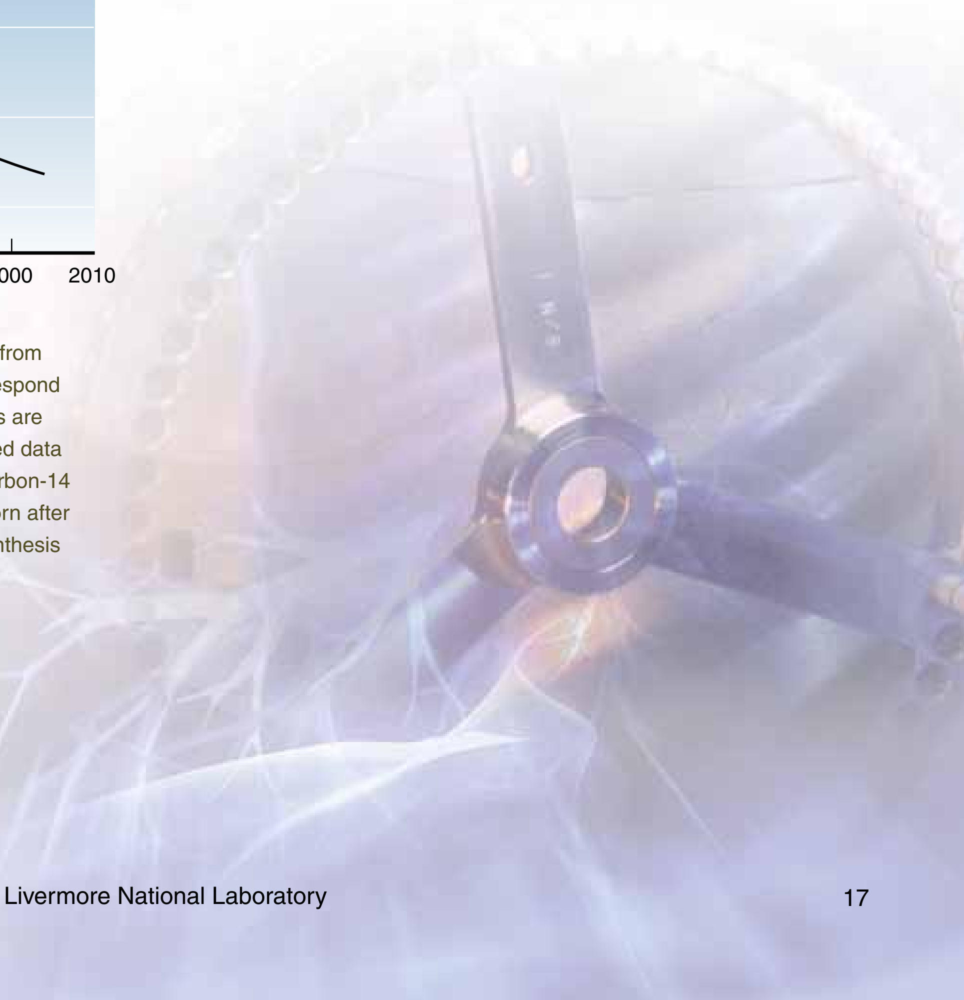
The researchers found that by analyzing individuals born at different times before 1955, they could establish the age at which DNA synthesis occurs and whether it continues beyond that age. They found that cardiomyocytes are renewed at a rate of 1 percent a year up to the age of 20 years. The rate gradually decreases to less than half a percent per year by old age.

"Creation of the bomb pulse was an unintentional side effect of aboveground nuclear testing, but it has proved to be highly useful for research in many fields, including climate change, carbon turnover, and forest and animal populations," says Buchholz. "The carbon-14 dating technique is allowing us to measure reality rather than an artificial system such as a cell culture."

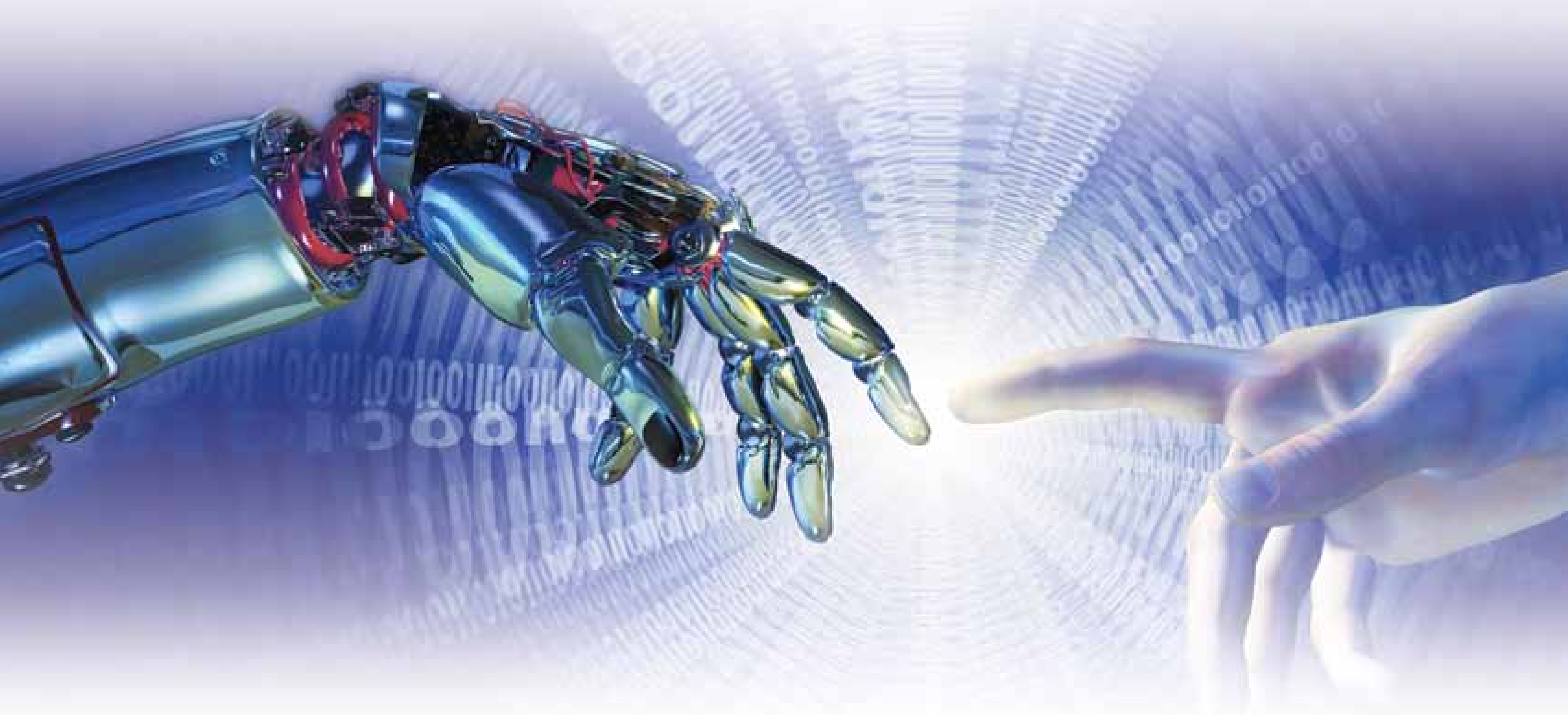
—Katie Walter

Key Words: carbon-14 dating, cardiomyocyte, Center for Accelerator Mass Spectrometry (CAMS), heart-cell regeneration.

For further information contact Bruce Buchholz (925) 422-1739 (buchholz2@llnl.gov).



Unique Marriage of Biology and Semiconductors



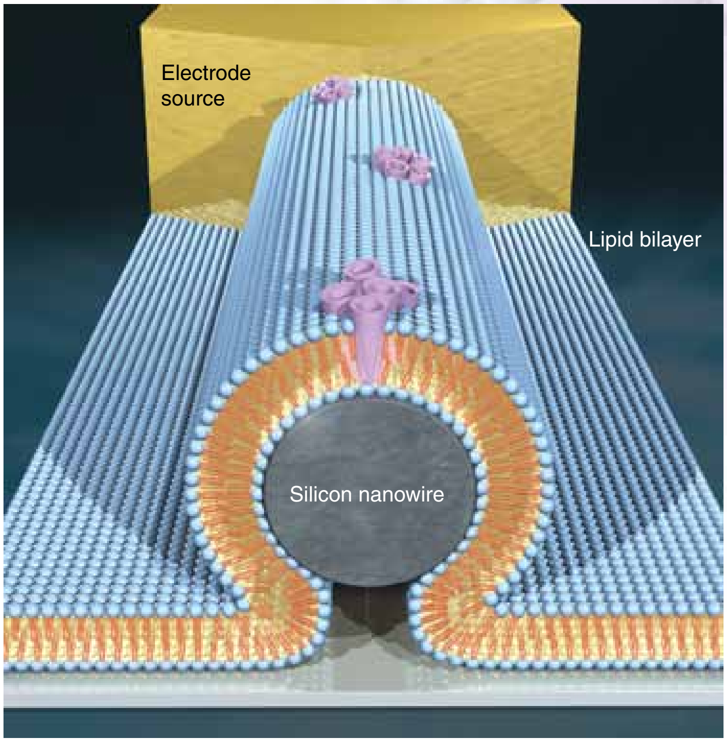
ADVANCES in armor for U.S. soldiers and their vehicles have helped save soldiers' lives in overseas conflicts. Yet, many injuries do still occur, such as the loss of a limb from a roadside bomb or other explosion, and sometimes result in the need for a prosthetic device. Over the years, the quality of prostheses has improved, but many remain clumsy or uncomfortable to use. Thanks to a recent Laboratory project, prosthetic devices that are more tightly integrated with the body and more natural to operate may soon be possible. Livermore researchers have successfully combined biological material with semiconductor nanowires in what could be the first step toward vastly improved bioelectronic interfaces. Collaborators on the effort include researchers from the University of California at Berkeley and Davis.

Semiconductor nanowires, made of silicon, are so small that they are considered to have just one dimension. Each nanowire is a few micrometers long but only a few tens of nanometers in width. (One nanometer is a billionth of a meter, half the width of the DNA double helix.) The Livermore team, led by materials expert Aleksandr Noy, has made major advances in the new field of bionanoelectronics by using silicon nanowires wrapped with a layer of fatty organic molecules. The fat, or lipid, becomes a membrane into which a protein or other molecule can be inserted. Noy explains, "If biological material is deposited directly on silicon, the organic material will die. With the lipid as an interface, the two disparate materials can be combined." This marriage of biomolecules and silicon could greatly increase our ability to communicate with living systems in general.

Modern communication technology relies on electric fields and currents to carry the flow of information. In contrast, biological systems follow an entirely different paradigm that is far more effective and efficient. Living organisms use a sophisticated arsenal of membrane receptors, channels, and pumps to control signal transduction—the ordered sequences of biochemical reactions inside the cell—to a degree that is unmatched by man-made devices. Electronic circuits that make use of biological components, for example as a source of input, could have dramatically greater capabilities, but only if the biological and man-made structures are integrated seamlessly.

Fat Is Good after All

According to Noy, how humans communicate with a computer is very inefficient by biological standards: we push buttons, the machine generates light and sound, and images appear on the screen. "Our



An artist's rendering of the bionanoelectronic device shows how antibiotic molecules (purple) spontaneously insert themselves into the lipid layer (blue) and group together, allowing ion movement through them. When an electrical field is applied to the device, researchers can control ion transport, the first step toward converting biological signals into electronic impulses. (Rendering by Scott Dougherty.)

team's goal is to design a device in which individual biomolecules can communicate directly with semiconductor circuits."

Previous efforts to combine microelectronics with biomolecules have met with varying degrees of success. However, the fairly recent development of nanomaterials, which are comparable in size to biological molecules, has opened up possibilities for successful integration. Other researchers have used carbon nanotubes as carriers for transporting intracellular proteins and DNA. Also, researchers have used silicon nanowires as gene delivery vehicles for mammalian cells. In both instances, the nanomaterial provided a conduit for some substance. However, fully integrating the biological with the nanoelectronic requires a whole new process.

A lipid membrane—the fat we love to hate—turns out to be the perfect medium. The fat mimics a cell wall, and electrostatic interactions make the lipid stick to silicon. The lipid membrane forms a stable, self-healing, virtually impenetrable barrier to ions and small molecules. At the same time, the lipid membrane holds proteins that are vital for almost every cell function, including recognition, transport, and signal transduction. "Lipid membranes can house an unlimited number of protein machines that perform a large number of functions in the cell," says Berkeley collaborator Nipun Misra.

The Device in Action

In 2009, the researchers used protein pores as functional electronic device components. The pores worked as "gate conduits" for turning electrical voltage on and off and for ion transport in a way that is similar to the processes used by living cells to move salts and other electrolytes from place to place.

The initial bionanoelectronic device consisted of a silicon nanowire connected to a pair of metallic source and drain electrodes. Because bionanoelectronic devices will likely be deployed in an environment comparable to that of the human body—mostly water with a heavy dose of salt—Noy's team replicated such conditions in the experimental setup.

"An exciting possibility is to use the intrinsic electronic functionality of the device to control ion transport through an ion channel in the lipid membrane surrounding the nanowires," says Noy. In experiments, antibiotic molecules spontaneously inserted themselves into the lipid layer and grouped together to form large pores. The researchers found these groups of pores to be of sufficient size for small ions to diffuse through. By applying an electrical field to the device, the team could open and close the biological pores.

Just the First Step

The next step is to directly convert biological signals into electronic impulses, which would require a more sophisticated device made with other nano- and biomaterials. The lipid layers provide a matrix for a virtually unlimited number of transmembrane proteins with different and exciting functionalities. Noy says, "Faster computers, much improved biosensing and diagnostic tools, and prosthetic devices that operate in a whole new way are just a few of the possibilities."

—Katie Walter

Key Words: bionanoelectronics, lipid, nanotechnology, silicon nanowire.

For further information contact Anne Stark (925) 422-9799 (stark8@llnl.gov).

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

Patents

Smart Membranes for Nitrate Removal, Water Purification, and Selective Ion Transportation
William D. Wilson, Charlene M. Schaldach, William L. Bourcier, Phillip H. Paul
U.S. Patent 7,632,406 B2
December 15, 2009
This computer-designed nanoengineered membrane is designed to separate dissolved species. One model with an apparatus for treating a fluid includes ions comprising a microengineered porous membrane, a system for producing an electrical charge across the membrane, and a series of nanopores extending through the membrane. The pore size is such that the nanopores will form a double-layer overlap when the fluid contacts the membrane. As a result, only those ions whose electrical charge is opposite that of the membrane can pass through the pores.

Awards

A Laboratory researcher's paper published in November 2008 is a cowinner of this year's **American Association for the Advancement of Science Newcomb Cleveland Prize**. The paper is one of two outstanding papers published in *Science* from June 1, 2008, through May 31, 2009.

Bruce Macintosh of the Physical and Life Sciences Directorate is one of the lead authors for the paper entitled "Direct Imaging of Multiple Planets Orbiting the Star HR 8799," which appeared in the November 28, 2008, edition of *Science*. **Christian Marois**, a former Livermore postdoctoral researcher now at the National Research Council's Herzberg Institute of Astrophysics in Canada, is the other lead author.

The Macintosh–Marois paper details how astronomers for the first time took snapshots of a multiplanet solar system, much like ours, orbiting another star. The new solar system orbits a dusty young star named HR 8799, which is 140 light years away and about 1.5 times the size of our Sun. Three planets, roughly 7 to 10 times the mass of Jupiter, orbit the star.

Another paper entitled "Images of an Exosolar Planet 25 Light-Years from Earth," which also appeared in the November 28, 2008, edition of *Science*, shares the award. That paper includes Livermore author **Mike Fitzgerald** of the Physical and Life Sciences Directorate, with Paul Kalas of the University of California at Berkeley as the lead author.

Laboratory physicist **Ramona Vogt** has been selected **vice-chair** of the **American Physical Society** (APS) **Topical Group on Hadronic Physics**. She is the first woman to serve in this position. As a Livermore postdoctoral researcher from 1989 to 1991, Vogt worked in the Heavy Ion Group, predicting heavy particle and lepton pair production rates in nucleus–nucleus collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. She later returned to Livermore in 2007 as a staff scientist in the Physical and Life Sciences Directorate. Currently, her work involves modeling fission, event by event, using Monte Carlo methods. Another area of interest is heavy quark–related physics at RHIC.

The Topical Group on Hadronic Physics is one of the APS units helping to fulfill the organization's mission to "advance and diffuse the knowledge of physics." Topical groups provide opportunities for members to interact with colleagues with similar interests and to keep abreast of new developments in their specialized fields.

The Laboratory's **Terascale Simulation Facility** (TSF) has received a **Leadership in Energy and Environmental Design** (LEED) **gold level certification** under the **U.S. Green Building Council** rating system. LEED is an internationally recognized certification system providing third-party verification that a building or community was designed and built using strategies aimed at improving performance in areas such as energy savings, water efficiency, and carbon dioxide emissions reduction.

"This is truly a noteworthy achievement for NNSA [National Nuclear Security Administration] and LLNL [Lawrence Livermore National Laboratory] that symbolizes our commitment to transforming the Cold War–era nuclear weapons complex into a modern, efficient nuclear security enterprise," said Brigadier General Garrett Harencak, NNSA principal assistant deputy administrator for Military Application, in a congratulatory communication. Completed in late 2004, TSF is a 23,500-meter-square building that houses some of the world's fastest supercomputers, including Dawn (BlueGene/P), BlueGene/L, and ASC Purple—Advanced Simulation and Computing (ASC) systems largely dedicated to stockpile stewardship.

Abstract

A Stellar Performance

Recently, the Laboratory achieved a major milestone in its pursuit of inertial confinement fusion with the completion of the National Ignition Facility (NIF), the world's largest and most powerful laser system. NIF contains 192 individual beamlines designed to simultaneously fire onto a deuterium–tritium target capsule and create ignition and energy gain—where more energy is produced by the fusion reaction than was put into it. The National Ignition Campaign, currently under way, is defining the necessary steps to achieve ignition and develop a robust ignition platform. Test shots over the last several months have provided critical data on the laser's timing, pulse shape, energy, and power required to control ignition experiments. These tests have also demonstrated how the laser can be "tuned" to optimize key physics parameters related to ignition capsule performance.

Contact: Trish Damkroger (925) 422-5816 (damkroger1@llnl.gov).

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Pressure Dynamics at the Microscale

New capabilities in high-pressure science are helping Livermore scientists better understand how extreme pressure affects a material's structure.

Also in June

• Livermore scientists are developing techniques to predict the response of granular materials under pressure.

• A briefcase-size device for nuclear magnetic resonance is designed for onsite analysis of suspected chemical weapons.

• A series of shots at the National Ignition Facility is helping scientists put the finishing touches on targets designed for ignition experiments.

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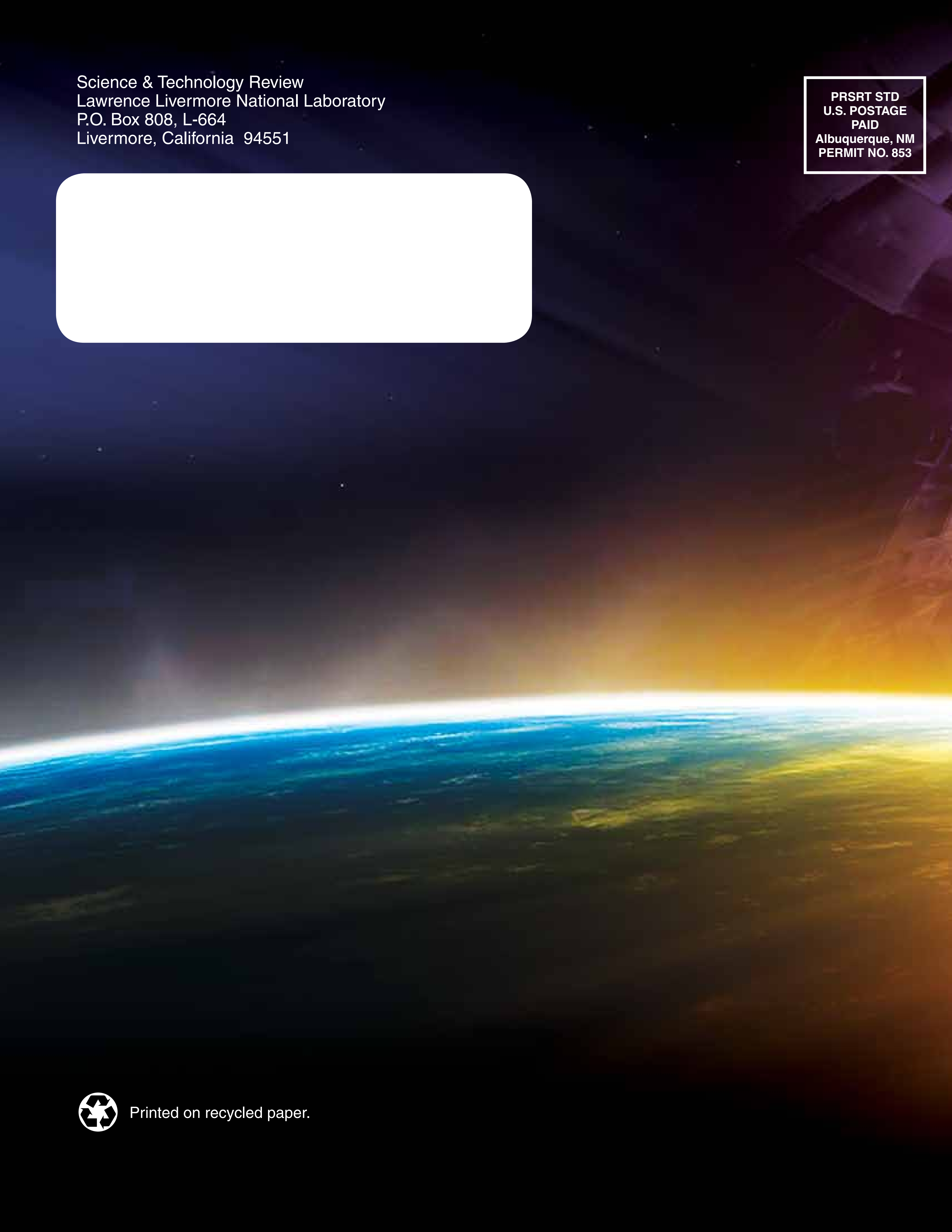
Coming Next Issue



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