Lawrence Livermore National Laboratory

June 2014

Science & Technology Review

A New Approach Energizes Ignition Experiments

Also in this issue:

Mapping the Path of Fission Fragments

Carbon Nanotubes for Toxin Detection

Why Rainfall Patterns Change

About the Cover

Groundbreaking experiments at the National Ignition Facility (NIF) are helping scientists better understand the physics of ignition, in which fusion reactions generate substantially more energy than the laser beams used to initiate those reactions. As described in the article beginning on p. 4, Livermore researchers implemented a new shape for the laser pulse. This so-called "high-foot" pulse shape is more forgiving of capsule imperfections and instabilities that can dampen fusion reactions. High-foot experiments have produced record yields of fusion neutrons through a process called alpha heating. The results provide an important benchmark for the computational models used to predict the behavior of matter under extreme conditions, such as those occurring in a nuclear detonation or powering the Sun and stars.

Cover design: George A. Kitrinos

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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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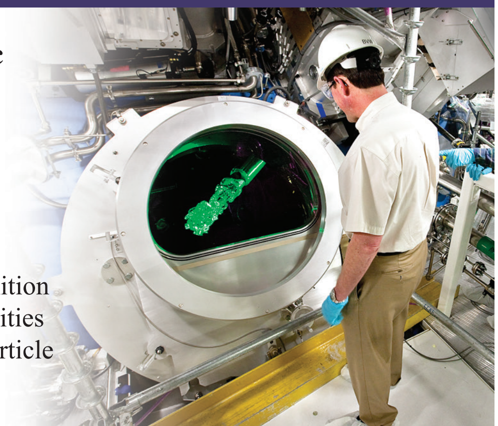

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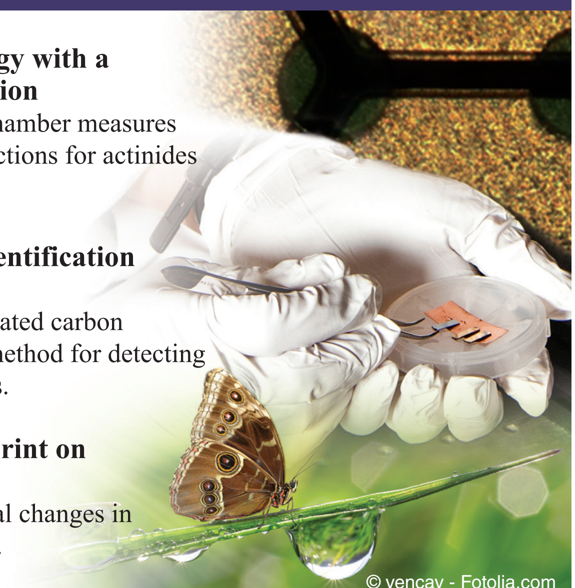

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William H. Goldstein Selected as Laboratory Director

William H. Goldstein has been named director of Lawrence Livermore National Laboratory. Appointed with the concurrence of the Department of Energy (DOE) and the National Nuclear Security Administration (NNSA), Goldstein is the 12th director of the Laboratory since it was established in 1952. He will also serve as president of Lawrence Livermore National Security, LLC (LLNS), which manages the Laboratory for DOE and NNSA.

In announcing the selection, LLNS President Norman Pattiz said Goldstein was chosen "because of his proven scientific leadership and senior management experience across a broad range of Laboratory programs, his passion for the Lab's mission and people, and his ability to strategically manage the breadth of Livermore's science and technology capabilities and operations to meet critical national security needs. He is a respected and trusted scientist among Laboratory managers and employees and with the DOE, NNSA, and other key government sponsors and academic and industrial partners."

A 29-year Laboratory employee, Goldstein previously served as Livermore's deputy director for Science and Technology and as associate director for Physical and Life Sciences. His contributions to stockpile stewardship include generating data that underlie advanced codes and simulations. In addition, he led the creation of Livermore's Jupiter Laser Facility and, in 2006, oversaw completion of the Titan laser platform. Goldstein received a Ph.D. in theoretical physics from Columbia University and a bachelor's degree in physics from Swarthmore College. He is a fellow of the American Association for the Advancement of Science and, in 1994, was honored with the DOE Weapons Recognition of Excellence Award.

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Volcanic Eruptions Slow Warming

An international research team led by Livermore climate scientist Benjamin Santer found that volcanic eruptions in the early part of the 21st century have cooled the planet, partly offsetting the warming produced by greenhouse gases. In the February 23, 2014, edition of *Nature Geoscience*, the team reported that most climate models have not accurately accounted for this cooling effect.

Despite continuing increases in atmospheric levels of greenhouse gases, the global mean temperatures at the planet's surface and in the troposphere (the lowest layer of Earth's atmosphere) have shown little warming since 1998. The Livermore-led collaboration explored whether increased amounts of volcanic aerosol in the stratosphere (the layer above the troposphere) could be a factor in the warming "slowdown" because these aerosols reflect some of the incoming sunlight back into space.

The researchers performed two statistical tests to determine whether recent volcanic eruptions have cooling effects that can be distinguished from the intrinsic variability of the climate. They found evidence for significant correlations between observed levels of volcanic aerosols, satellite-based estimates of lower temperatures in the troposphere, and the amount of sunlight reflected back to space by the aerosol particles.

The team's research was funded by DOE's Office of Biological and Environmental Science in the Office of Science. The study included scientists from Remote Sensing Systems, Massachusetts Institute of Technology, NASA's Goddard Institute for Space Studies, and the Canadian Centre for Climate Modeling and Analysis.

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A Deeper Look into Giant Gas Planets

Working at Deutsches Elektronen-Synchrotron (DESY) in Hamburg, Germany, an international collaboration that included Livermore researchers simulated the lower atmospheric layers of giant gas planets such as Jupiter and Saturn. The team's findings show how liquid hydrogen becomes a plasma. The research also enhances understanding of the plasma's thermal conductivity and its internal energy exchange, both important components of planetary models.

The atmosphere of gas giants consists mainly of hydrogen, the most abundant chemical element in the universe. "Some of hydrogen's properties at extreme conditions remain uncertain despite our very good theoretical models," says Livermore physicist Tilo Doeppner, a coauthor of the team's paper appearing in the March 12, 2014, online edition of *Physical Review Letters*.

The researchers chose liquid hydrogen because its mass density is similar to that found in the lower atmosphere of giant gas planets. Using FLASH, the x-ray laser at DESY, the scientists heated the liquid hydrogen almost instantaneously, from –253°C to about 12,000°C, and observed characteristics of the heating process through the increase in the x-ray scattering signal.

The x-ray laser pulse initially heats only electrons. These electrons slowly transfer their energy to protons, which are about 2,000 times heavier, until a thermal equilibrium is reached. During the process, hydrogen's molecular bonds break, forming a plasma of electrons and protons. Although this process takes many thousands of collisions between electrons and protons, the studies showed that the thermal equilibrium is attained in just under one-trillionth of a second.

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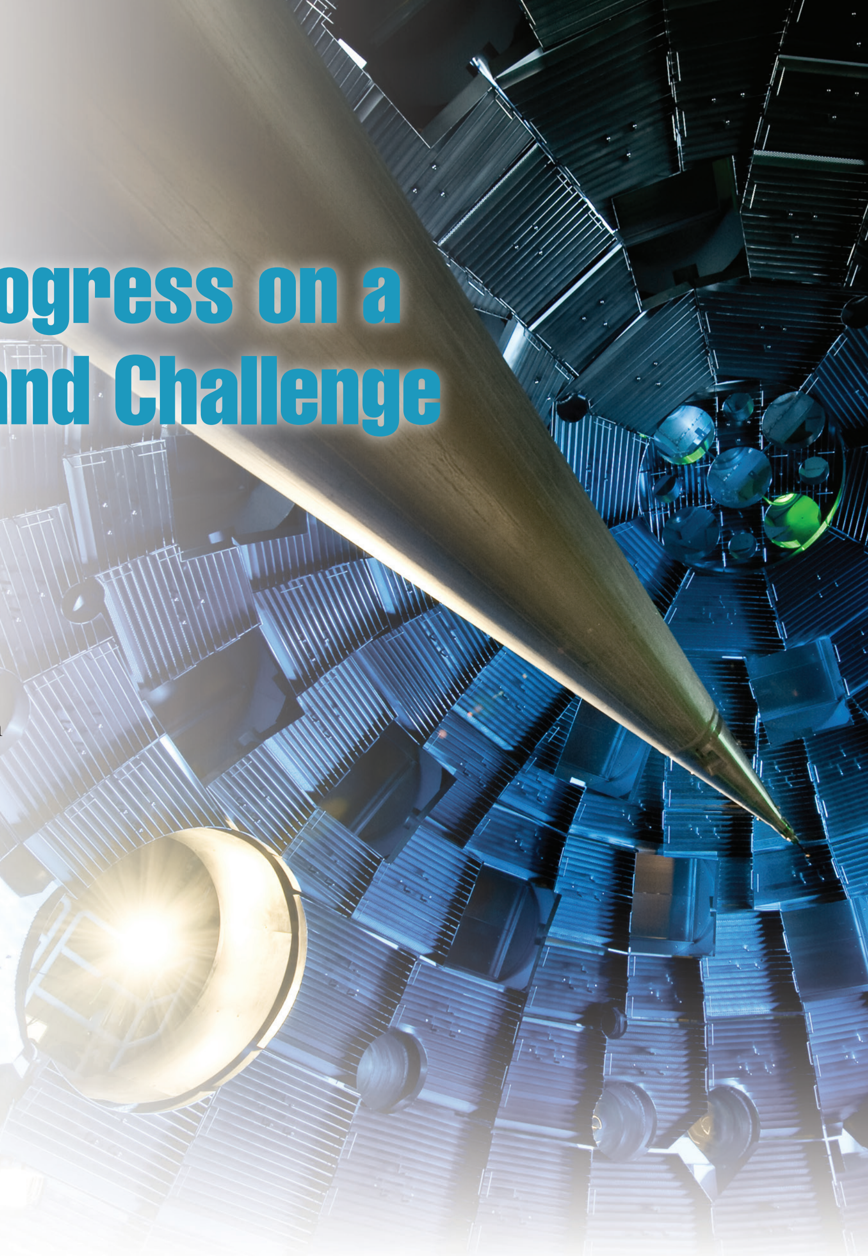
(continued on p. 24)

Commentary by William H. Goldstein

Important Progress on a Scientific Grand Challenge



AMONG the great scientific grand challenges is achieving fusion ignition in the laboratory. Realizing this long-term goal will help us understand the power source of the Sun and stars, enhance our understanding of the physics of nuclear weapons, and allow us to explore the potential of fusion as a source of clean, plentiful energy.

Livermore scientists made substantial progress toward ignition during the three-year-long National Ignition Campaign (NIC), which ended in 2012. NIC experiments were highly successful in establishing the National Ignition Facility (NIF) as an experimental laser system with unprecedented energy, precision, flexibility, and reliability. During NIC, Livermore researchers, working with colleagues from universities, other national laboratories, and our industrial partners, installed diagnostics, established target fabrication capabilities, and developed experimental platforms. The experiments achieved physics regimes of extreme temperature, pressure, and density never before observed in the laboratory and impossible to duplicate elsewhere. In the process, they generated a large set of quality data on high-compression fuel capsule implosions.

NIC experiments gave us an appreciation of the physics that remains to be explored and understood for ignition to be achieved. We also observed, as often occurs when scientists tackle a grand challenge, that nature can surprise us when we reach beyond the known landscape of scientific knowledge.

As the article beginning on p. 4 describes, recent efforts at NIF have focused on a new experimental ignition design that lowers the maximum compression of the capsule containing deuterium and tritium fuel. The lower compression is the result of modifying and simplifying NIF's laser pulse to suppress instabilities that can dampen fusion reactions. These so-called high-foot experiments, named for a characteristic of the new laser pulse, are designed to systematically explore the boundaries of our understanding of fuel compression, with an eye toward establishing clear milestones on the path to ignition.

High-foot experiments have been tremendously successful. Since September 2013, they have increased the yield of fusion neutrons by more than a factor of 10 over previous experiments. In particular, the experiments have demonstrated a significant amount of alpha heating, which is the critical physical process for reaching ignition.

Data from the high-foot experiments are helping us determine the accuracy of supercomputer simulations of inertial confinement fusion implosions. The results have also provided insights into the models we use for stockpile stewardship, leading to new areas of inquiry and improving our confidence in those models.

The high-foot campaign has demonstrated the ability of the Laboratory's scientific staff to explore new ways of thinking about a problem and to work together to make progress on very difficult challenges. The outstanding experimental results have also engaged and expanded the community of scientists interested in exploring the compelling science of ignition on NIF. I anticipate additional progress in the months and years ahead on our path to ignition, as we probe nature to reveal its deepest secrets.

■ William H. Goldstein is director of Lawrence Livermore National Laboratory.

A Significant Achievement on the

A new shape for the laser pulse used in ignition experiments at the National Ignition Facility is taming long-standing instabilities and increasing the amount of alpha heating and neutron yield.

TEAMWORK among scientists in different disciplines has been a hallmark of research conducted at Lawrence Livermore. Ernest O. Lawrence, the Laboratory's cofounder, was noted for eschewing job titles and assembling cohesive teams of researchers with a variety of expertise. Once again, this enduring strategy has paid off. Scientists from two Livermore principal directorates—National Ignition Facility (NIF) and Photon Science, and Weapons and Complex Integration—are collaborating on a series of NIF experiments in which fusion reactions have generated substantially more energy than the laser-driven implosion had deposited into the fusion fuel.

The experimental results are remarkably close to supercomputer simulations. They also provide an important benchmark for the models used to predict the behavior of matter under extreme conditions, such as those generated during a nuclear explosion. These results, which were reported in leading physics journals in early 2014, have also energized scientists worldwide who have been working for more than four decades to understand and control fusion, the power source of the Sun and stars.

The experiments use a new shape to NIF's laser pulse. Called a high foot, this pulse shape is more forgiving of imperfections in the fusion fuel capsule and of instabilities that can grow quickly and dampen fusion reactions. The goal of these experiments is to "gain control and learn more about what Mother Nature is doing," says Livermore scientist Omar Hurricane, who led the high-foot campaign. He adds that the campaign builds on advances in laser operations, experimental platforms and diagnostics, cryogenics, target fabrication, and physics results, which were developed under the National Ignition Campaign (NIC). NIF itself grew out of decades of research at laser facilities worldwide, including those at the University of Rochester's Laboratory for Laser Energetics.

Since the summer of 2013, high-foot shots have produced record yields of fusion neutrons through a process called alpha heating—a result that is consistent with predictions made in computer simulations. In alpha heating, helium nuclei (alpha particles) generated by the fusion of deuterium and tritium (DT) atoms deposit enough energy to increase the fuel's temperature above that produced as the fuel capsule is compressed by the x-ray energy from NIF's laser light. The alpha particles further heat the fuel, increasing the rate

Path to Ignition

of fusion reactions and thereby producing additional alpha particles. This feedback process is the mechanism that is needed to achieve ignition on NIF. "We see a steadily increasing contribution to the yield coming from alpha-particle self-heating as we push the implosion a little harder with every experiment," says Hurricane.

Since September 2013, the fusion yield in high-foot experiments has systematically increased by more than a factor of 10 over previous approaches, largely because the implosion is better controlled. An experiment on September 27, 2013, resulted in about 5 quadrillion (5×10^{15}) neutrons and about 14.4 kilojoules of energy, almost 75 percent more than NIF's previous record. In addition, for the first time, the amount of energy released through fusion reactions exceeded the amount of energy deposited in the fusion fuel (11 kilojoules). The contribution from alpha heating was also substantial, exceeding any previous shot.

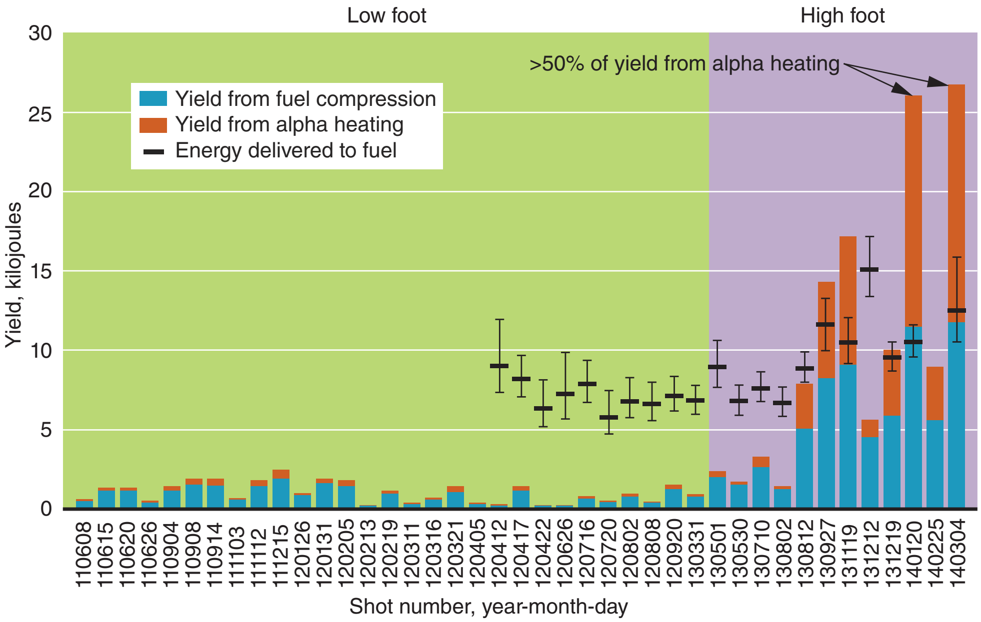
A subsequent high-foot experiment on November 19 produced an even higher neutron yield of 6.1×10^{15} for 17.3 kilojoules of energy. On January 20, 2014, an experiment delivered 9.3×10^{15} neutrons or 26 kilojoules of energy, and a March 4 experiment essentially duplicated these results, yielding 9.6×10^{15} neutrons or 27 kilojoules.

In the January 20 and March 4 shots, the fusion yield from alpha-particle self-heating was 1.25 times the yield from fuel compression, another historic accomplishment. The number of neutrons produced during each shot was just shy of 10^{16}, a target for neutron yield set by the National Nuclear Security Administration (NNSA) in 2009 as a clear demonstration of alpha-particle self-heating.

Quest for Ignition

The 192-beam NIF, the world's largest and most energetic laser, is designed to demonstrate thermonuclear burn and energy gain in a laboratory setting. NIF's primary mission is to provide experimental insight and data for NNSA's science-based Stockpile Stewardship Program. After NIF construction was completed in March 2009, researchers embarked on NIC, a three-year experimental effort to achieve ignition.

NIC experiments (and the later high-foot shots) used indirect drive, in which a fuel capsule containing DT fuel is placed inside a 1-centimeter-long gold cylinder, or hohlraum. Laser energy focused onto the interior walls of the hohlraum is converted



This graph shows the yield of fusion neutrons that result from fuel compression (blue) and alpha heating (orange) in low- and high-foot experiments at the National Ignition Facility (NIF). The shot number is the date of the experiment in year-month-day format (for example, 110608 is June 8, 2011). Two shots in 2014 achieved a performance milestone for ignition experiments when the amount of fusion energy yield from alpha heating exceeded that from fuel compression.

into x rays, which bathe the plastic shell of the capsule, ablate the shell's surface, and drive the capsule inward like a rocket blast. The implosion heats and compresses a layer of frozen DT positioned just inside the outer plastic layer, creating a hotspot within a high-pressure region about 60 micrometers in diameter, where temperatures exceed 50 million kelvins. Each fusion reaction within the hotspot produces a helium nucleus and a neutron. Measuring the number of neutrons generated is one way to characterize the extent of fusion in an experiment.

Simulations and theoretical calculations show that, under ignition conditions, a self-sustaining burn wave starts in the hotspot when the fuel capsule is at peak compression and propagates into the surrounding main fuel. Because the energy that NIF delivers does not provide a large performance margin for achieving ignition, the implosion of DT fuel must be nearly perfect in terms of compression, with implosion velocities greater than 300 kilometers per second, a uniformly spherical hotspot, and minimal mixing of the ablator shell with the core fuel. (See *S&TR*, March 2013, pp. 10–17.) The design of the laser pulse is critical to reaching these conditions. The pulse must be shaped to send a precisely timed series of shocks that propagate through the capsule ablator and overtake each other near the DT–gas interface.

Under NIC, researchers adopted a low-foot laser pulse to obtain maximum compression by keeping the capsule relatively cool until near the end of the pulse. With this pulse shape, they could meet a large fraction of the conditions required to achieve ignition in key areas independently, but not all at the same time. The highest neutron yield obtained was 7.5×10^{14}, about 10 times below both the simulated values and the regime in which alpha heating begins to dominate. Increasingly, scientists suspected that the low-foot pulse made the implosion susceptible to instabilities that grew significantly during compression and decreased neutron yield.

Improved Understanding

The high-foot campaign, along with experiments on hydrodynamic growth radiography, carbon–deuterium mix, and Viewfactor measurements, has focused on improving scientific understanding of implosion physics and validating computer simulations. The high-foot experiments are part of the Path Forward effort, sponsored by NNSA, to study how defects grow on the capsule's outside surface, penetrate the hotspot, and affect performance. Results show that with the high-foot pulse shape, the ablator is more resistant to breakup during the high-velocity implosion, and hydrodynamic instabilities are thus less likely to cause ablator material to mix with the DT fuel.

The high-foot pulse lasts 15 nanoseconds (instead of the 20 nanoseconds used in low-foot shots) and features three main shocks instead of four. It also uses a higher power initial pulse, called the "picket," and a lower peak power. Turning up the power during the picket increases the radiation drive temperature, which generates a stronger first shock in the foot, or trough period, of the pulse (hence the name high-foot pulse).

Boosting the x-ray drive early in the implosion and eliminating one of the four low-foot shocks help control ablator instability by increasing the density gradient scale length (essentially the in-flight thickness of the ablator). These changes also smooth out the ablator's roughness early on. Because the high-foot picket heats up the hohlraum more than the first low-foot shock, the overall pulse is shortened by 5 nanoseconds. With the higher heating, helium gas in the hohlraum must be increased from 0.96 to 1.6 milligrams per cubic centimeter to hold back gold ions vaporized from the inner hohlraum wall, which can interfere with the propagation of NIF's inner laser beams. The three high-foot shocks passing through the DT ice also yield simpler wave structures of transmitted shocks than the four shocks used with previous experiments.

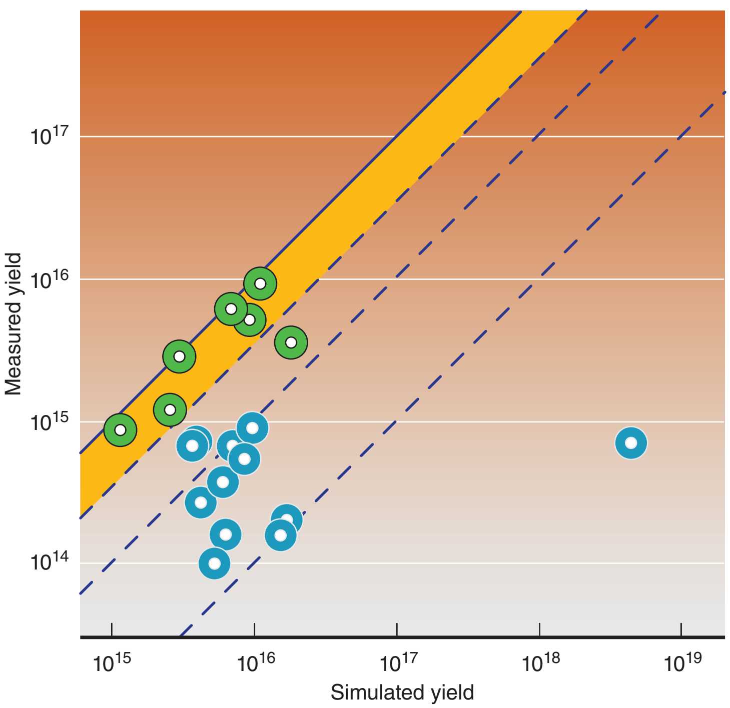
The higher adiabat (a measure of entropy) improves performance but with a trade-off: it reduces the compression of the fuel capsule. Low-foot experiments were designed to optimize compression to obtain ignition. The high-foot design is better at controlling instabilities and brings experimental performance in line with simulations. Although compression is reduced, the absolute implosion performance remains relatively high.

Sharing Ideas for Progress

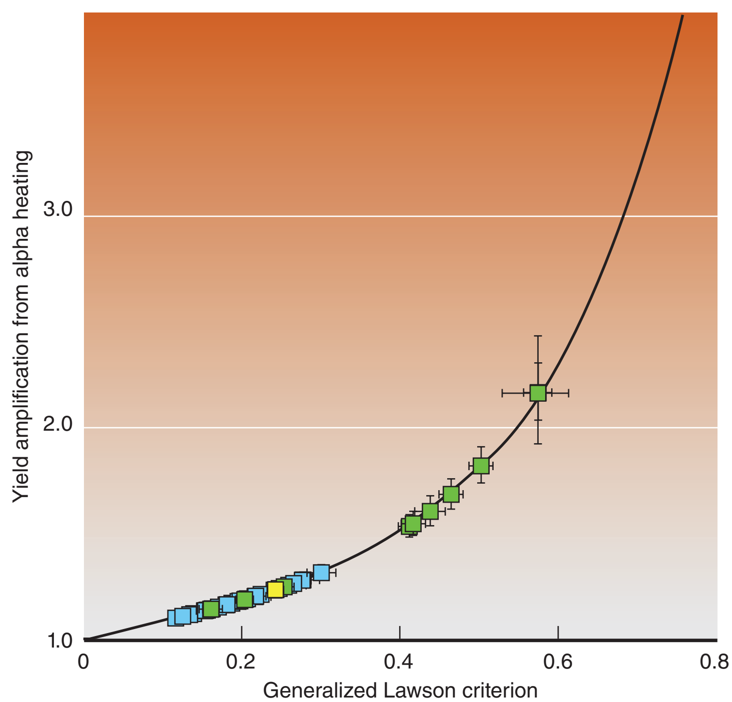
The high-foot campaign was conceived in 2012 after scientists explored possible methods to address hydrodynamic instabilities observed in low-foot experiments, including the ablator shell breakup and hotspot mix. A May 2012 workshop organized by Laboratory Director Bill Goldstein (at the time, deputy director for Science and Technology) brought together experts from throughout the world to share ideas for advancing ignition experiments and countering instabilities.

Many promising ideas resulted from the workshop. "Given time and money constraints, we wanted to test a concept that would not require a lot of research and development, such as a new ablator material, but that could make a difference in performance," says Hurricane. "We wanted to make a simple change and test it. That way, if the change didn't work, we would 'fail fast' and could move on to another idea. We chose the high foot because simulations showed that changing the pulse characteristics could pay off." He adds that the ensuing experiments "were born out of the fierce competition of ideas but then coming together as a team to move the best ideas forward."

The first high-foot experiment using frozen DT fuel, performed on May 1, 2013, yielded 7.6×10^{14} neutrons and matched the best NIC shot. The experimental results



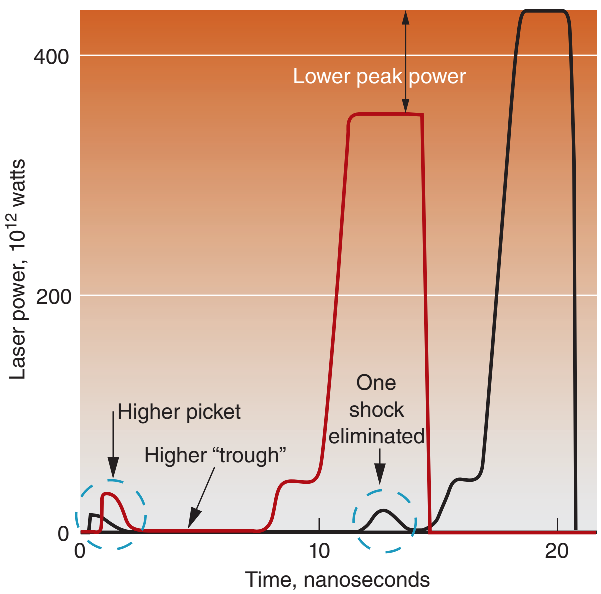
This graph compares the alpha-heating yield predicted by two-dimensional simulations (dashed lines) with yield produced in low-foot (blue circles) and high-foot (green circles) experiments on NIF. The high-foot pulse shape produces results that agree with simulations at close to 100 percent (solid blue line). Experimental data also show that yields from high-foot experiments have mostly increased with each successive shot.



A high-foot experiment conducted in March 2014 (upper right square) more than doubled the fusion yield from alpha heating compared with low-foot shots (blue squares). Green squares denote data from high-foot shots. The yellow square indicates an experiment using a high-density carbon ablator shell instead of plastic. Generalized Lawson criterion defines the conditions needed to reach ignition, which is 1.0.

also demonstrated much better consistency with simulations. A July 10 experiment using higher laser power and energy than the original May 1 shot resulted in more than 1×10^{15} neutrons. However, instead of being round, the hotspot had a toroidal shape. Tests with a longer hohlraum flattened the toroidal shape, and the yield declined.

The team returned to lower power but increased the laser energy, reasoning (correctly) that this combination would better control the hotspot shape and increase yield. On August 13, an imploded capsule released a neutron yield of nearly 2.8×10^{15} (or about 8 kilojoules of energy), almost three times NIF's previous record for neutron yield in cryogenic implosions. Shots since September 2013 have continued to produce increased neutron yields and greater contributions from alpha heating.



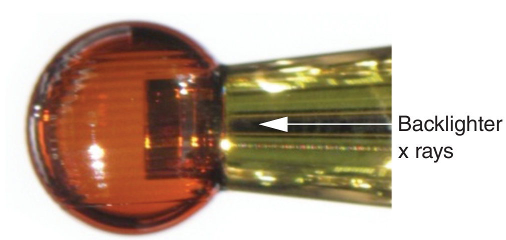
The high-foot pulse (red curve) for ignition experiments lasts 15 nanoseconds, instead of the 20 nanoseconds used in low-foot (black curve) shots. High-foot experiments also feature three main shocks instead of four, a higher-power initial pulse called a "picket," and lower peak power.

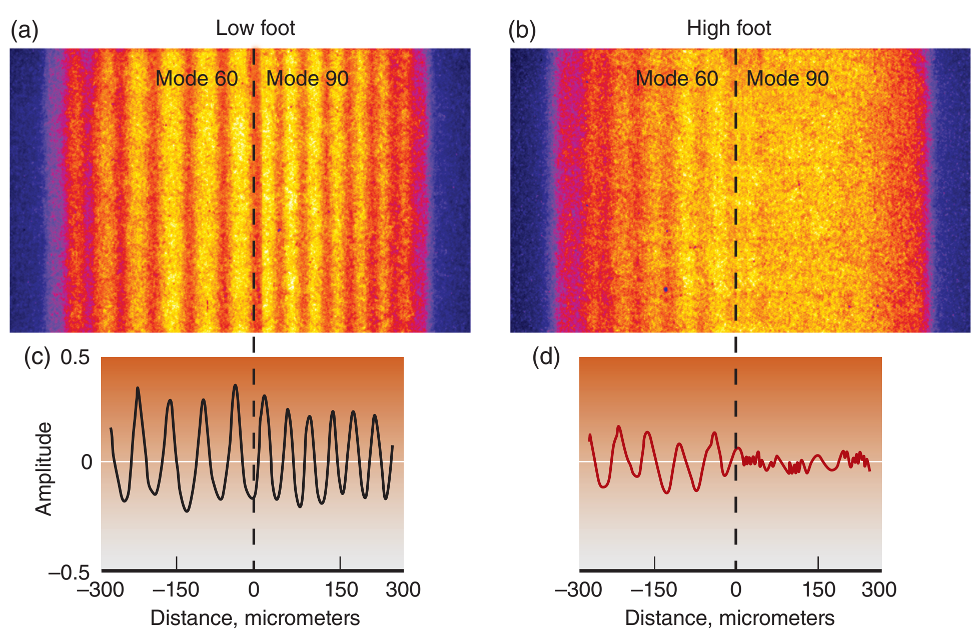
Examining Implosion Physics

The high-foot experiments are only one of several efforts to examine the physics of ignition experiments in detail. For example, although General Atomics manufactures the surface of the plastic ablator to an unprecedented degree of smoothness, it still contains microscopic bumps and dips. Once the capsule begins to implode, these tiny surface variations can cause fast-growing Rayleigh–Taylor instabilities, which can lead to the damaging mix of plastic and fuel.

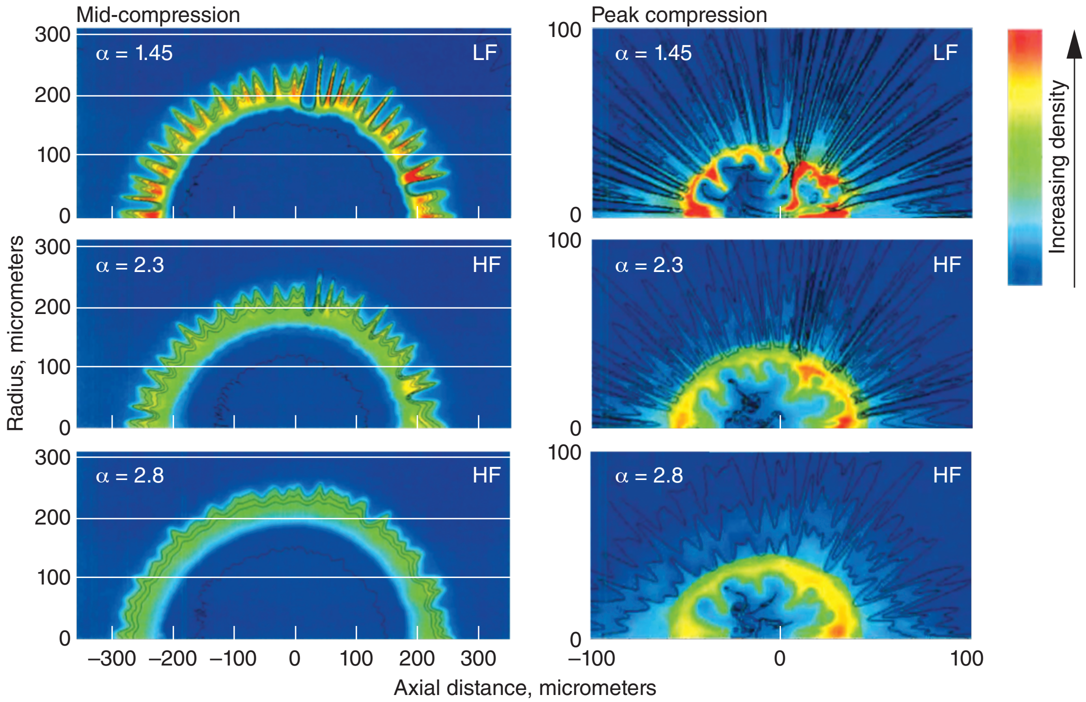
High-fidelity radiographic images of the ablation front have verified the accuracy of instability models. Hydrodynamic growth rate experiments, currently led by physicist Vladimir Smalyuk, confirmed that high-foot pulses damp down surface instabilities. For these experiments, modulations, or "ripples," of different sizes were inscribed on the ablator's surface to seed instabilities during the implosion. X rays entering the hohlraum through a gold cone in each capsule backlight the capsule. The cone works like a periscope, allowing researchers to observe the growth of perturbations as the capsule implodes.

The modulations are inscribed as perfectly as possible so they are easier





Hydrodynamic growth rate experiments measure the growth of different-size "ripples," which are inscribed on the outside surface of a plastic ablator (above) to seed instabilities during an implosion. X rays enter the hohlraum through a gold cone inserted into each capsule. The resulting radiographs track the growth of instabilities in (a) low- and (b) high-foot experiments. The ripple amplitude is more pronounced in (c) low-foot shots than in (d) high-foot shots, indicating that the high-foot pulse substantially reduces implosion instabilities.



Computer simulations show how a plastic fuel capsule filled with deuterium–tritium fuel responds to compression in low-foot (LF) and high-foot (HF) experiments. The capsule's plastic shell has been "roughened" to better illustrate the effect of instabilities. At mid-compression (left column), the LF pulse (top row) produces an adiabat (α, a measure of entropy) of 1.45, whereas the HF pulse results in adiabats of (middle row) 2.3 and (bottom row) 2.8. At peak compression (right column), the low-foot capsule suffers extensive mixing.

to model. Time-resolved radiographs taken with a framing camera through 20-micrometer-wide slits track the growth of instabilities in the ablator during both high- and low-foot experiments. The images clearly show that the high-foot pulse substantially reduces implosion instabilities. Ablator surface imperfections are one potential seed for instability. Other sources include glint from the laser beams hitting the hohlraum wall, surface imperfections in the DT ice layer, and the plastic tent holding the fuel capsule in place inside the hohlraum. Scientists suspected that features looking like rips in the fuel capsule originated in the tent, not the ablator. However, high-foot implosions showed no evidence of the tent ripping the capsule because of the improved stability from the experimental design.

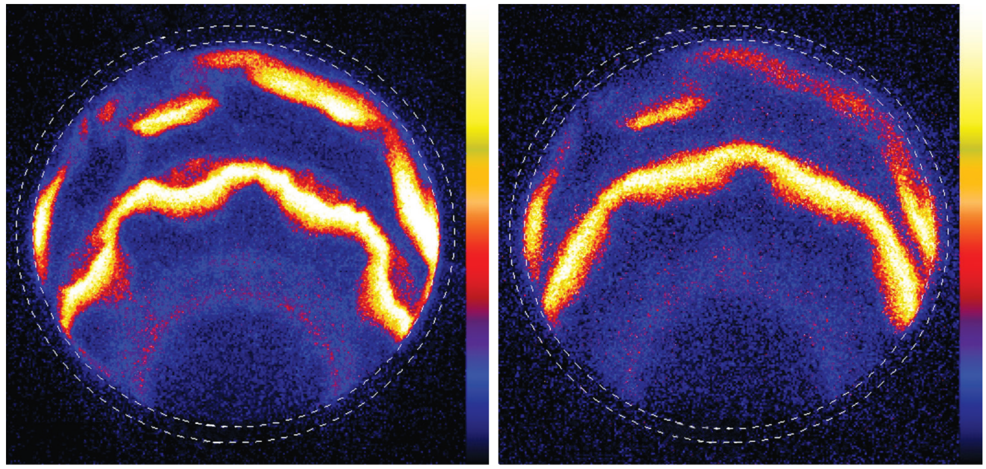
A Laboratory team led by physicist Steve MacLaren is using a Viewfactor diagnostic to measure the hohlraum x-ray drive during low- and high-foot pulses. For these experiments, one end is cut off an ignition-scale hohlraum, exposing the hohlraum interior and the far laser entrance hole to x-ray diagnostics. The traditional fuel capsule is replaced by a thin plastic shell to reproduce the plasma environment of an ignition experiment while keeping the capsule transparent for x-ray diagnostics and permitting a more complete view of the hohlraum interior than is possible with a fully enclosed hohlraum. The experiments are for the first time allowing researchers to measure x-ray emission across the entire region where the laser deposits its energy at peak power.

Viewfactor experiments demonstrated that the magnitude of x-ray drive had been overestimated by up to 20 percent. Those results explain why computational scientists had to "dial down" the simulated strength of the implosion x-ray drive for model predictions to match experimental data. The work showed that the hohlraum model, not the ablator model, was the source of the discrepancy in the slower-than-expected capsule implosion velocity. Viewfactor images revealed three-dimensional gold "bubbles" appearing in the hohlraum wall, much like a growing blister. These bubbles may absorb some of the laser light and reduce the efficiency of converting laser energy into x rays.

One possible solution is to manufacture the hohlraum from depleted uranium (DU) to improve the efficiency of the hohlraum walls. DU would also improve the symmetry of the capsule irradiation by allowing inner-cone laser beams to penetrate more deeply. High-foot shots using a DU hohlraum have attained promising results.

Other experiments have focused on measuring the mix of ablator shell fragments into the gas core, which dampens the fusion energy yield. An experimental series using carbon and deuterium identified the ablator shell regions that contribute most to hydrodynamic mix. In those shots, a noncryogenic capsule with pure tritium gas in the center was surrounded by an ablator with a 4-micrometer-thick layer of carbon–deuterium placed at a different depth in each experiment. The resulting DT yield provided a direct measure of how much the carbon–deuterium layer penetrated the pure tritium hotspot and where in the ablator the debris originated.

Results indicate that the ablator region closest to the inner-shell boundary is responsible for most of the mix. In addition, the reduced yield with pure tritium is consistent with instability growth at the outer-shell surface, underscoring the importance of ablator surface smoothness.



Results from Viewfactor experiments show the hohlraum x-ray drive occurring in the fuel capsule during (left) low- and (right) high-foot experiments. Colors indicate the intensity of soft x-ray emission, which ranges from high (white) to low (black). For these experiments, one end of the hohlraum is cut off, exposing the interior and the far laser entrance hole to x-ray diagnostics. The cutaway also permits diagnostics for the first time to measure x-ray emissions where the laser deposits its energy. The high-foot shot design produced a more uniform x-ray emission pattern.

High Foot Still Evolving

Hurricane notes that the high-foot strategy represents a wide spectrum of possible pulse shapes. "For example, we can change the degree of 'highness' to control how much we suppress instability and increase compression," he says. "We know we need to increase pressure, and we know what levers affect pressure. Our results from the high-foot campaign provide a new understanding that we can build on."

Laboratory researchers are exploring modest changes to NIF's pulse shape to increase implosion speeds and obtain greater peak pressures. In addition, they want the hotspot shape to be rounder, an effort that may involve modifying the cylindrical hohlraum into different shapes, such as one resembling a rugby ball. Scientists at Los Alamos are exploring ablators made of beryllium to determine whether this design would lead to higher pressures. A separate effort involving Lawrence Livermore and General Atomics is testing ablators composed of high-density carbon (also called diamond).

Ignition—a long-sought goal for generations of laser scientists—has proven to be fiendishly difficult to achieve. By working together, across disciplines and organizational boundaries, Laboratory researchers on the high-foot campaign and related experiments have advanced scientific understanding of indirect-drive implosion physics and taken a key step along the path to ignition.

—Arnie Heller

Key Words: alpha heating, alpha particle, carbon–deuterium mix, depleted uranium (DU), deuterium–tritium (DT) fuel, high-foot pulse shape, hohlraum, hydrodynamic growth rate, ignition, low-foot pulse shape, National Ignition Campaign (NIC), National Ignition Facility (NIF), pure tritium gas, Viewfactor experiment.

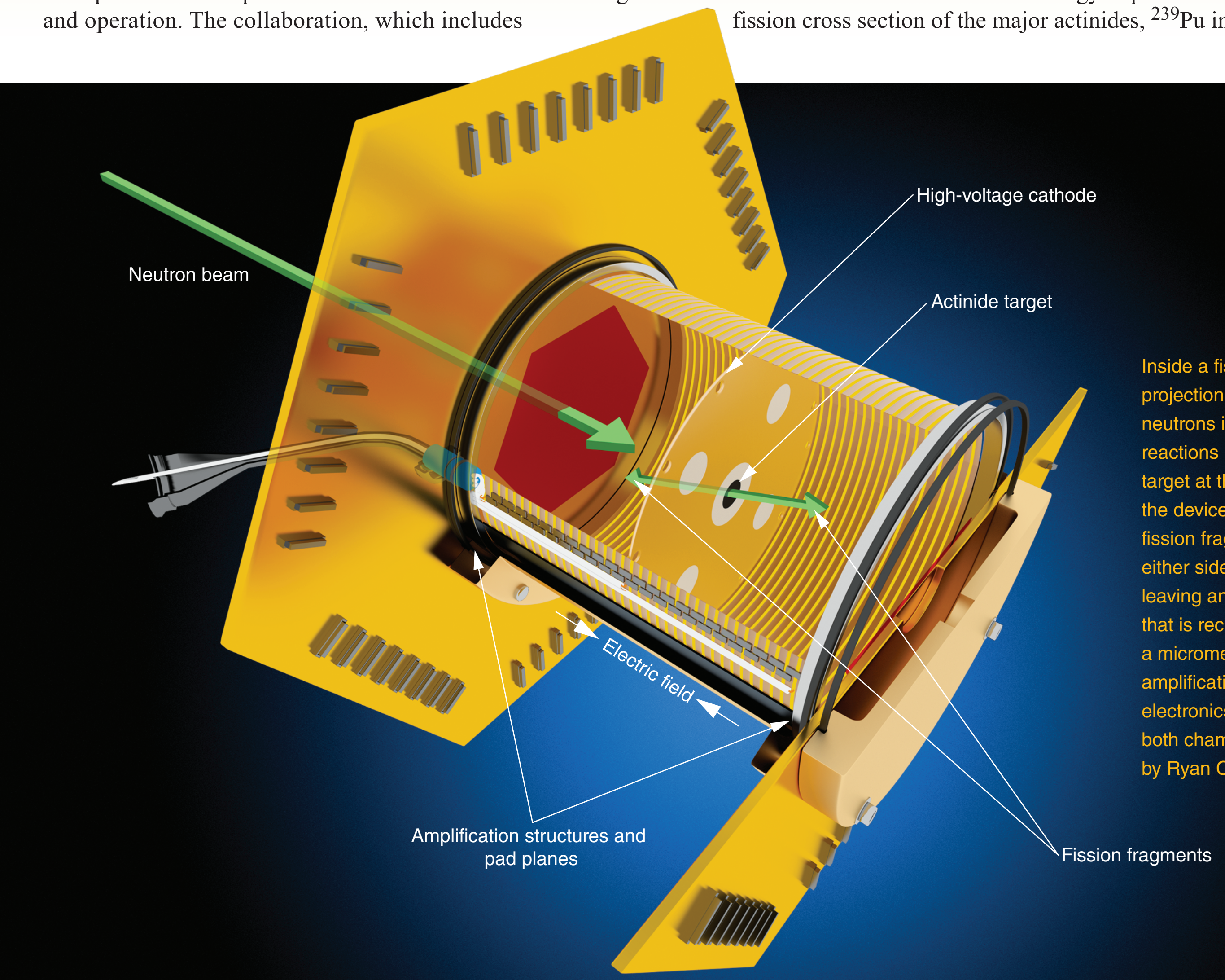
For further information contact Omar Hurricane (925) 424-2701 (hurricane1@llnl.gov).

Particle Detection Technology with a New National Security Mission

SINCE the 1970s, time projection chambers (TPCs) have been valuable tools for high-energy physics research, especially for tracking and identifying particles produced in accelerator experiments. TPCs are gas-filled devices that measure the trajectory and energy of charged particles in motion. This established technology is being further advanced to resolve a significant challenge in nuclear physics.

Lawrence Livermore scientists are leading a collaboration, called the Neutron Induced Fission Fragment Tracking Experiment, to develop a TPC for improving the accuracy of nuclear cross-section measurements—essential data for stockpile stewardship and commercial nuclear reactor design and operation. The collaboration, which includes several national laboratories and universities, is funded by the National Nuclear Security Administration through Livermore's Campaign-1 Science Program in the Weapons and Complex Integration Principal Directorate and previously by the Department of Energy's Office of Nuclear Energy.

Nuclear cross sections are a measure of the probability that two particles will react. Precise measurements are notoriously difficult to obtain for neutron reactions on actinides, specifically plutonium-239 (^{239}Pu). Fission chambers, the traditional technology for this application, have achieved accuracies within 2 to 3 percent for neutron energies below 14 megaelectronvolts. "The fission TPC measures the energy-dependent neutron-induced fission cross section of the major actinides, ^{239}Pu in particular, to

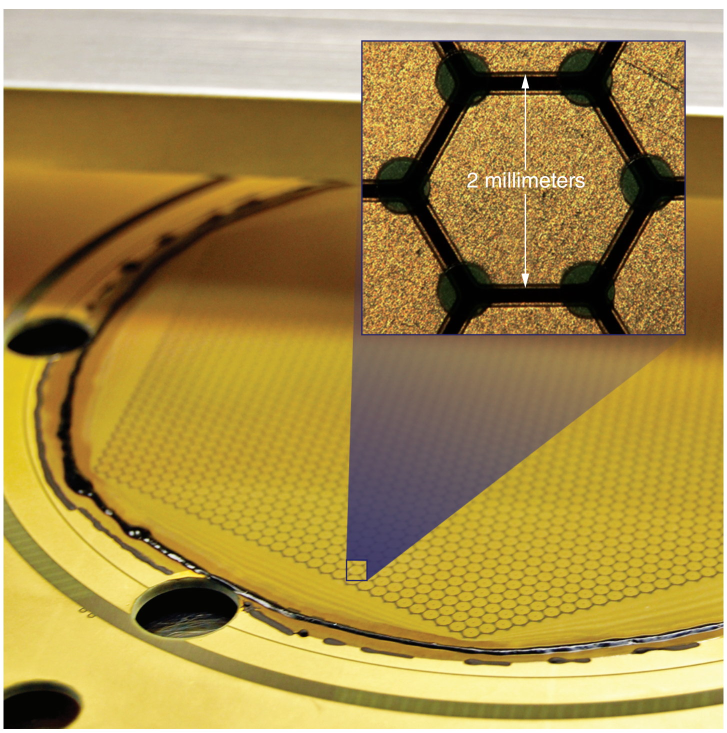


Inside a fission time projection chamber (TPC), neutrons induce fission reactions in a thin actinide target at the center of the device. The resulting fission fragments exit either side of the target, leaving an ionization track that is recorded using a micromesh gaseous amplification structure and electronics at the ends of both chambers. (Rendering by Ryan Chen.)

an uncertainty of less than 1 percent," says Livermore physicist Mike Heffner, who leads the collaborative effort.

The significant improvement stems from a TPC's inherent ability to record the ionization track of a charged particle in three dimensions. (See *S&TR*, April/May 2009, pp. 26–27.) As a result, scientists can substantially reduce systematic errors and more accurately identify particle type. They can also measure target and beam nonuniformities and quantify neutron flux rates, all of which help improve data fidelity.

Standard TPCs were designed to measure particle energies exceeding many gigaelectronvolts. At these high energies, only a portion of the ionization track can be recorded because the particle exits the chamber before it comes to a stop, thus leaving a low density of ionization in the chamber. The fission TPC is designed for the opposite extreme—examining highly ionizing particles that result from fission reactions. The inaugural demonstration of these capabilities is being conducted at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory in experiments with ^{239}Pu. The fission TPC will reduce measurement uncertainty in ^{239}Pu cross sections by at least a factor of 3. It also has the potential to record other neutron-induced charged-particle reactions with high precision.



Each of the two amplification structures contains about 3,000 millimeter-sized hexagonal pads (inset) that collect electrons and record their charge.

Taking a Fission Photo

During a fission reaction, an incoming neutron excites a nucleus that splits into smaller, lighter nuclei, called fission fragments, which can be measured by gas ionization detectors such as fission chambers and TPCs. Fission chambers measure only the total energy deposited in the gas. TPCs, on the other hand, record the charged particle trajectories in the active gas volume in three dimensions (3D). "In simple terms," says Heffner, "a TPC is like a digital camera that takes a 3D 'picture' of an ionization event."

The fission TPC is a compact (15-centimeter-diameter), two-chamber device with an actinide target in its center. A neutron beam aimed orthogonally at the target induces fission in the target material. Fission fragments exit either side of the target and ionize the gas, separating atoms from their electrons along the path of the fragment. An electric field prevents the ions and the electrons from recombining. Instead, it forces the electrons toward sophisticated gaseous electron multipliers and electronics at the ends of both chambers. The amplification structures contain about 6,000 hexagonal pads that collect the electrons and measure their combined charge.

Amplifier and data-acquisition systems connected to the pads acquire a two-dimensional set of coordinates for each cluster of amplified electrons. "The drift speed of the electrons is approximately 5 centimeters per microsecond," says Heffner, "and the fission TPC records the time that ionization occurs. With that information, we can project back in time to get the spatial (third) dimension, hence the name time projection chamber." The 3D image of the ionization track provides the particle's trajectory and ionization energy loss, which are used to identify the particle type and the position of the nuclear interaction. With this more complete information, researchers can assess systematic errors with better accuracy. Using one device to acquire all of this information greatly improves measurement precision, reducing uncertainty to less than 1 percent.

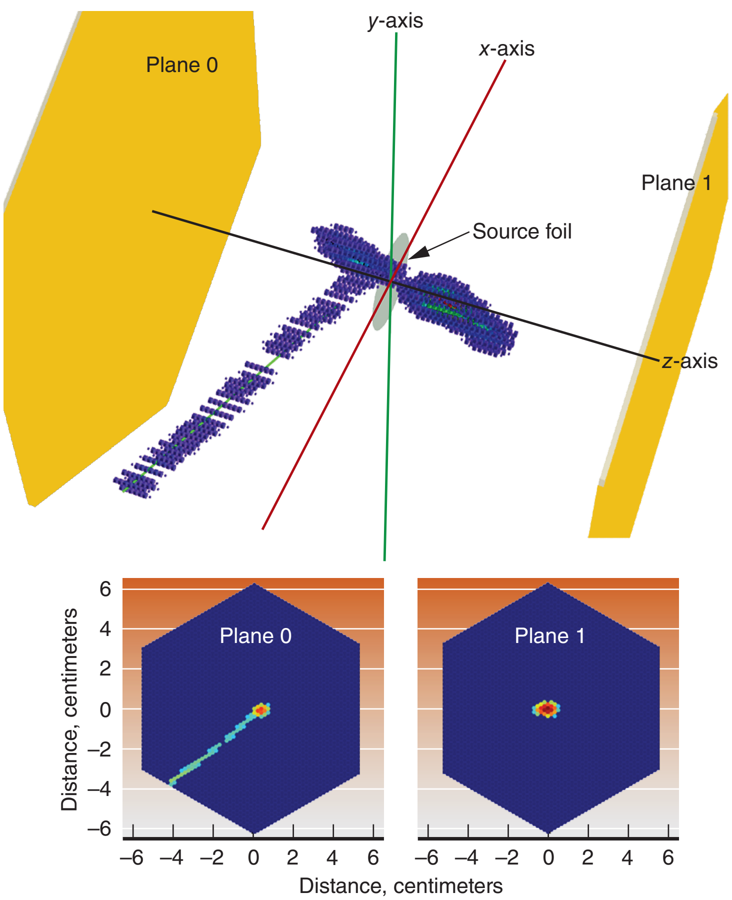
Quantifying Errors to Reduce Uncertainties

Resolving data uncertainties will improve the design and operation of nuclear reactors and help maintain the nation's nuclear weapons stockpile. "The greatest sources of error are particle species differentiation, target and beam nonuniformity, and the cross-section uncertainty of the reference material," says Heffner. The fission TPC dramatically reduces these uncertainties by quantifying the known and suspected systematic errors in fission chamber measurements.

Fission chambers record only the total amount of energy that a fission event deposits in the chamber. Unfortunately, different types of particles—fission fragments, alpha particles, and neutrons scattering off the target chamber—can produce events with similar energies, skewing the data. The fission TPC records both the deposited energy and the length of the ionization track, which depends on each particle's mass and charge. Heavy fission fragments lose energy quickly and thus leave short ionization tracks, while alpha particles have longer trajectories. When track ionization is plotted as a function of distance, those for alpha particles have a pronounced spike, or Bragg peak, which indicates an increase in energy loss. The ionization information for each particle, including Bragg peak data, enables the fission TPC to distinguish particle type.

Target and beam nonuniformities also affect measurement uncertainty. Target mass is typically recorded by alpha counters outside the diagnostic instrument. Once a target is placed inside a fission chamber, nonuniformities cannot be corrected with precision. The fission TPC measures where each alpha particle is emitted from the target, providing a map of the target's thickness. With this method, the target can be characterized to within a few hundred micrometers because the ionization tracks point back to precise locations on its surface.

The fission TPC also measures neutron beam profiles by tracking another kind of interaction—ions recoiling from the neutrons that scatter on the drift gas. In this reaction, a neutron collides with a hydrogen atom in the gas, causing a proton to recoil at an angle as it is knocked away from its electron. The proton continues to ionize the gas, leaving its own ionization track. "The fission TPC allows us to use one device to measure the uniformity of the target and beam at the same time and as a function of neutron energy," says Heffner. With the target thickness map and the beam profile, researchers can directly compute the cross section, reducing the effect of systematic errors in fission chamber measurements.



Data from a TPC test show measurements for a single fission event. The top diagram illustrates the fission event and the resulting ionization tracks. The bottom plots are a projection of the same event as recorded on each amplification pad plane. Colors indicate the amount of charge, where blue is sparse and red is dense.

Up to New Tricks

Data collected from the LANSCE experiments will demonstrate the ability of the fission TPC design to measure nuclear cross sections and its efficacy as a replacement for fission chambers. Acquiring more precise and accurate cross-section data is key to the Laboratory's missions and improving nuclear security both in the U.S. and abroad.

The collaboration's work also serves as a model for reengineering established technologies to address other challenges. For more than four decades, TPCs have been an effective particle detection device for basic scientific research. Now, they are being applied to other issues of global importance.

—Caryn Meissner

Key Words: actinide, alpha particle, high-energy physics, fission time projection chamber (TPC), ionization track, Los Alamos Neutron Science Center (LANSCE), nuclear cross section, Neutron Induced Fission Fragment Tracking Experiment, plutonium.

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Livermore engineer Tiziana Bond holds a surface-enhanced Raman spectroscopy (SERS) detector that uses arrays of carbon nanotubes double-coated with hafnium dioxide and gold. (Photograph by George A. Kitrinos.)

Tangled Nanotubes Ease Identification of Trace Chemicals

WHEN identifying trace amounts of biological and chemical toxins in the environment—whether for homeland security, forensics, or medical applications—the smaller the amount that can be detected the better. A sensitive and reliable ideal detector would also be cost-effective and portable. A Lawrence Livermore team led by Tiziana Bond of the Engineering Directorate has been exploring various solutions to this challenge. In collaboration with Ali Altun, Hyung Gyu Park, and others from the Swiss Federal Institute of Technology (ETH) in Zurich, the Livermore team has developed an innovative method to create tangled forests of double-coated carbon nanotubes that improve the sensing capability of existing devices, making it possible for researchers to detect a single molecule.

Looking for an Elusive Signal

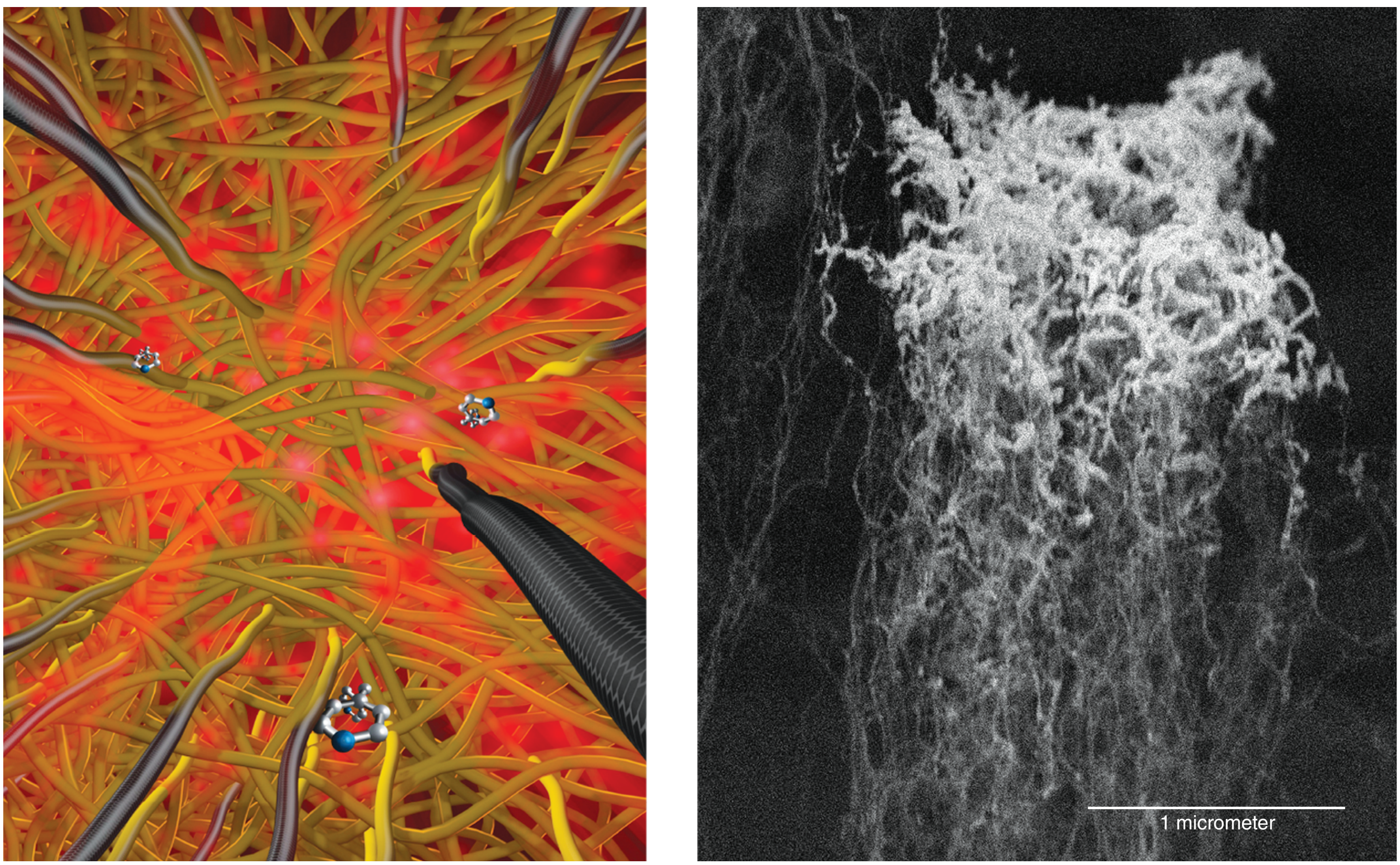
These easily reproducible nanotube structures are a result of research conducted by Bond and others directed at raising the sensitivity of surface-enhanced Raman spectroscopy (SERS) techniques used for nondestructively identifying trace substances. Early research efforts began with funding from Livermore's Laboratory Directed Research and Development Program. (See

S&TR, July/August 2011, pp. 20–23.) With Raman spectroscopy, molecules of a material are first illuminated by fixed-frequency light (visible light limited to a single frequency). In response, these molecules exhibit inelastic scattering closely related to their vibrational and rotational modes, emitting light in the process. The emitted light includes frequencies that differ from the fixed frequency of the irradiating light, producing a frequency pattern, or fingerprint, unique to the material. Such fingerprints help detect and identify substances such as biological and chemical toxins that could be used in a terrorist attack. The smaller the amount of a substance, the weaker its signal. However, some toxic materials can be deadly even in minuscule amounts, so detecting their weak signals is especially important.

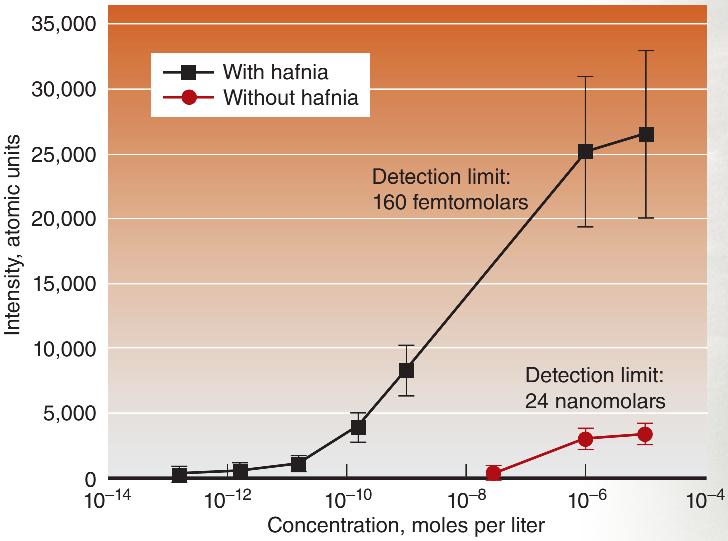
With SERS, a metallic surface is used to amplify the signal, which is then recorded by a spectrograph. Many researchers, including Bond and her colleagues, have been searching for ways to improve the ability of the SERS technique to amplify weak signals in detector systems. A class of SERS-based detectors use substrates of vertically oriented, carbon nanotube “trees” coated with metal and assembled into densely packed miniature “forests.” However, in this configuration, the strength of the signal emitted by the surface is weakened when charges are quenched at the interface of the nanotubes and the metal. As a result, the signals are strong enough for detection only when a significant quantity of the material is present.

Breakthrough to a Stronger Signal

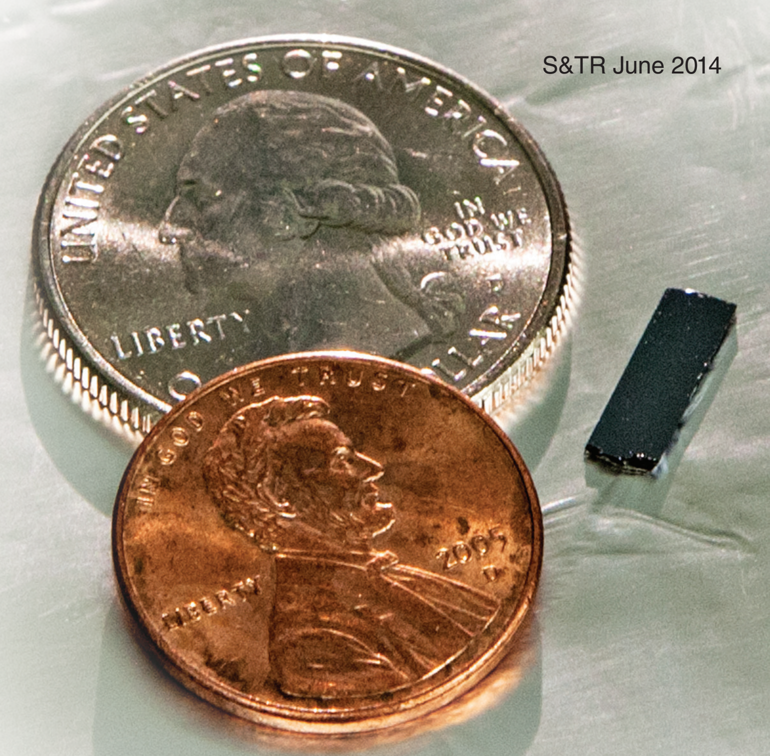
Bond and her colleagues solved this conundrum by depositing a layer of hafnium dioxide (hafnia) near the active surface of the carbon nanotubes and then a layer of gold. The hafnia



(left) A simulation and (right) a scanning electron micrograph show how the tips of the carbon nanotubes bend, touch, and tangle, forming gaps in their configuration. These gaps, or “hotspots,” allow Raman-scattered light to pass through for detection. Hafnium dioxide (hafnia) forms a dielectric layer that prevents coupling between the electron energy levels of the gold outer layer and the carbon atoms in the nanotubes. (Micrograph courtesy of the Swiss Federal Institute of Technology Zurich.)



A 2.5-nanometer-thick layer of hafnia inserted between a carbon nanotube and a 21-nanometer-thick gold outer coating increases the detection capabilities of SERS. The spectra show results for a femtomolar sample of 1,2-bis(4-pyridyl)ethylene in methanol with and without the hafnium layer.



The tiny SERS sensor has many potential uses, including portable detectors for military and law-enforcement applications. (Photograph by George A. Kitrinos)

creates a dielectric barrier between the gold outer layer and the carbon nanotube, reducing the loss of photons down the shaft of nanotubes. “The hafnia layer also encourages the nanotubes to bunch up, similar to a tangled forest canopy,” says Bond. This bunching generates a high density of deep holes or open spaces beneath the tips of the nanotubes. The randomly arranged, nanometer-sized holes, or “hotspots,” allow scattered light to pass through. Having multiple metallic nanocrevices leads to the extreme amplification of very weak signals.

The team arrived at this configuration after first experimenting with various substrates, coatings, and processing methods. The researchers eventually developed a technique to grow the dense, tangled forests of micrometer-long carbon nanotubes in a uniform and controlled manner. “One of our goals is reproducibility,” says Bond. “We now have a process that reliably creates a wide distribution of metallic nanocrevices, resulting in the intense and reproducible signal enhancements that this method requires for many applications.” In laboratory tests conducted with the Livermore–ETH sensors, the team detected the organic species 1,2-bis(4-pyridyl)ethylene in a concentration of a few hundred femtomoles (10^{-15} moles) per liter.

Applications Beckon from Forensics to Medicine

Bond notes that many applications are possible for a highly sensitive, reliable, and cost-effective device that can detect and identify molecules in the tiniest of concentrations. “Eventually, sensors based on this technique could be used in portable devices to analyze pollutants or pharmaceutical residues in the environment,” she says. “They could also be used by the biomedical industry for real-time point-of-care monitoring of physiological levels, such as searching in nanogram-per-liter levels for THC [tetrahydrocannabinol] or aflatoxin, which is vectored by spores that thrive in nuts, seeds, and legumes. In other applications, the sensors could offer a rapid drug-screening process for law-enforcement agencies or provide the military with early detection of chemical or biological weapons.” Bond also believes the production process itself could be used to create ultracapacitors and batteries of the future. “The resulting structures are thin and lightweight, and they contain a large surface area in a small space,” she adds.

Meanwhile, the team continues to improve the technique. The next step is to enhance the sensitivity of the sensors even further and create a portable system for field deployment. “It is a very simple system at heart,” says Bond. “I can envision a system with a sensor, a small laser to provide the fixed-frequency light, and perhaps a smart phone with a camera integrated with a portable spectrometer to capture the resulting spectrum.” That vision could become reality in the not-too-distant future. The team’s sensitive detector may be small in size, but it is large in possibilities.

—Ann Parker

Key Words: carbon nanotube, detector, homeland security, nanoarray, nanotechnology, sensor, surface-enhanced Raman spectroscopy (SERS), toxin.

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Photograph by George A. Kitrinos

Discerning Humanity's Imprint on Rainfall Patterns

IT'S the perfect storm. At a time when global demand for water is rising rapidly due to population growth, urbanization, industrial activities, and expanded use of crop irrigation systems, climate change may be altering the timing, location, and amount of rain and snow that fall on large swaths of the planet. Computational models indicate that increases in global surface temperatures will redistribute rainfall in two ways. First, warmer air, which holds more water vapor, will intensify existing precipitation and drought conditions. That is, more rain will fall in wet areas, and evaporation will increase in drier areas. Second, shifts in atmospheric circulation patterns will push storm paths and subtropical dry zones toward the poles.

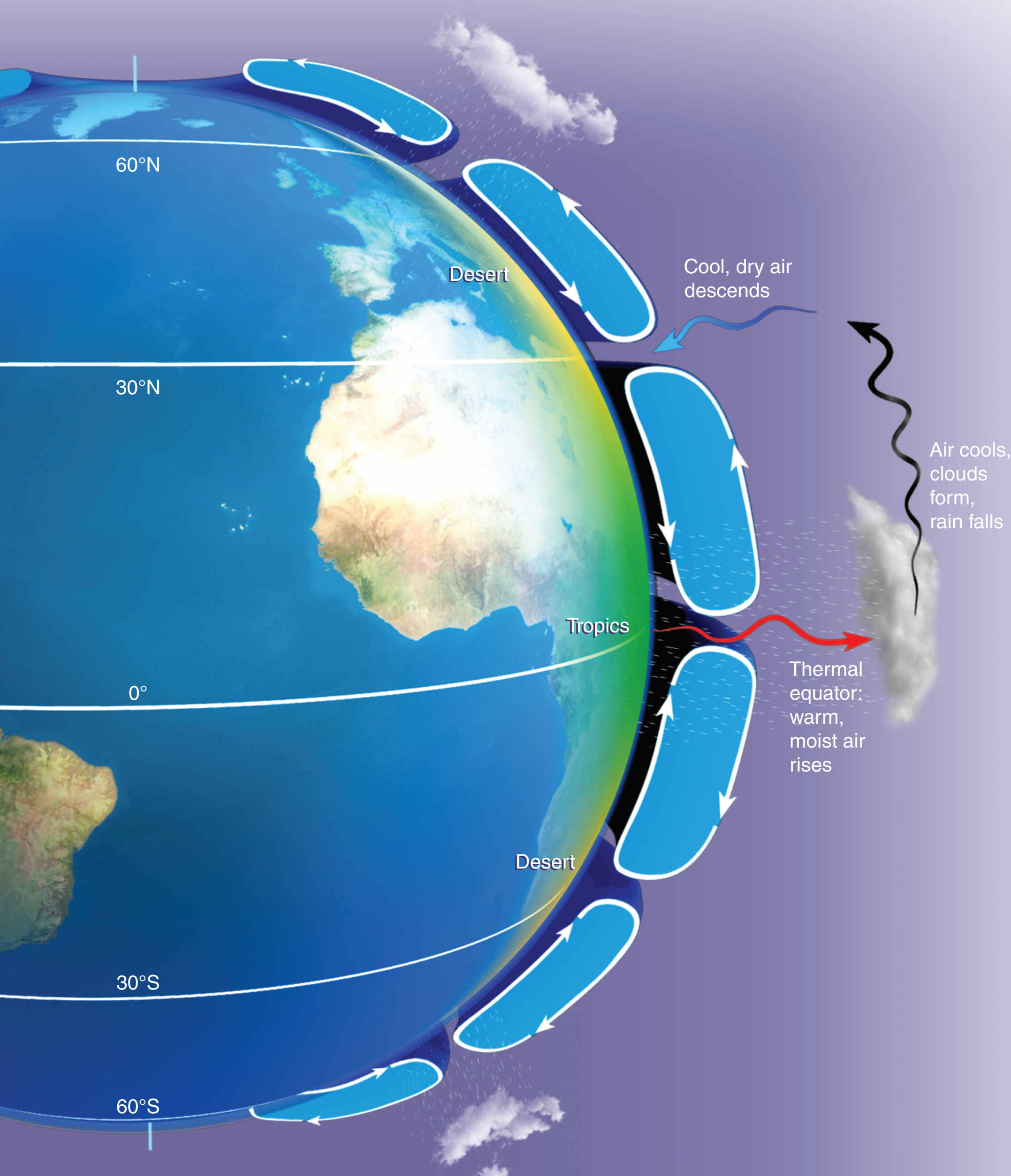
Satellite records for the past few decades show that rainfall patterns worldwide are changing. If the observed trends continue, they could magnify existing problems with water scarcity, food shortage, and possibly even political instabilities, thereby transforming an environmental concern into a global security issue. Are these changes indicative of global warming, as predicted by models? Are the pattern shifts caused by naturally occurring fluctuations or human-induced (anthropogenic) forces, such as greenhouse-gas emissions and ozone depletion? Determining the answers to these questions may help policy makers develop strategies for mitigating or adapting to the changes. However, extracting this information from global precipitation data can be challenging.

The models that scientists use for climate predictions are generally poor at simulating the exact location and magnitude of Earth's major precipitation features. Because of these inaccuracies, the changes that individual models project in rainfall intensity and atmospheric patterns may be canceled out when results from several models are averaged together. In addition, "noise" from short-term climate fluctuations can drown out potential evidence of more permanent changes.

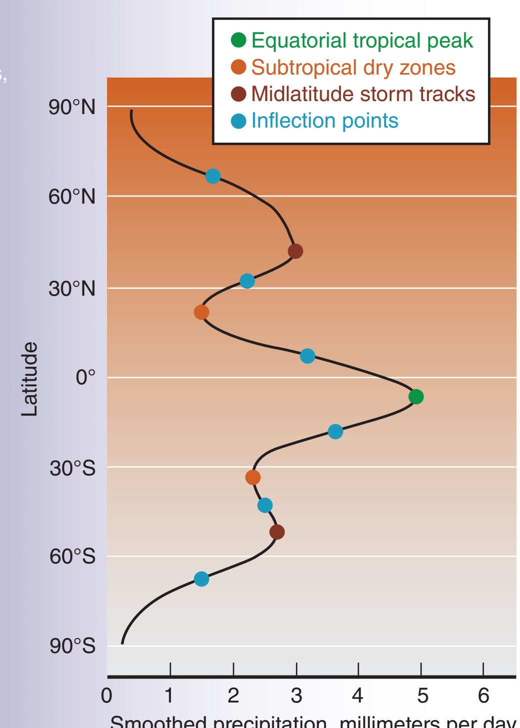
Livermore physicist Kate Marvel and climate scientist Céline Bonfils have developed a straightforward method for detecting trends in both the location and intensity of global precipitation and ascribing causes to these trends. Their study was funded by Livermore's Laboratory Directed Research and Development Program and an Early Career Research Grant awarded to Bonfils by the Department of Energy. Results from their research show for the first time that certain changes displayed in the observational record of global precipitation patterns most likely result from human activities rather than from natural climate variability.

A Global Focus

Marvel and Bonfils, who work in Livermore's Program for Climate Model Diagnosis and Intercomparison, began by examining monthly rainfall data compiled from rain gauges and satellite observations as part of the Global Precipitation Climatology Project (GPCP). Because Earth's major circulation patterns undergo a seasonal north–south migration, the researchers focused on a single season—winter in the northern hemisphere—to prevent the cyclical behavior from muddying evidence of longer term trends.



(left) Wind circulation patterns in each hemisphere help transport moist equatorial air toward the poles. These loops are driven by such properties as Earth's size, rotation rate, atmospheric depth, and heating. (below) A smoothed map of satellite data reveals distinct zones of wet and dry land produced by the circulation patterns. Livermore researchers used this information to detect changes in the location and intensity of global precipitation over the past three decades. (Rendering by Kwei-Yu Chu.)



They compiled rainfall data for the winters of 1979 through 2012 and applied a smoothing technique to filter out the noise from small-scale precipitation patterns. They then averaged precipitation results at a given latitude over all longitudes and identified the wettest and driest regions.

Data from each winter displayed three peaks and two troughs in precipitation. The peaks represent the rainfall in the equatorial tropics and a band of storms at the midlatitudes in both hemispheres. The troughs correspond to subtropical latitudes where many of the world's deserts are located. Bonfils and Marvel used the inflection points for these five features to gauge the approximate width of the rainy and dry zones. In reducing 32 winters of rainfall data to 32 sets of peaks, troughs, and inflection points, they defined two indicators: a dynamic indicator measuring changes in the location of wet and dry regions, and a thermodynamic indicator measuring the amount of precipitation in those regions.

Climate Detectives

Spotting location and intensity trends in the satellite data was merely the first step. "Climate science is somewhat like detective work," says Bonfils. "It's not enough just to find the crime—we also want to identify the culprit. We want to know what is causing the observed changes." Establishing a unique response pattern, or fingerprint, for precipitation changes would help researchers compare model results with GPCP data and determine causes for the observed trends. (See *S&TR*, June 2012, pp. 4–12.)

To formulate a climate change fingerprint, Marvel and Bonfils worked with results from 26 computational models run by climate research groups worldwide for the World Climate Research Programme's Coupled Model Intercomparison Project Phase 5 (CMIP5). (See *S&TR*, January/February 2013, pp. 4–11.) The 26 models examined the same scenario, one that accounted for human influence as well as naturally occurring internal and external factors.

While performing the smoothing and peak detection procedure on the data sets, the researchers noted significant differences in where individual models located precipitation extremes. Bonfils says, "We decided to focus on the patterns—peaks, troughs, and inflection points—and the relative changes to those patterns, rather than on the exact latitude of the events." Tracking location shifts in these features rather than the latitude identified in the satellite observations allowed the researchers to bypass model location inaccuracies. Then they used a statistical technique called principal component analysis to examine correlations between the different data sets and formulate a characteristic spatial pattern that explained most of the similarities. This pattern served as the precipitation fingerprint for climate change.

To contrast the fingerprint of anthropogenic climate change with natural climate fluctuations, Marvel and Bonfils examined CMIP5 preindustrial control simulations. Control simulations are run without external influences from human activities (greenhouse gas emissions, for example) and naturally occurring events such as large volcanic eruptions and solar radiation fluctuations. (See *S&TR*, July/August 2002, pp. 4–12.). The control simulations represent scientists' best understanding of how internal mechanisms affect climate patterns.

Of primary interest was the simulated behavior of the El Niño Southern Oscillation (ENSO). One of the largest natural contributors to climate variability, ENSO is characterized by sporadic and prolonged alterations in surface temperatures in the tropical Pacific Ocean—fluctuations that can affect atmospheric circulation and rainfall patterns over much of the globe.

The team's modeling results indicate that during El Niño events, the wet tropical region becomes wetter, and atmospheric features shift toward the equator. El Niño's counterpart, La Niña, pushes circulation patterns toward the poles but does not intensify existing rainfall patterns. These findings verified the utility of the precipitation fingerprint. Individually, rainfall intensification and poleward circulation movement are consistent with natural variability. Taken together, those trends allowed the researchers to distinguish human-induced global warming from natural climate behavior.

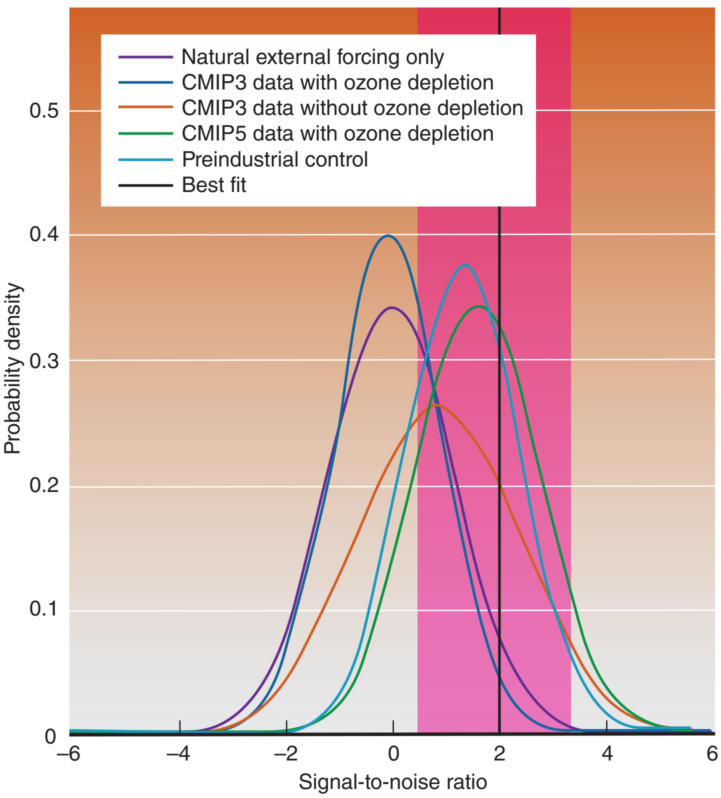
Matching Fingerprints

Next, the researchers established that, per the observational data, the wettest latitudes were becoming wetter and the driest latitudes drier, while the storm tracks and subtropical dry zones had shifted toward the polar regions—findings that were consistent with theoretical and model predictions. The fingerprint is present in the observational data, and the two are increasingly correlated over time. As anticipated, ENSO patterns did not match the fingerprint. These results indicate that the changes in the GPCP data for precipitation intensity and location were likely caused by external factors rather than internal climate variability.

Further confirmation was needed to ensure that the upward trend was not a coincidence and that GPCP data patterns were not simply a product of natural variability. Using more than 25,000 years of data from the preindustrial control simulations, Marvel and Bonfils established that the observed trend was very unlikely to result from internal climate variability alone.

Although they had eliminated a potential explanation for the observed trends, other possibilities remained. Human activities, natural events, or a mix of natural and human factors could be responsible for the precipitation changes. Results from a CMIP5 model incorporating only natural external influences did not match the fingerprint nearly as well as results from models with human influence included, suggesting that the observed trends result from human activities.

"This finding makes sense, based on our understanding of physics and atmospheric science," says Marvel. "Volcanic eruptions and solar fluctuations certainly affect precipitation patterns, but only anthropogenic factors are likely to result in a pattern that matches the fingerprint." She notes that the natural external influence scenario simulated only 26 years of climate behavior, a briefer span than other scenarios considered. "With the shorter period, we can't entirely rule out natural effects," she says, "but the evidence is strong that the pattern change is due to human activities."



This graph shows the probability distributions of signals (that is, the similarity to the fingerprint) arising from various sets of climate simulations. The preindustrial control and natural forcing distributions are centered around zero because climate noise (from internal and natural variability) is not expected to resemble the human fingerprint, except by chance. The observed signal (black line) is outside and incompatible with those distributions at the 95-percent confidence level. The observed signal is, however, located near the mean (pink bar) of the forced distributions that include both natural and human-caused external influences, indicating that human activities are likely contributing to the two effects incorporated into the Livermore-defined fingerprint. CMIP3 and CMIP5 refer to the third and fifth phase of the Climate Model Intercomparison Project.

As a final step, the researchers used the fingerprint to investigate the roles of specific human activities in precipitation changes. They found that the release of chlorofluorocarbons and other gases that deplete the ozone layer helps explain some of the observed poleward shift in atmospheric circulation features. However, greenhouse gases are likely the largest contributor to recent precipitation trends.

From Rainfall to Clouds

By narrowing their study to two climate mechanisms for precipitation changes and widening their outlook to the global scale—where confidence in model accuracy is higher than it is at the local level—Marvel and Bonfils showed that the changes observed over the past few decades of satellite data are external in origin and most likely a result of human influences. Their study builds on the work of Livermore scientists Benjamin Santer and Karl Taylor, who pioneered techniques for studying and comparing climate models and using fingerprints to evaluate the relative importance of various climate change drivers. The CMIP5 archive has served as an important resource for this project and others. In fact, the CMIP5 results used by Marvel and Bonfils formed the scientific backbone for the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, which planners and policy makers will use to help prepare for and respond to climate change.

Marvel is now applying the same methods to study cloud patterns, the leading source of model uncertainty. Clouds are a vital part of the climate change equation because they can either mitigate or accelerate warming, depending on their height. Bonfils is incorporating findings from the precipitation project into her broader effort to understand the precursors to drought. "The precipitation study has helped me develop a more complete picture of what will happen in the future," says Bonfils. "I find that being able to highlight simple patterns in a complex ensemble, as we did here, is the most interesting part of a project."

—Rose Hansen

Key Words: atmospheric circulation, climate change, Coupled Model Intercomparison Project Phase 5 (CMIP5), drought, El Niño Southern Oscillation (ENSO), Global Precipitation Climatology Project (GPCP), La Niña, Program for Climate Model Diagnosis and Intercomparison, World Climate Research Programme.

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Patents and Awards

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

Methods and Systems for Synthesis of a D-Aminoluciferin Precursor and Related Compounds
Amy L. Gryshuk, Julie Perkins, John V. LaTour
U.S. Patent 8,586,759 B2
November 19, 2013
These methods are used to generate 6-amino-6-deoxy-D-luciferin precursor, 2-cyano-6-aminobenzothiazole, and related compounds and derivatives.

Enhancement of the Visibility of Objects Located below the Surface of a Scattering Medium
Stavros Demos
U.S. Patent 8,586,924 B2
November 19, 2013
Techniques are provided for enhancing the visibility of objects located below the surface of a scattering medium such as tissue, water, and smoke. Example objects include a vein beneath the skin, a mine below sea surface, and a human in a location covered by smoke. The image contrast of a subsurface structure is enhanced using structured illumination. For specific applications, such as imaging the veins in an arm or another part of a body, the issue of controlling the intensity when imaging a metal object (such as a needle) inserted into the vein is also addressed.

Full-Wave Receiver Architecture for the Homodyne Motion Sensor
Peter C. Haugen, Gregory E. Dallum, Patrick A. Welsh, Carlos E. Romero
U.S. Patent 8,587,472 B2
November 19, 2013
A homodyne motion sensor or detector based on ultrawideband radar uses the entire received waveform by implementing a voltage boosting receiver. The device includes a receiver input and output, with a first diode connected to the receiver output. A first charge storage capacitor placed between the first diode and the receiver output is connected to ground. A second charge storage capacitor is connected between the receiver input and the first diode. A second diode between the second charge storage capacitor and the first diode is also connected to ground. The dual diodes boost the voltage of a radio-frequency signal received at the input, thereby enhancing receiver sensitivity.

Radial Reflection Diffraction Tomography
Sean K. Lehman
U.S. Patent 8,588,891 B2
November 19, 2013
A wave-based tomographic imaging method and apparatus developed for nondestructive evaluation are based on one or more outward-oriented transmitting and receiving elements that rotate radially. At successive angular locations at a fixed radius, a predetermined transmitting element can launch a primary field, and one or more predetermined receiving elements collect the backscattered field in a pitch-and-catch operation. A Hilbert space inverse-wave algorithm constructs images of the received scattered energy waves using operating modes chosen for a particular application, which include improved intravascular imaging, borehole tomography, and nondestructive evaluation of parts with existing access holes.

Apparatus and Method for Deterministic Control of Surface Figure during Full Aperture Polishing
Tayyab Ishaq Suratwala, Michael Dennis Feit, William Augustus Steele
U.S. Patent 8,588,956 B2
November 19, 2013
This system for polishing a workpiece includes a lap that contacts the workpiece and a septum that contacts the lap. The septum has an aperture with a radius substantially the same as the workpiece radius. The centers of the aperture and the workpiece are disposed at substantially the same radial distance from the lap's center, with the aperture along a first radial direction and the workpiece along a second. The two directions may be opposite directions.

Filter Casting Nanoscale Porous Materials
Joel Ryan Hayes, Gregory Walker Nyce, Joshua David Kuntz
U.S. Patent 8,602,084 B2
December 10, 2013
This method for developing nanoporous material includes steps to produce a slurry of liquid and nanoparticles, remove the liquid from the slurry, and produce a monolith.

Method and System to Measure Temperature of Gases Using Coherent Anti-Stokes Doppler Spectroscopy
Mark Rhodes
U.S. Patent 8,608,375 B2
December 17, 2013
This method is used to measure the temperature of a noble gas in a chamber. The noble gas is characterized by a pressure and a temperature. A first laser beam is directed into the chamber followed by a second laser beam. The first beam is characterized by a first frequency, and the second beam by a second frequency. At least a portion of the first laser beam and the second laser beam are converted into a coherent anti-Stokes beam. The Doppler broadening of the coherent anti-Stokes beam is then measured and used to compute the temperature.

Laser Heating of Aqueous Samples on a Micro-Optical-Electro-Mechanical System
Neil Reginald Beer, Ian Kennedy
U.S. Patent 8,610,032 B2
December 17, 2013
In this system, a sample is positioned within the microchannel flow channel of a microchip, and a laser directs a laser beam onto the sample to heat it. The microchannel flow channel has a wall section that receives the laser beam and allows it to pass through without appreciably heating the flow channel. The carrier fluid that moves the sample through the flow channel is also not appreciably heated by the laser beam.

Solar-Powered Cooling System

Joseph C. Farmer
U.S. Patent 8,613,204 B2
December 24, 2013
A solar-powered adsorption–desorption refrigeration and air-conditioning system uses nanostructural materials made of a high-specific-surface-area adsorption aerogel as the adsorptive media. Refrigerant molecules are adsorbed on the high surface area of the nanostructural material. A circulation system moves refrigerant from the nanostructural material to a cooling unit.

Radar Signal Pre-Processing to Suppress Surface Bounce and Multipath

David W. Paglieroni, Jeffrey E. Mast, N. Reginald Beer
U.S. Patent 8,618,976 B2
December 31, 2013
This method is designed to detect subsurface objects within a medium. In some embodiments, the imaging and detection system operates in a multistatic mode to collect radar return signals generated by an array of transceiver antenna pairs positioned across and traveling down the surface. The system preprocesses the return signal to suppress certain undesirable effects. It then generates synthetic aperture radar images from real aperture radar images that were generated from the preprocessed return signal. The synthetic images are postprocessed to improve detection. Peaks in the energy levels of the postprocessed image frame indicate whether a subsurface object is present.

High Surface Area Silicon Carbide–Coated Carbon Aerogel

Marcus A. Worsley, Joshua D. Kuntz, Theodore F. Baumann, Joe H. Satcher, Jr.
U.S. Patent 8,629,076 B2
January 14, 2014
This metal oxide–carbon composite includes a carbon aerogel with an oxide overcoat. The composite is made by immersing a carbon aerogel in a metal oxide sol under a vacuum, raising the aerogel with the metal oxide to atmospheric pressure, curing it at room temperature, and drying it to produce the composite. An activated carbon aerogel or a carbon aerogel with carbon nanotubes can be provided to make the aerogel mechanically robust. The aerogels can also be coated with solgel silica, which can be converted to silicon carbide to improve thermal stability.

Interface for the Rapid Analysis of Liquid Samples by Accelerator Mass Spectrometry

Kenneth Turteltaub, Ted Ognibene, Avi Thomas, Paul F. Daley, Gary A. Salazar Quintero, Graham Bench
U.S. Patent 8,642,953 B2
February 4, 2014
An interface for analyzing a liquid sample with carbon content by an accelerator mass spectrometer includes a wire with defects on it, a system for moving the wire, and a droplet maker, which places drops of a liquid sample onto the defects in the wire. The system converts the carbon content of the sample into carbon dioxide gas in a helium stream, and a gas-accepting ion source introduces the carbon dioxide gas into the accelerator mass spectrometer.

Electrostatic Generator/Motor Configurations

Richard F. Post
U.S. Patent 8,643, 249 B2
February 4, 2014
These electrostatic generator–motor designs may include a cylindrical rotor between two cylindrical stators. The stators and rotor are centered about a longitudinal axis and may be concentrically aligned. A magnetic field is also provided with field lines parallel to the longitudinal axis.

Contact Stress Sensor

Jack Kotovsky
U.S. Patent 8,646,335 B2
February 11, 2014
This method for producing a contact stress sensor includes one or more sensor elements fabricated by microelectromechanical systems. Each element includes a thin nonrecessed portion, a recessed portion, and a pressure-sensitive element adjacent to the recessed portion. An electric circuit connected to the pressure-sensitive element has a circuit element that provides a signal when the pressure-sensitive element moves.

Automated Diagnostic Kiosk for Diagnosing Diseases

John Frederick Regan, James Michael Birch
U.S. Patent 8,647,573 B2
February 11, 2014
An automated and autonomous diagnostic apparatus dispenses collection vials and kits to users who want to collect a biological sample and submit it to the apparatus for automated diagnostic services. The user communicates with the apparatus through a touch-screen monitor to enter information about his or her medical history, insurance, and copayment and to answer questions about his or her illness. This information is used to determine which assay will most likely yield a positive result. Physicians who are remotely located can communicate with users via video telemedicine and request specific assays to be performed. The apparatus archives submitted samples for additional testing. Users may receive results electronically and may allow diagnoses to be uploaded to a central databank for disease surveillance purposes.

High Voltage Photo Switch Package Module

James S. Sullivan, David M. Sanders, Steven A. Hawkins, Stephen E. Sampayan
U.S. Patent 8,655,125 B2
February 18, 2014
A photoconductive switch package module has a photoconductive substrate or wafer with opposing electrode-interface surfaces and at least one light-input surface. First metallic layers are formed on the electrode-interface surfaces. One or more optical waveguides with input and output ends are bonded to the substrate so that the output end of each waveguide is bonded to a corresponding one of the light-input surfaces of the photoconductive substrate. This setup forms a waveguide–substrate interface for coupling light into the photoconductive wafer. A dielectric material such as epoxy encapsulates the photoconductive substrate and optical waveguide so that only the metallic layers and the input end of the waveguide are exposed. Second metallic layers are formed on the first metallic layers so that the waveguide–substrate interface is positioned under the second metallic layers.

Zero Source Insertion Technique to Account for Undersampling in GPR Imaging

David H. Chambers, Jeffrey E. Mast, David W. Paglieroni
U.S. Patent 8,659,467 B1
February 25, 2014
A system for detecting the presence of subsurface objects within a medium is provided. In some embodiments, the imaging and detection system operates in a multistatic mode to collect radar return signals generated by an array of transceiver antenna pairs positioned across the surface and traveling down it. The system preprocesses the return signal to suppress undesirable effects. It then generates synthetic aperture radar images from real aperture radar images that were generated from the preprocessed return signal. The system postprocesses the synthetic images to improve detection and identifies peaks in the energy levels of the postprocessed image frame, which indicate the presence of a subsurface object.

Method and System for Powering and Cooling Semiconductor Lasers

Steven J. Telford, Anthony S. Ladran
U.S. Patent 8,660,156 B2
February 25, 2014
A semiconductor laser system has a diode laser tile. The tile includes a mounting fixture with a first side, a second side opposing the first side, and an array of semiconductor laser pumps coupled to the first side. The semiconductor laser system also includes an electric pulse generator thermally coupled to the diode bar and a cooling member thermally coupled to the diode bar and the electric pulse generator.

Estimating Atmospheric Parameters and Reducing Noise for Multispectral Imaging

James Lynn Conger
U.S. Patent 8,660,359 B2
February 25, 2014
This system for estimating atmospheric radiance and transmittance is divided into two phases. In the first phase, an observed multispectral image is input along with an initial estimate of the atmospheric radiance and transmittance for each spectral band. The system then calculates the atmospheric radiance and transmittance for each band, which can be used to generate a "corrected" multispectral image that is an estimate of the surface multispectral image. In the second phase, the observed multispectral image and the surface multispectral image generated by the first phase are input. Noise from the surface image is then removed by smoothing out change in the average deviations of temperatures.

High Surface Area, Electrically Conductive Nanocarbon-Supported Metal Oxide

Marcus A. Worsley, Thomas Yong-Jin Han, Joshua D. Kuntz, Octavio Cervantes, Alexander E. Gash, Theodore F. Baumann, Joe H. Satcher, Jr.
U.S. Patent 8,664,143 B2
March 4, 2014
This metal oxide–carbon composite includes a carbon aerogel with an oxide overcoat. The metal oxide–carbon composite is made by immersing the carbon aerogel in a metal oxide sol under a vacuum, raising the aerogel with the metal oxide to atmospheric pressure, curing it at room temperature, and drying it to produce the metal oxide–carbon composite. An activated carbon aerogel or a carbon aerogel with carbon nanotubes can be provided to make the carbon aerogel mechanically robust.

Spot Test Kit for Explosives Detection

Philip F. Pagoria, Richard E. Whipple, Peter J. Nunes, Joel Del Eckels, John G. Reynolds, Robin R. Miles, Marina L. Chiarappa-Zucca
U.S. Patent 8,669,115 B2
March 11, 2014
In this explosion tester system, a lateral flow membrane swab unit is connected to a unit with two reagent holders and dispensers. The first holder and dispenser contain an explosives-detecting reagent that can be delivered to the lateral flow membrane swab unit. The other holder and dispenser contain a second explosives-detecting reagent that can be delivered to the swab unit connected to the body.

Method and System for Compact and Efficient High Energy Pulsed Laser Amplifier

Alvin Charles Erlandson
U.S. Patent 8,670,175 B2
March 11, 2014
An optical amplifier system includes an input aperture that receives light propagating along an optical path in a first direction and a polarizer along the path. The polarizer passes light having a polarization state aligned with the polarization axis, and a Pockels cell receives this light. The system also includes an optical gain element, a second Pockels cell, and a second polarizer, all placed along the optical path. The second polarizer passes light having a polarization state aligned with the first polarization axis. One mirror receives light reflected from the second polarizer, and a second mirror receives light reflected from the first polarizer. An output aperture transmits the light passing through the second polarizer.

Physics-Based, Bayesian Sequential Detection Method and System for Radioactive Contraband

James V. Candy, Michael C. Axelrod, Eric F. Breitfeller, David H. Chambers, Brian L. Guidry, Douglas R. Manatt, Alan W. Meyer, Kenneth E. Sale
U.S. Patent 8,676,744 B2
March 18, 2014
This distributed sequential system detects and identifies radioactive contraband from highly uncertain (noisy) low-count, radionuclide measurements—that is, an event mode sequence (EMS). The system uses a statistical approach based on Bayesian inference and physics-model-based signal processing that represents a radionuclide as a monoenergetic decomposition of monoenergetic sources. The appropriate monoenergy processing channel is determined for a given photon event using a confidence interval condition-based discriminator for the energy amplitude. Interarrival time and parameter estimates are used to update a measured probability density function estimate for a target radionuclide. A sequential likelihood ratio test then determines one of two threshold conditions signifying whether an EMS is the target radionuclide or not. If it is not, the process is repeated for the next sequential photon event until one of the two threshold conditions is satisfied.

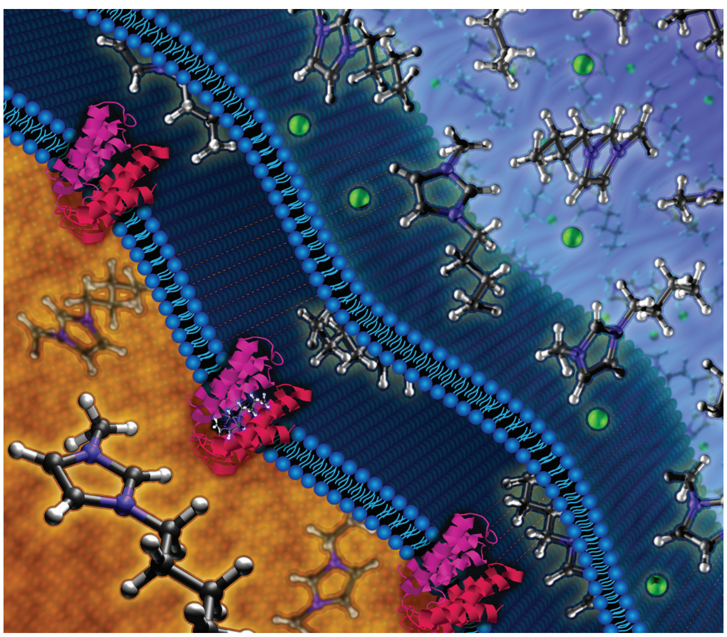
The Laboratory in the News (*continued from p. 2*)

Bacterial Resistance Improves Biofuel Performance

Research by scientists from Lawrence Livermore and the Joint BioEnergy Institute (JBEI) suggests that a type of bacterial resistance may lead to more efficient production of biofuels. The team identified the genetic origin of bacterial resistance to an ionic liquid (a salt in the liquid state) and introduced it into a strain of *Escherichia coli*, a bacterium used to produce advanced biofuels.

"Ionic liquids are potent solvents for extracting cellulose from biomass so that it can be broken down into sugars," says Livermore biochemist Michael Thelen, who also works at JBEI. "Microbes then use the sugars to make new liquid fuels that could replace gasoline or diesel."

Using an approach devised by Thomas Ruegg, a graduate student from Basel University, the team identified two genes in *Enterobacter lignolyticus*—a soil bacterium that is native to a tropical rainforest in Puerto Rico and is tolerant to specific ionic liquids. When the genes were transferred as a module into an *E. coli* biofuel host, they conferred the tolerance *E. coli* needed to grow well in the presence of toxic concentrations of ionic liquids. The module thus enhanced production of a terpene-based biofuel.



"The genetic module encodes both a membrane transporter and its transcriptional regulator," says Ruegg. While a pump exports ionic liquids from the cell (see image below left), the substrate-inducible regulator maintains the appropriate level of the pump so that the microbe can grow normally either in the presence or absence of ionic liquid. The results, published in the March 26, 2014, edition of *Nature Communications,* are likely to eliminate a bottleneck in JBEI's biofuels production strategy, which relies on ionic liquid as a pretreatment for cellulosic biomass.

Contact: Michael Thelen (925) 422-6547 (thelen1@llnl.gov).

Carbon Nanotubes Help Tissues Heal

A collaboration involving scientists from Lawrence Livermore, the Feinstein Institute for Medical Research, and University of California campuses at Davis and Merced has found that single-wall carbon nanotubes (SWNTs) can help with tissue healing and repair. Carbon nanotubes are cylindrical nanostructures of carbon used in applications ranging from biology to optics to material science.

The researchers hypothesized that a suitably treated SWNT nanocomposite matrix would provide an improved substrate for growing chondrocytes—cells for producing and maintaining healthy cartilage. To test this hypothesis, they covered the surfaces of SWNTs with carboxyl molecular groups and combined them with tissues. Results from the study indicate that chondrocytes tolerate functionalized SWNTs well, with minimal evidence for cell toxicity. The biomechanical properties of tissues containing the nanotubes were improved relative to the control tissues. More studies are needed to determine if these properties are maintained in vivo, but the results indicate that nano-based substrates could one day provide alternative approaches for treating osteoarthritis and other cartilage defects in humans.

The team's research was funded by a Lawrence Fellowship awarded to project lead Nadeen Chahine of the Feinstein Institute and by Livermore's Laboratory Directed Research and Development Program. Research results appeared in the March 2014 issue of *Tissue Engineering Part A*.

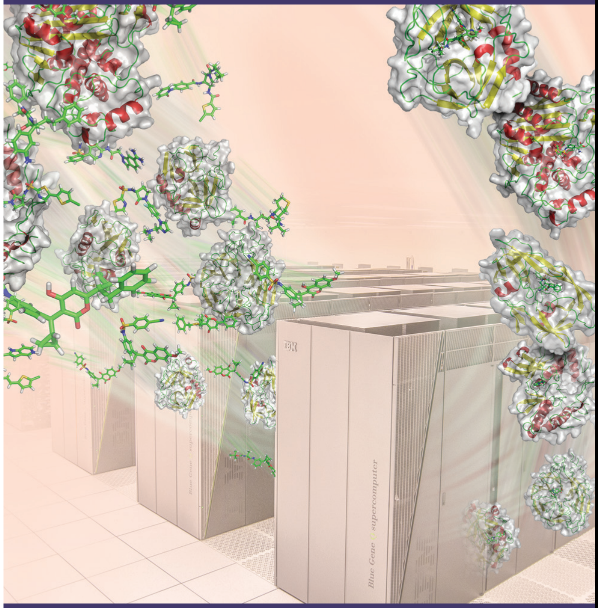
Contact: Gabriela Loots (925) 423-0923 (loots1@llnl.gov).

Abstract

A Significant Achievement on the Path to Ignition

A scientific team at Lawrence Livermore has conducted a series groundbreaking experiments in which fusion reactions have generated substantially more energy than the laser-driven implosion had deposited into the fusion fuel. The experiments use a new laser pulse shape produced by the National Ignition Facility (NIF). This pulse shape, called a high foot, is producing record yields of fusion neutrons through a process called alpha heating. The new pulse shape is more forgiving of capsule imperfections and instabilities that can grow quickly and dampen fusion reactions. The experimental results, remarkably close to supercomputer simulations, provide an important benchmark for the models used to predict the behavior of matter under conditions similar to those generated during a nuclear explosion. They have also energized scientists worldwide who have been working for more than four decades to understand and harness fusion—the process that powers the Sun and stars.
Contact: Omar Hurricane (925) 424-2701 (hurricane1@llnl.gov).

Computational Drug Discovery



Livermore researchers combine chemistry, biology, physics, machine learning, and computer modeling to catalyze drug development.

Also in July/August

• Isotopic differences between the Allende meteorite and terrestrial samples indicate a supernova occurred early in our solar system's formation.

• New software tools help scientists debug codes, increase the efficiency of simulations, and prepare for the next generation of massively parallel supercomputers.

• A Livermore-developed simulation code makes hydraulic fracturing for shale gas more productive.

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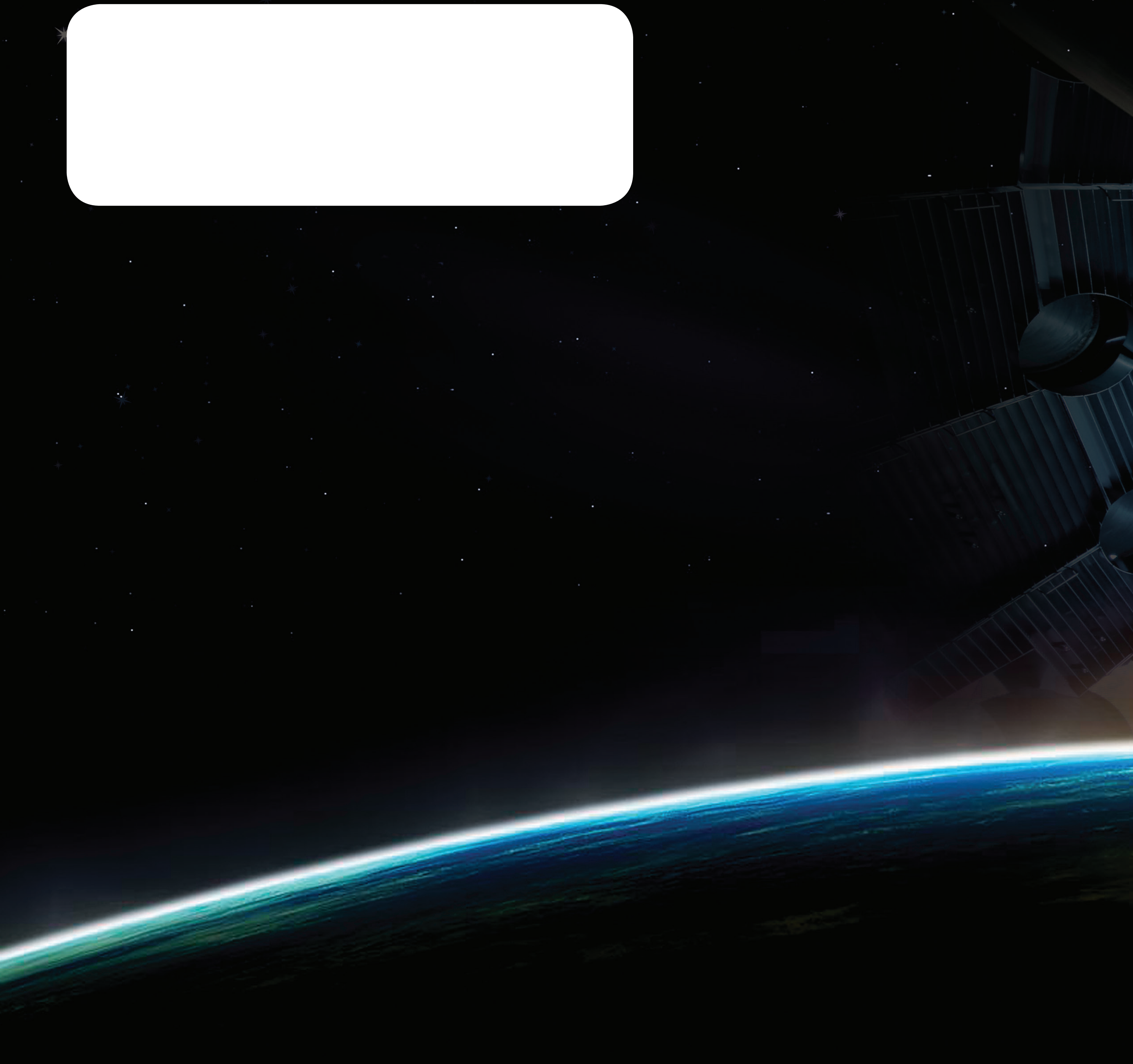

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