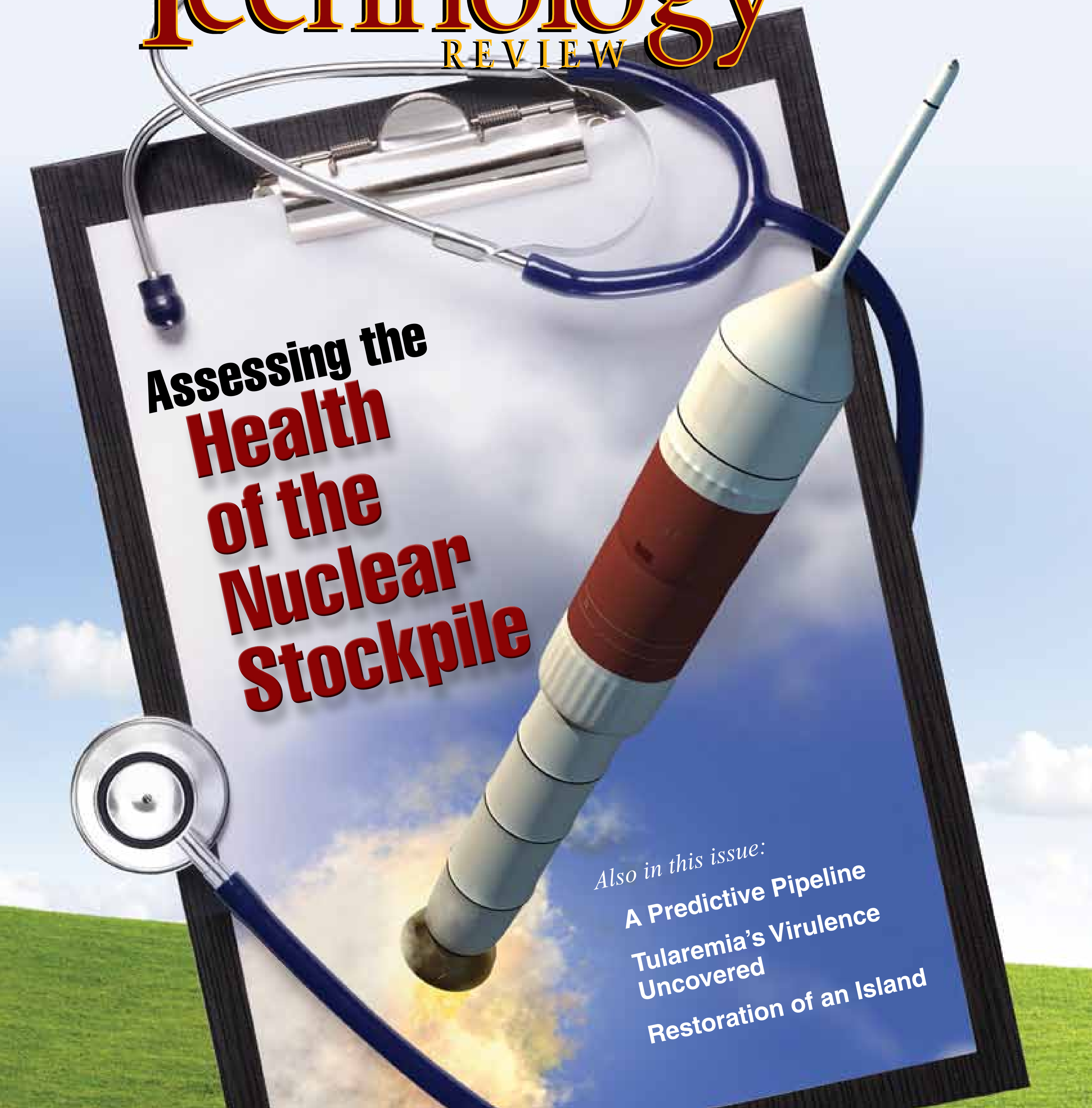
Lawrence Livermore National Laboratory

Science & Technology Review

July/August 2010



Assessing the Health of the Nuclear Stockpile

Also in this issue:

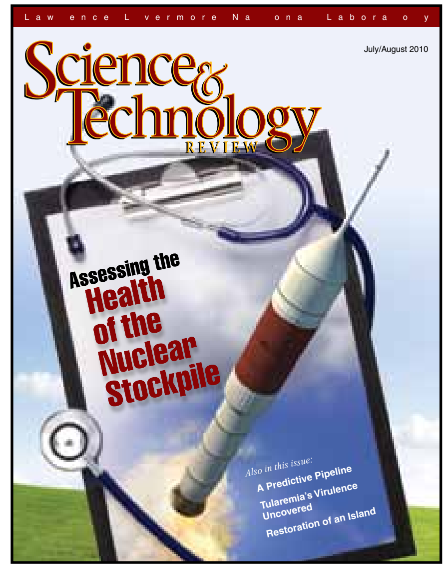
A Predictive Pipeline

Tularemia's Virulence Uncovered

Restoration of an Island

About the Cover

The artist's conception on the cover features a solid-phase microextractor, one of the tools developed in Lawrence Livermore's efforts, on behalf of the National Nuclear Security Administration, to assess the health of critical nuclear weapon components and monitor their external environment. As the article beginning on p. 4 describes, researchers are combining materials science, experiments, and numerical models to anticipate how thousands of weapon components made of various materials will likely age over time. Results from these efforts are fundamental to life-extension programs, which extend the time that a specific weapon system can safely and reliably remain in the stockpile.



Cover design: Amy E. Henke

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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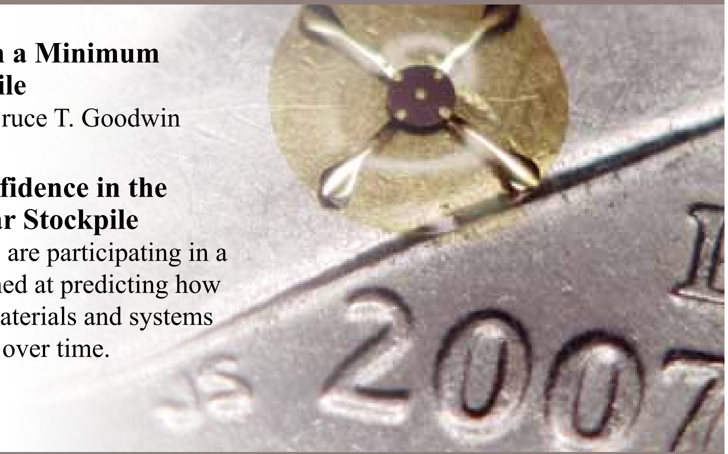
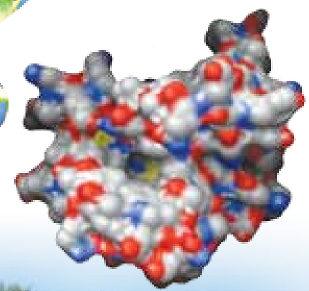


Research Highlights



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Device Detects Array of Biohazards

An advance in a Livermore detection technology, known as the Lawrence Livermore Microbial Detection Array (LLMDA), could enable law enforcement, medical professionals, and others to detect within 24 hours any virus or bacterium that has been sequenced and included among the array's probes. The array provides researchers with the capability to detect pathogens over the entire range of known viruses and bacteria. Current multiplex polymerase chain reaction techniques can detect, at most, 50 organisms in one test.

LLMDA has 388,000 probes arranged in a checkerboard pattern on a tiny glass slide. "The ability to detect the major bacterial and viral components of any sample can be used in countless ways," says Tom Slezak, Livermore's associate program leader for Informatics. "It can also fill a cost-versus-performance gap that is relevant to many missions such as biodefense, public health, and product safety."

LLMDA's probes can detect more than 2,000 viruses and about 900 bacteria. Slezak's team is testing a next-generation LLMDA that boasts 2.1 million probes. This version contains probes representing about 178,000 viral sequences from all sequenced viruses and about 785,000 bacterial sequences from thousands of bacteria. Livermore researchers working with a scientist from the San Francisco–based Blood Systems Research Institute used LLMDA technology to confirm the presence of an apparently benign pig virus in a vaccine for preventing diarrhea in infants. Slezak says, "One result of this research is that it demonstrates how modern technologies could change and dramatically improve product safety."

The Livermore researchers plan to update probes on the array with new sequences of bacteria, viruses, and other microorganisms from GenBank and other public databases about once per year, in addition to using sequences obtained from collaborators. Their work was reported in the April 2010 issue of *Journal of Virology*.

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Clues Could Reveal the Age of Our Galaxy

Using the OMEGA laser facility at the University of Rochester's Laboratory for Laser Energetics, a collaborative team has discovered that dense helium—which is found in the atmospheres of white dwarfs and the deep interiors of giant planets such as Jupiter and Saturn—transforms from a transparent insulator to a moderately reflecting conductor. A white dwarf is a small star composed mostly of electron-degenerate matter. Its mass is comparable to that of the Sun, while its volume is comparable to that of Earth's. White dwarfs are thought to be the final evolutionary state of stars whose mass is not high enough to become a supernova, and they have the potential to be used by astrophysicists to benchmark the age of a group of stars. This knowledge is important for understanding the ages of different parts of our galaxy and how it formed and evolved. The age of a white dwarf is connected with its luminescence, which decreases as it cools.

In the Livermore-led research, scientists combined diamond anvil cell and laser-driven shock wave techniques to produce dense helium samples. They then took measurements of temperature and optical reflectivity and found that electronic conduction in helium at these conditions is temperature-activated. In white dwarfs, electronic conduction makes the atmosphere opaque and limits the amount of heat that can be radiated away from the star, thus controlling its cooling rate. The research will allow scientists to accurately model the opacity of very cold white dwarfs.

The research team included Livermore scientists Peter Celliers, Jon Eggert, Damien Hicks, and Gilbert Collins and collaborators from Commissariat à l'Énergie Atomique in France, Washington State University, University of Rochester, and University of California at Berkeley.

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New Hominid Species Rocks Cradle of Humankind

An international team of scientists, including the Laboratory's Dan Farber, has reported a fossil find and a new species of hominid, *Australopithecus sediba*, thought to be about 2 million years old, in an area of South Africa known as the Cradle of Humankind. The fossils of *Au. sediba* reveal its skeletons are exceptionally well preserved, providing insight into the period when the earliest members of the genus *Homo* evolved.

Using Livermore's Center for Accelerator Mass Spectrometry, Farber and a team of researchers, including former Livermore postdoctoral researcher Anne-Sophie Meriaux of the University of Newcastle in Australia and Geoff King of the Institut de Physique du Globe in France, were able to track the evolution of the landscape from where the fossils originally were deposited to where they were found in the present day. According to Farber, the site has produced arguably the most notable assemblage of early human ancestors ever found, including the most complete skeletons of early hominids ever discovered and the most complete remains of any hominid dating to about 2 million years ago. The research was reported in a pair of papers in the April 9, 2010, issue of *Science*.

(*continued on p. 24*)

Commentary by Bruce T. Goodwin

Deterrence with a Minimum Nuclear Stockpile

SOME people think of the nation's nuclear weapons as immutable and inert objects sitting somewhere on a shelf, sometimes for decades, but capable of performing flawlessly if they are ever needed. In truth, nuclear weapons are more like vastly complex chemical experiments slowly evolving in ways we are still coming to fully understand. Inside these aging systems, metals can corrode and weaken, plastics can break down and release destructive gases, and other components, subject to continuous high radiation and external temperature extremes, can behave and interact in unforeseen ways.

Since 1992, the U.S. has ceased testing of nuclear weapons. Instead, we certify the safety and reliability of existing warheads through the National Nuclear Security Administration's Stockpile Stewardship Program of surveillance, advanced simulation, laboratory experiments, and refurbishment. Despite stiff technical challenges, stockpile stewardship has worked exceedingly well. A comprehensive new report, called the Nuclear Posture Review (NPR), underscores the importance of extending the lifetimes of existing warheads so that the nation can retain the smallest possible nuclear stockpile consistent with our need to deter adversaries and reassure our allies.

Released in April, the NPR recommends overall U.S. nuclear policy and strategy and the capabilities and forces needed to ensure that the nation's nuclear weapons remain safe, secure, and effective far into the future. The study was conducted by the Department of Defense in close consultation with the Departments of State and Energy. Lawrence Livermore researchers provided technical support for the in-depth report, as they did for the two previous NPRs conducted in 2001 and 1994.

The most recent NPR explains how the U.S. will continue to reduce the role and number of nuclear weapons while maintaining the moratorium on both nuclear testing and the development of new nuclear weapons. The report also affirms the long-term goal of a world free of nuclear weapons and calls for an invigorated nuclear weapons complex, of which Lawrence Livermore is a major part.

The report discusses the need over the next two decades for several weapon systems to undergo "overhauls" called life-extension programs (LEPs). These programs significantly extend a weapon's useful lifetime by refurbishing or replacing critical parts; they also result in weapon systems that are safer to transport and store and more resistant to attack by terrorists. LEPs are tremendous efforts that typically cost billions of dollars and take years to complete. They are based in part on the findings of enhanced surveillance, a science-based effort that demands the creativity and scientific genius of Livermore, Los Alamos, and Sandia scientists, engineers, and technicians to produce informed estimates about how nuclear weapon materials and components are likely to change over the next few decades.

For example, in a scientific tour de force, Livermore and Los Alamos researchers in 2006 announced that the plutonium aging inside modern U.S. nuclear weapons should not be a concern for nearly a century. The finding was made possible by advances in theory, new kinds of experiments, and the largest supercomputer simulations ever conducted that together permitted us to confidently look ahead 100 years, an amazing achievement.

As the article beginning on p. 4 describes, Livermore people are developing remarkable enhanced surveillance tools and technologies. For example, they have invented tiny sensors designed to report on conditions from deep inside a weapon and perfected minuscule fibers that "sniff" for trace amounts of gases given off by aging plastics.

As our stockpile moves toward fewer weapon types with perhaps hundreds instead of thousands of each type, the importance of the health of each weapon increases tremendously. Because of this factor, continuing to move toward deterrence with a minimum stockpile demands outstanding scientific and engineering talent and unparalleled experimental and computational resources. In that respect, I am gratified that the NPR calls for substantial investments to rebuild America's aging nuclear infrastructure and to strengthen the science, technology, and engineering base needed for conducting enhanced surveillance activities and LEPs. Stockpile stewardship works, and we've gotten very good at it. With continued support, we will get even better.

■ Bruce T. Goodwin is principal associate director for Weapons and Complex Integration.

Enhancing Confidence in the Nation's Nuclear

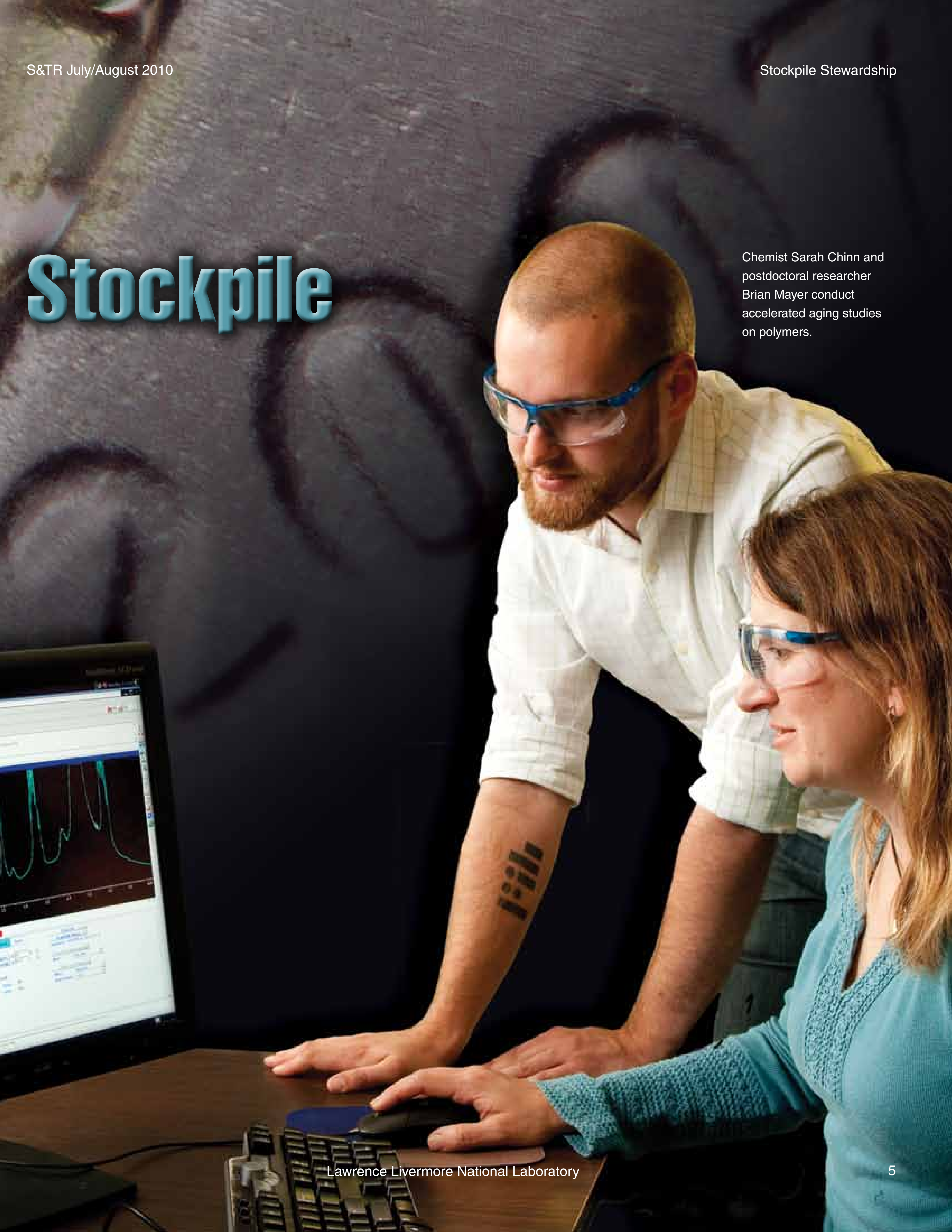
Livermore researchers combine materials research, experiments, and advanced numerical models to anticipate any problems in America's aging nuclear weapons.

SOME experts compare the National Nuclear Security Administration's (NNSA's) mission to maintain and enhance the safety and security of America's nuclear stockpile with the National Aeronautics and Space Administration's mission to safely land a human on the moon. The comparison is often made because nuclear weapons are extremely complex devices, with thousands of components that must work together seamlessly to produce a nuclear detonation. What's more, since 1992, scientists can no longer check the performance of nuclear weapons by detonating them underground at the Nevada Test Site. (See the box on p. 6.)

Nuclear weapon components are made of various materials such as high explosives (HEs), steel, plutonium, uranium, and polymers (plastics). Scientists have found age-related changes in some of the components and materials in weapons removed from the stockpile and disassembled. These changes are occurring, in part, because many weapons have been in the stockpile longer than originally intended. Plastics can break down and give off potentially destructive gases, metals can corrode and weaken, and coatings can deteriorate. Some materials may change properties unpredictably in response to the high radiation fields, fluctuating temperatures, and other environments to which nuclear weapons are subject.

In the absence of developing new nuclear weapons, experts must work to extend the life of existing units and understand how their constituent materials and components age. Scientists conduct a comprehensive program of weapon surveillance (close examination), laboratory experiments, and maintenance and refurbishment of components. Data from all activities are used to refine computational models, some of which serve as electronic surrogates for underground testing. These combined activities, which require the efforts of

Stockpile



Chemist Sarah Chinn and postdoctoral researcher Brian Mayer conduct accelerated aging studies on polymers.

chemists, materials scientists, engineers, physicists, and computer scientists, are called stockpile stewardship. The Stockpile Stewardship Program has been enormously successful to date and has permitted the directors of Lawrence Livermore, Los Alamos, and Sandia national laboratories to annually assess the status of the stockpile and conclude that currently a need does not exist for nuclear testing.

Livermore chemist Bob Maxwell notes that relying solely on routine surveillance of nuclear weapons provides little insight into possible future changes in materials and components that could affect safety or performance. "Inspecting or testing components doesn't help us predict beyond today," he says. "For example, a test of HE material taken from a stockpiled unit may tell us the material is capable of detonating this month but does not necessarily give us confidence in its performance a decade from now."

To gain added confidence, Livermore experts lead numerous efforts in NNSA's Enhanced Surveillance Campaign, aimed at producing informed estimates about how nuclear weapon materials and components will likely change over the next one to two decades. Results from enhanced surveillance efforts are fundamental to life-extension programs, which entail refurbishing or replacing parts to extend the time that a specific weapon system can safely and reliably remain in the stockpile. "We must look 15 to 20 years in the future because it can take that long to fix a problem, given the current lean nuclear weapons infrastructure," explains Bill McLean, manager of Livermore's Enhanced Surveillance Campaign.

For several years, a key thrust of enhanced surveillance centered on studying the properties and aging of plutonium pits found in every modern nuclear weapon. In 2006, the two NNSA nuclear design laboratories—Lawrence Livermore and Los Alamos—issued a joint report stating that "subtle age-induced changes in the atomic structure and composition of plutonium do not, in themselves, limit the lifetime of U.S. weapon pits," and "the majority of plutonium pits for most nuclear weapons have minimum lifetimes of at least 85 years." That finding has permitted Livermore stockpile stewards to shift the focus of their attention to obtaining a better scientific understanding of how other weapon materials and components age and interact during the decades they remain in the stockpile.

Some Livermore enhanced surveillance experiments artificially age materials and components by subjecting them to high temperatures or intense gamma or neutron radiation. Other efforts focus on developing new diagnostics and nondestructive tests. Data obtained from

Managing the Nation's Ever-Shrinking Nuclear Arsenal

The nation's current nuclear stockpile consists of sea-based, land-based, and air-carried systems. For decades, the performance of the complex nuclear explosive package as well as the nonnuclear components in these weapon systems was confirmed with underground tests conducted at the Nevada Test Site. Since the nuclear test moratorium was adopted in 1992, the U.S. has deployed no new weapons, while thousands of existing weapons have been retired or dismantled.

Under the 2002 Moscow Treaty on Strategic Offensive Reductions, the U.S. has been reducing the number of its operationally deployed nuclear weapons to between 1,700 and 2,200 by 2012. In April 2010, U.S. President Barack Obama and Russian President Dmitry Medvedev signed a new arms reduction pact that pledges to reduce the number of operationally deployed, strategic nuclear weapons in both countries and commits the nations to adopt new procedures for verifying which weapons each country possesses. Under this treaty, called New START, both countries will be limited to 1,550 ready-to-use, long-range nuclear weapons. In the future, as the number of U.S. weapons shrinks, fewer weapons will be available for disassembly, underscoring the importance of nondestructive testing of existing weapons and science-based studies of materials and components.

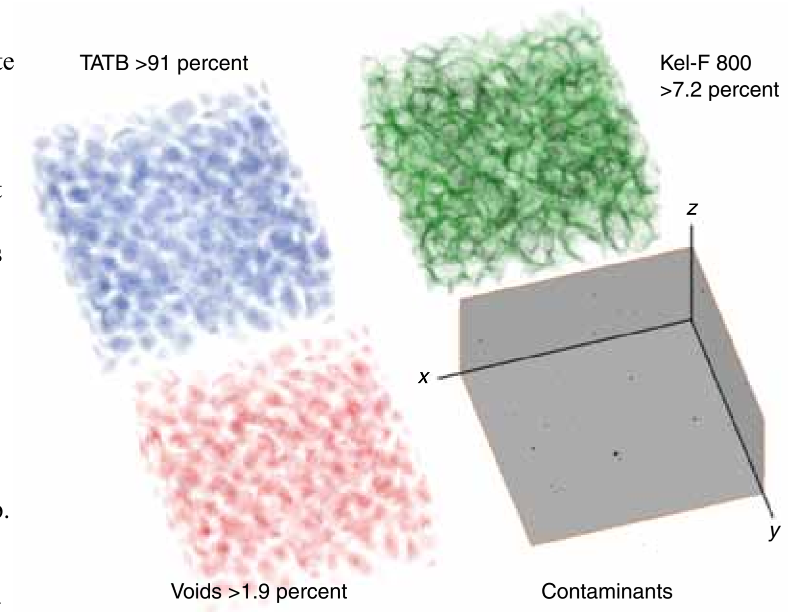
The New START force reductions are a key step in implementing the Obama administration's strategy to reduce nuclear dangers, which is described in the 2010 Nuclear Posture Review (NPR). NPR emphasizes as one of its five major findings the need for the nation to sustain a safe, secure, and effective nuclear arsenal as long as nuclear weapons exist.

Stockpile stewardship is a responsibility of the National Nuclear Security Administration (NNSA), which was established by Congress in 2000 as a semi-autonomous agency within the Department of Energy. The Stockpile Stewardship Program includes science and engineering experiments and computer simulations to study the mechanisms of how nuclear weapon components age. NNSA assesses each nuclear weapon to detect or anticipate potential problems that may come about as a result of aging. As part of that effort, each weapon receives routine maintenance and surveillance (a thorough examination). In addition, the agency extends nuclear warhead lifetimes through the refurbishment of critical components and safely dismantles and disposes of units that have been retired.

NNSA nuclear weapons laboratories—Los Alamos, Lawrence Livermore, and Sandia—assess the health of the current stockpile, design the components and systems for the life-extension programs, and certify the life-extended models when they enter the stockpile. Over the past decade, NNSA has funded new experimental capabilities at the laboratories, including the National Ignition Facility at Livermore and the Dual-Axis Radiographic Hydrodynamic Test Facility at Los Alamos. One of the most far-reaching efforts was instituting the program now known as Advanced Simulation and Computing, which permits the computational "testing" of components and entire systems, and which has impelled a transformation of the nation's supercomputing industry.

enhanced surveillance are used to validate and refine computational models that identify any problems long before they could affect safety or performance. By elucidating the mechanisms of aging—at times, on the atomic scale—the models can also help determine the likely effects of substituting different materials.

"Our goal is to increase confidence in the stockpile, reduce uncertainties about weapon systems, and save taxpayers money in the process," says chemist Pat Allen. He notes that the Livermore work straddles basic materials science and applied science for stockpile stewardship. Allen points to important Livermore advances over the past few years, including a new technique for measuring HE detonations, miniaturized sensors, improved corrosion models, and better methods for measuring polymer gases. These advances could not have been made without the fundamental scientific research conducted over the course of many years at Livermore.



A three-dimensional computed tomography scan of the insensitive high explosive LX-17 reveals the concentration of triaminotrinitrobenzene (TATB), the binder polymer Kel-F 800, and other constituents. The data provide input to codes modeling shock response and detonation.

High Explosives Set Things Off

One critical enhanced surveillance effort is directed at understanding in greater detail how aging affects the complicated detonation of the chemical HEs that are used to implode the plutonium pit in modern nuclear weapons. Scientists are concerned that, with age, HE components could lose some of their safety and performance features. Experts investigate the physical, chemical, detonation, and mechanical properties of HE taken from the stockpile, such as with the use of radiography to measure the size and density of microscopic grains. They also ensure adequate reserves exist of triaminotrinitrobenzene, an insensitive HE (meaning it is highly unlikely to explode in the event of an accident). (See *S&TR*, June 2009, pp. 4–10.)

Researchers artificially age HE samples and detonation systems with high temperature and radiation. They then look for changes such as cracks and swelling. "These studies give us an opportunity to observe in a relatively short time the same kinds of changes produced over decades in a weapon," says engineer Constantine Hrousis. The studies also provide the data used to improve and validate models of aging HE developed by chemist Rick Gee.

Hrousis and his team are studying the aging of particular components that make possible the complicated event sequence involved in initiating the detonation of the main HE charge, which must properly explode and precisely squeeze the plutonium pit. Initiation systems are first triggered by a burst of current that explodes a small piece of metal, which then ignites a booster charge of HE to set off the main HE charge.

The Livermore-designed W87 warhead, deployed on U.S. intercontinental ballistic missiles, uses a mechanical arming device that features a small pellet of high-density HE, which is kept "out of line" for added safety. On command, the mechanical system moves the pellet into an orientation that permits the HE detonation process to begin. Enhanced surveillance creates tools for tracking these devices, enabling prolonged confidence in their reliable performance and ensured safety despite the fact that they are aging. Computational models are created to accurately simulate the arming and initiation functions of such devices, providing a virtual test bed for aging scenarios and their potential impact on performance and safety.

To extract more information from HE detonation tests conducted at NNSA's Pantex Plant near Amarillo, Texas, chemist George Overturf is overseeing the adoption of a diagnostic tool using photonic Doppler velocimetry (PDV). (See *S&TR*, July/August 2004, pp. 23–25.) Developed several years ago by Livermore physicist Ted Strand, PDV is allowing engineer Michael Gresshoff to measure the particle velocity at the HE outer surface resulting from the detonation, which can reach speeds exceeding 3 kilometers per second.

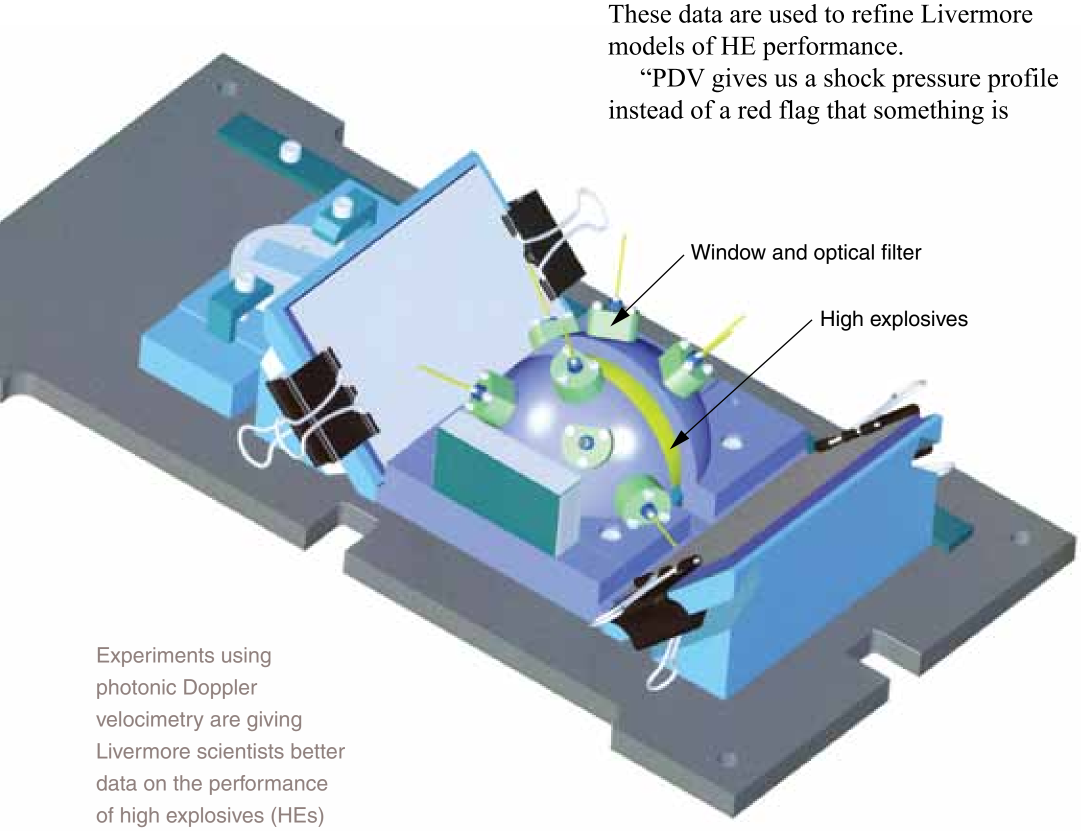
The technique currently used at Pantex, where warheads are disassembled and inspected, involves machining HE into a snowball shape and covering its outer hemispherical surface with a light-enhancing coating for capture by a streak camera. The value of this technique is limited because it cannot determine the completeness of detonation or the strength of the shock.

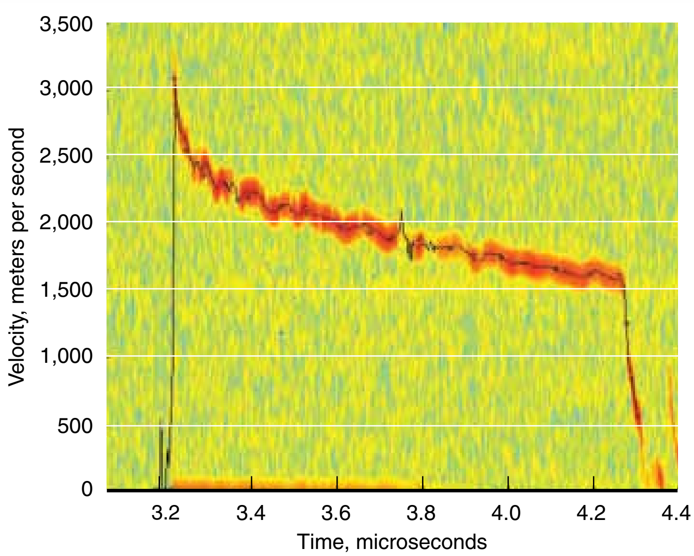
Instead, PDV focuses 1,550-nanometer-wavelength laser light onto the snowball through a fixture with eight clear windows that are in direct contact with the outer insensitive HE surface. During detonation, a detector senses the reflected laser light.

A portion of the original light is also sent to the detector. The difference in frequency between the two light sources is related to the speed at which the outer HE surface is traveling.

This technique provides a significant improvement in data characterizing the HE detonation. PDV measures the detonation particle velocity, which in turn yields the explosive pressure as well as the arrival time (or general shape of the detonation). These data are used to refine Livermore models of HE performance.

"PDV gives us a shock pressure profile instead of a red flag that something is amiss in the detonation," says Overturf. "We're going back to first principles to determine performance." The technique is now undergoing final tests for routine use at Pantex.





Experiments using photonic Doppler velocimetry are giving Livermore scientists better data on the performance of high explosives (HEs) contained in nuclear weapons. (above) HE is machined into a sphere about 62 millimeters in diameter and covered with an aluminum fixture that features eight windows (one is not visible from this view) through which laser light is focused using an optical fiber. (right) When HE is detonated, the particle velocity is recorded over time. From these data, exact pressures can be derived and used to refine models.

Tiny Sensors Report All

In another effort, researchers are developing a suite of tiny, rugged sensors that could be embedded inside every nuclear weapon to report on the health of critical components as well as on the external environment. The embedded sensors would relay information, perhaps through a USB-like port, whenever scientists deem it necessary. The sensors would thus make possible for the first time "persistent surveillance," that is, continuous monitoring of a weapon's state of health.

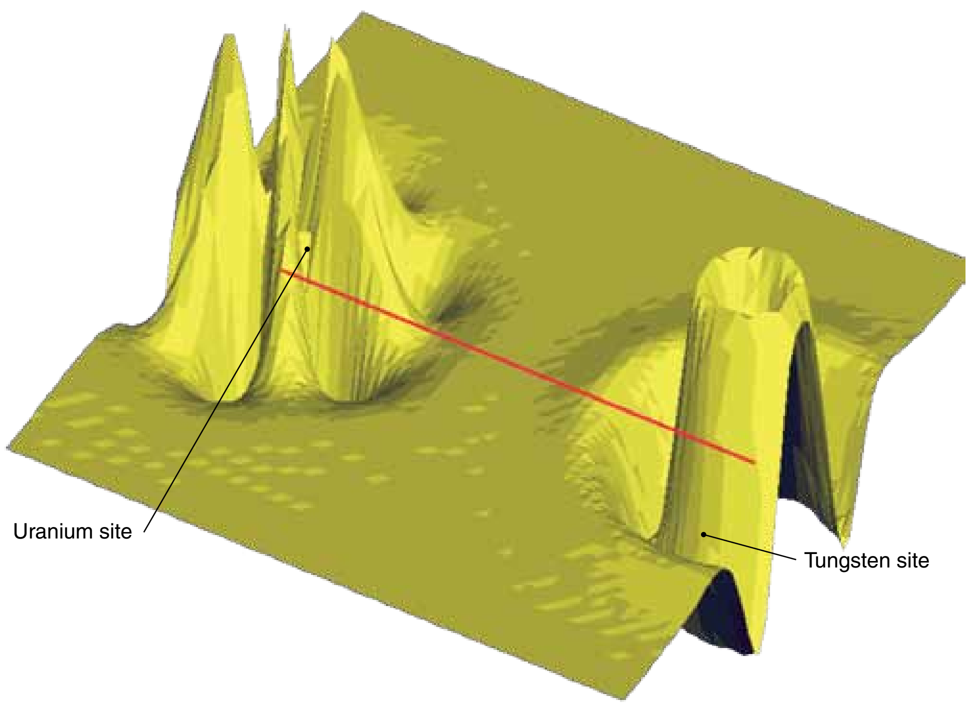
About a dozen sensors per weapon would monitor mechanical changes, internal gas composition, and the external environment. The sensors would most likely be emplaced during a weapon system's life-extension program. Sensors also could be added to so-called shelf units stored at NNSA's Y-12 Plant in Tennessee and at Pantex, where individual components identical to those in deployed weapons are monitored for unexpected physical and chemical changes. Once in place, the sensors could be checked to determine if unwanted gases or microscopic cracks and voids are present, and whether a weapon incurs stresses as it is moved.

Sensor experts at the Laboratory are collaborating with scientists throughout the NNSA complex and Britain's Atomic Weapons Establishment. Livermore's Laboratory Directed Research and Development Program funded much of the original proof-of-principle research. Says engineer Jim McCarrick, "We've taken the most promising designs and are developing and testing them."

Stress sensors would be based on microelectromechanical systems technology to measure forces, pressures, and accelerations that components experience. Gas-detecting sensors would combine infrared absorption and Raman scattering to take "fingerprints" of all gases inside the weapon. Both techniques measure how molecular bonds respond to a beam of infrared light generated by a laser and passed through an optical fiber. (See *S&TR*, July/August 2008, pp. 12–19.)

Also under development are sensors to monitor gaps in the relative positions of components to ensure that no parts have moved as well as sensors to look for tiny cracks in parts. Another type of sensor would measure and record a weapon's external temperature and shock history. With this device, scientists could possibly relate a mechanical change to a particular event (such as transporting the warhead) and thereby determine if a detected mechanical change was specific to that weapon or evidence of a systemic problem.

Livermore mechanical engineer Jack Kotovsky designed this tiny contact stress sensor (shown on a dime for scale) for monitoring weapons in the stockpile. The 60-micrometer-thick sensor can repeatedly measure changing loads perpendicular to a surface within a weapon system.



This simulation of an atomic electrical charge shows an atom of uranium next to an atom of tungsten, a contaminant. The close presence of tungsten gives the uranium atom a greater tendency to react with hydrogen and form uranium hydride, which can affect weapon performance.

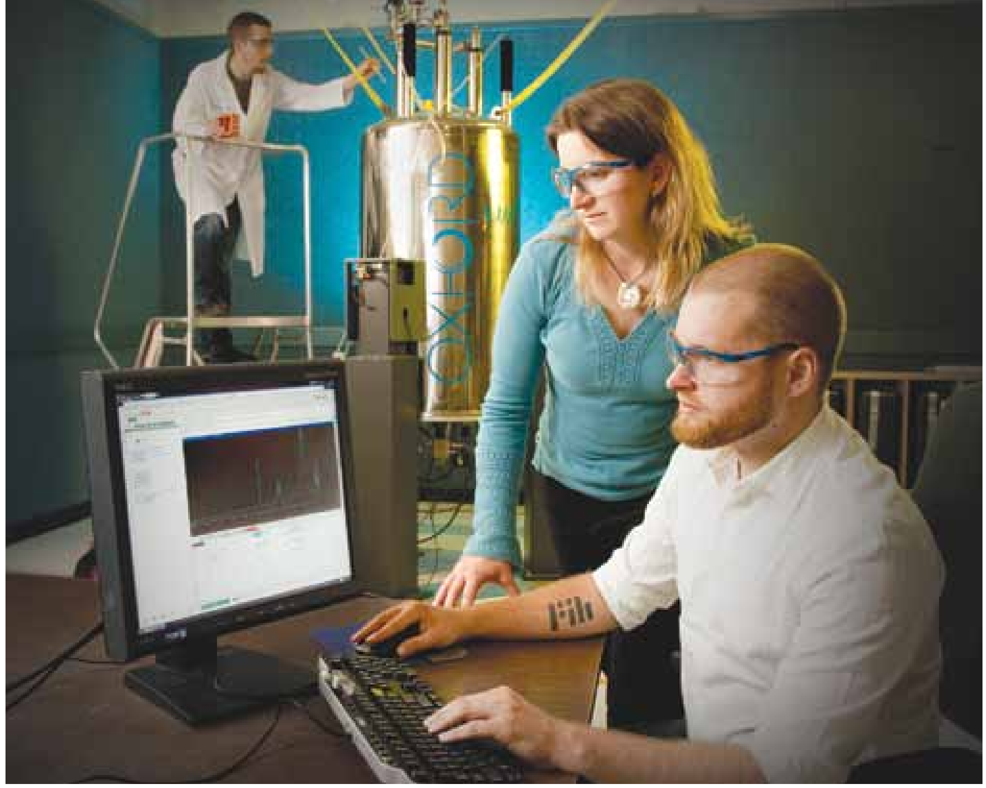
Modeling Corrosion from Hydrogen

Another enhanced surveillance effort is refining models that simulate uranium aging with unprecedented fidelity. Chemist Tyzh-Chiang Sun notes that uranium is virtually "pristine" when it is inserted into a nuclear device. The nuclear explosives package is then sealed with inert gases. However, within a few years, internal conditions can become corrosive from the liberation of simple compounds, especially hydrogen.

Warhead components can give off hydrogen directly, or they can react with a small amount of water vapor to form intermediate compounds that liberate hydrogen. Once in contact with uranium, hydrogen forms uranium hydrides, corrosion products that could potentially affect weapon performance.

Hydrogen corrosion can take years, even decades, to cause a problem. X radiography can reveal changes caused by uranium hydride when it is well established, but scientists need to better understand how corrosion initiates and propagates. Livermore's advanced aging models are used to determine how quickly hydrogen is emitted from various sources inside a weapon.

The corrosion models show the role played by uranium impurities, which, depending on the element, may possibly accelerate formation and growth of uranium hydride. One model, developed by Krishnan Balasubramanian, simulates on an atomic scale how impurities can cause corrosion and how the kinetics of hydrogen liberation are a function of temperature, radiation, and time.



Postdoctoral researchers Jim Lewicki (background) and Brian Mayer along with chemist Sarah Chinn use nuclear magnetic resonance spectroscopy to investigate key chemical reaction mechanisms responsible for polymer degradation.

Polymer compatibility is critical to a weapon's overall state of health. This example shows a sample of the polymer syntactic polysulfide, before (left) and after (right) exposure to an incompatible polymer.

Some Plastics Can Be a Gas

Modern nuclear weapons could not function without hundreds of parts made from polymers, such as foam cushions, O-rings, gaskets, seals, and washers. The parts fill gaps, transmit loads, dampen vibration, and provide cushioning and thermal insulation. Polymers are of particular concern to stockpile scientists because they tend to be reactive. Polymers can change chemically and physically when subjected to radiation, temperature swings, and physical loads. For example, many polymers lose their resiliency over time, potentially allowing components to move about slightly when the weapon is moved.

Chemist Sarah Chinn conducts accelerated aging studies on surplus polymers that were shelved at the same time the weapon entered the stockpile. These tests subject the materials to strong radiation levels and high temperatures. Data from tests are used to refine aging models that help predict changes over the next decade.

Aging studies are particularly important when a polymer must be replaced. "A seemingly simple piece of polymer can have many attributes," says Chinn. Most polymers have proprietary formulations that a manufacturer can change without notice. "As a result," she says, "we may obtain a replacement part made by the same manufacturer that produced the part 20 years ago, but the manufacturer has altered its formula. In which case, we must determine the new material's properties and compatibilities with other polymers. We can't merely swap the part."

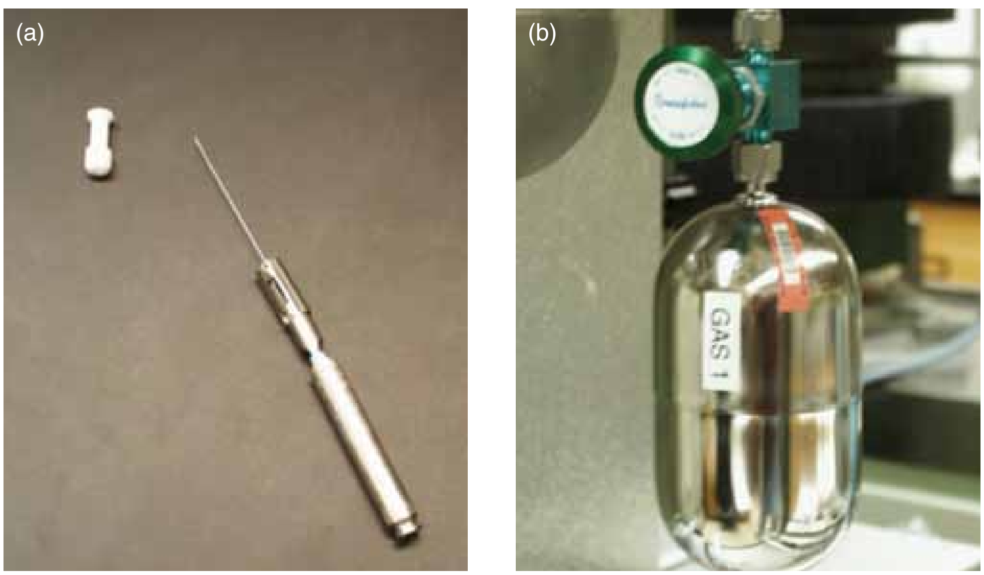
Chinn is also investigating the possible application of medical diagnostics to enhanced surveillance. For example, radiologists use magnetic resonance imaging to reveal details of soft tissue in humans, but the technology could also be used to detect defects in polymers. Chinn is investigating a nuclear magnetic resonance robotic instrument that could perform nondestructive testing of polymers.

A critical task is examining the gases polymers slowly release during decomposition and material interactions. Indeed, a major issue is potential incompatibilities among polymers. In one compatibility trial, ammonia outgassing by a polymer degraded a nearby component made of a different polymer, turning it into a shapeless blob.

A technique pioneered by Livermore scientists for stockpile stewardship involves solid-phase microextraction (SPME) to analyze organic gases liberated in the head space of nuclear weapons. This technique uses a narrow metal fiber coated with a polymer to adsorb organic compounds. The fiber is inserted into a weapon, and the volatile organic compounds stick to the coated needle. The retrieved needle is then inserted into a gas chromatograph–mass spectrometer to obtain a chemical analysis of a weapon's internal environment. With this technique, hundreds of compounds can be identified at concentrations down to a few parts per billion. In this way, chemists can spot potential material incompatibilities, such as degradation products, synthesis by-products and impurities, and defects such as incompletely cured adhesives. "SPME provides the first clue that a polymer is undergoing change, long before we can see or measure any physical change," says chemist Chris Harvey.

SPME sampling has been performed for a decade on Livermore-designed systems at Pantex. For more extensive analysis, Harvey patented a method to conduct the SPME analysis "offline" in a Pantex laboratory instead of directly on the weapon during disassembly. For this procedure, he adapted a 400-milliliter container to hold gas taken from the weapon. The container is lined with fused silica to prevent organic gases from adsorbing onto the container walls. In the laboratory, operators extract several samples and inject them into a gas chromatograph–mass spectrometer for repeated analyses. According to Harvey, the long-range plan is to build a database of compounds identified by the SPME sampling procedure and connect each compound with its source. In this way, scientists would be able to recognize a compound's likely source the next time it is identified.

The new offline method provides significant time savings, and thereby decreased costs, for SPME sampling. "The process is simple in concept and very beneficial in practice," says Harvey.



(a) The solid-phase microextraction (SPME) technique uses a tiny metal fiber coated with a polymer to adsorb organic compounds liberated in a weapon's headspace. The retrieved needle is inserted into a gas chromatograph–mass spectrometer to obtain a chemical analysis of the weapon's internal environment. (b) For more extensive analysis, chemist Chris Harvey developed a method to conduct SPME "offline" using a 400-milliliter container to hold the gas taken from a warhead. In a laboratory setting, several samples can be extracted for repeated analyses to build a database of compounds.

Tremendous Progress Made

"We've made tremendous progress over the past 10 years in understanding the aging of our stockpile," says McLean. He compares enhanced surveillance to a careful driver on an unknown road advancing cautiously but guided by powerful headlights to see the way ahead.

Allen notes with satisfaction the strong advances the Laboratory has made in enhanced surveillance and assessing the health of the nation's stockpile. He points out that because Livermore's Enhanced Surveillance Campaign has such a large science component, much of the materials aging work is published in peer-reviewed scientific journals. As a result, the program has helped attract bright, young scientists and engineers to the Laboratory. According to Chinn, "Enhanced surveillance allows next-generation stockpile stewards the opportunity to tackle tough science issues. There are tremendous opportunities to publish and gain exposure beyond our gates."

As the nation gains increased confidence in its nuclear defense, young scientists and engineers are drawn to be future stewards of America's nuclear arsenal and to advance the science of materials. The Stockpile Stewardship Program ensures that the nation's nuclear weapons remain reliable, while developing the science, technology, and knowledge base for the future.

—Arnie Heller

Key Words: Enhanced Surveillance Campaign, high explosive (HE), life-extension program (LEP), Nuclear Posture Review (NPR), Pantex Plant, photonic Doppler velocimetry (PDV), plutonium, solid-phase microextraction (SPME), Stockpile Stewardship Program, uranium hydride.

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Narrowing Uncertainties

DOZENS of climate models are in use throughout the world, and their predictions for global warming as a result of a doubling in atmospheric carbon dioxide vary from about 1 to 5°C over the next 30 years. A globally averaged increase of 1°C might not matter in many parts of the world, but the larger increase could mean vast changes in snowpack, rainfall, water availability, crop production, and ocean levels, affecting billions of people.

Predictions and accompanying margins of error are used constantly, for example, to foresee where the economy is headed, determine how much will be needed in the Social Security fund for aging boomers, estimate future oil production from a particular well, anticipate the efficacy of a new drug, or determine the chance of a terrorist attack in a U.S. city. Occasionally, the magnitude of the uncertainty can rival or even exceed the value of the prediction.

How to reduce uncertainty can be unclear, in part, because it can take many forms. For example, uncertainty may exist in regard to the assumptions and inputs to a model, the errors associated with experimental data, or the approximations inherent in the physics, numerical algorithms, and mathematics of the model itself.

> ***"The uncertainty is as important a part of the result as the estimate itself. . . . An estimate without a standard error is practically meaningless."***
>
> *—Sir Harold Jeffreys, statistician, Cambridge University (1891–1989)*

Furthermore, a prediction may include uncertainties from many factors that may be interrelated.

"At Livermore, significant advances in uncertainty quantification have been made in the weapons program," says Richard Klein, a theoretical astrophysicist in the Laboratory's weapons program and a professor of astronomy at the University of California at Berkeley. Several years ago, Lawrence Livermore and Los Alamos national laboratories worked together to develop an improved methodology for assessing the performance of nuclear weapon systems without nuclear testing. (See *S&TR*, March 2004, pp. 19–21.) Known as quantification of margins and uncertainties, the work entailed systematically combining the latest data from computer simulations, past nuclear tests, nonnuclear experiments, and theoretical studies to quantify confidence factors for the key potential failure modes in each weapon system in the stockpile.

Recognizing the applicability of this work to a wide range of scientific fields, a large collaboration at Livermore began studying uncertainty quantification (UQ) and error analysis. Klein leads this three-year Laboratory Directed Research and Development Strategic Initiative involving more than 20 scientists from four organizations: Weapons and Complex

Integration, Physical and Life Sciences, Computation, and Engineering. "The experts in software, mathematics, statistics, and physics from these organizations create highly complex models and routinely deal with uncertainty," says Klein. "With this research, our goal is to get them speaking the same language and advancing the science of UQ."

Organizations from around the world have also been searching for ways to identify sources of uncertainty to improve the predictive capability of models. The Livermore project, which began in October 2009, brings to the table not only the Laboratory's unique combination of expertise but also some of the largest, most powerful computers in the world.

First on the Agenda

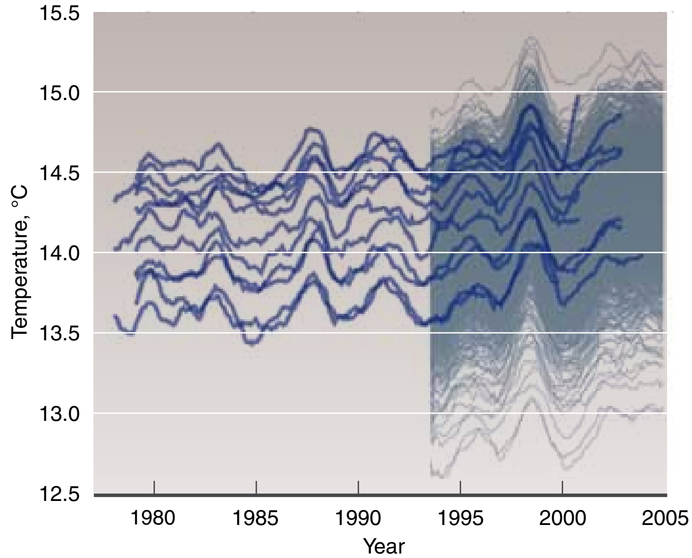
The project is focused primarily on quantifying uncertainty in climate prediction, where the consequences of uncertainty are vast. Carbon dioxide in the atmosphere is increasing, and climate change is upon us. As stated in *Climate Change 2007*, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level." However, the dozens of predictive climate models now in use are not in agreement about what Earth will be like in another 50 or 100 years. New methodologies are needed to more rigorously quantify uncertainties so that sources of uncertainty can be reduced where possible. Improvements in UQ achieved in the Laboratory project will undoubtedly spin back to the weapons program and other Laboratory projects.

The primary U.S. climate model, known as the Community Climate System Model, is managed by the National Center for Atmospheric Research in Boulder, Colorado. The model simulates Earth's past, present, and future global climate. The Laboratory has a long history of involvement in atmospheric research through its National Atmospheric Release Advisory Center and works primarily on the Community Atmosphere Model, one component of the larger model.

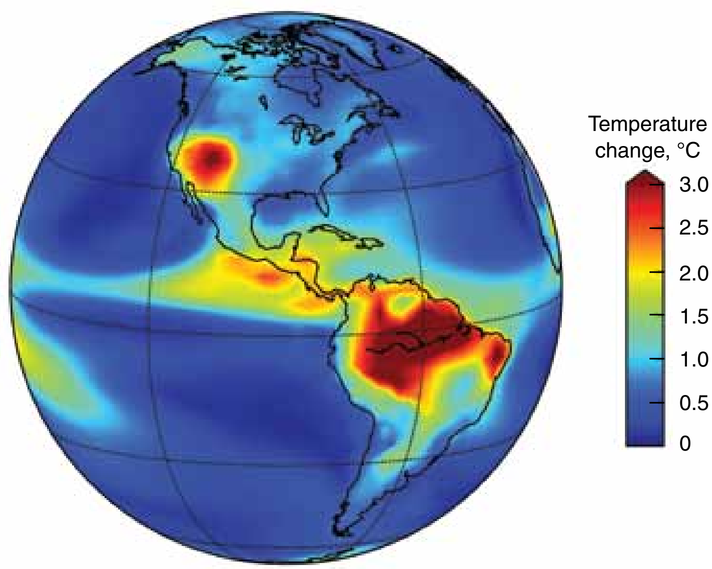
Atmospheric scientist Curt Covey, who has been involved in climate modeling for more than 20 years, notes that uncertainties have always been addressed in climate models. "However, applying UQ at the same level of rigor as it is being used in the weapons program is new." Working with Covey are Don Lucas, John Tannahill, and Yuying Zhang of the Laboratory's Atmospheric, Earth, and Energy Division.

The Curse of Dimensionality

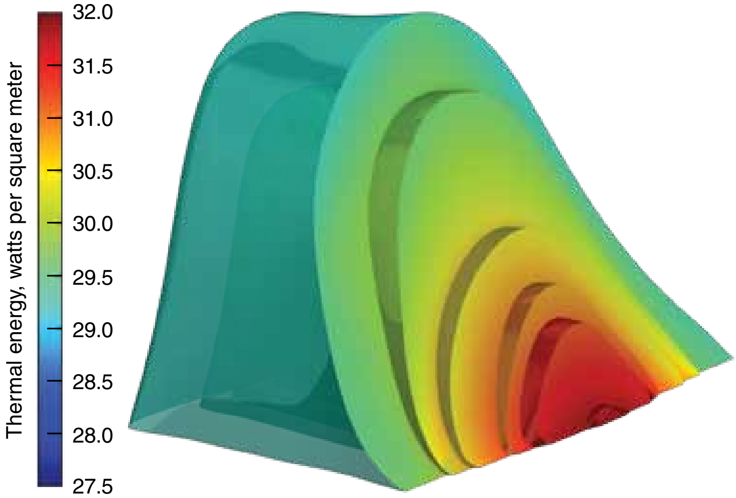
UQ for climate modeling and other predictions is typically performed with an ensemble of models. Because computing power is limited, scientists identify a small subset of input quantities (usually 7 to 10) that they think are the dominant source of prediction



Dark blue lines show the global average surface air temperature computed by 11 climate models run using the same simulation protocols. Thin gray lines result from more than 1,000 simulations using only the Community Atmosphere Model and different combinations of input parameters. Applying uncertainty quantification methods to a single climate model increases the spread in calculated temperature, which makes apparent the effects of uncertainties.



Variations in uncertain physical parameter inputs can dramatically affect climate model output variables. This simulation by the Community Atmosphere Model shows the magnitude of the changes in surface air temperature as a result of varying a single parameter at different points in a 21-dimensional parameter hypercube. Similar maps are used to identify and rank important sources of uncertainty. (Rendering by Kwei-Yu Chu.)



The colored surfaces in this image show the effects of varying three parameters in simulations using the Community Atmosphere Model across their uncertainty ranges. Specifically, the parameters are associated with cloud-forming processes, and the surfaces represent the amount of thermal energy that escapes Earth's atmosphere. The variation in energy along the contour surfaces corresponds to about 5 watts per square meter. (Rendering by Kwei-Yu Chu.)

uncertainties. The ensemble is produced by running the model thousands of times using differing combinations of input quantities. These inputs are constrained by available data and have their own associated uncertainties. Statistician Gardar Johannesson, who refers to this method as the "shotgun approach," says, "The process takes many computer runs, and the result of some simulations may be inconsistent with existing real-world data. Those cases narrow down the space of possible realizable parameter combinations." Traditional approaches to UQ focus on parameter variations from a center point where all parameters assume their most likely values. This approach misses the corner regions, which may contain the most important possibilities for future scenarios—scenarios that may be less likely but more consequential.

Input parameters and their associated uncertainties are known to statisticians as dimensions, and the more dimensions, the less merry the statistician's task. Two dimensions are easy enough to solve, as are three. Beyond that, the difficulty of accommodating all the different uncertainties grows exponentially, outstripping the capacity of the most powerful computers—a problem known as "the curse of dimensionality."

Charles Tong, a mathematician on the project, likens the curse of dimensionality to the old story of a blind man trying to identify an elephant by touching it part by part. Feeling the eyelashes leads to one conclusion about what the animal looks like, while feeling the trunk yields a different conclusion. And so it is with climate models. Upwards of 100 parameters can influence simulation predictions in climate models, and each has associated uncertainties, leading to very different results.

Uncertain climate model parameters include the humidity at which clouds form, the size of liquid droplets that make up clouds, the size at which droplets convert to rain, and many more. Covey's team narrowed 100 or so climate parameters to the 21 most important for initial UQ studies. With a 21-dimensional hypercube, more than 2 million corners exist, and traditional Monte Carlo calculation methodologies (the shotgun approach) examine only a miniscule fraction of the total volume. Johannesson and Tong, together with physicists Bryan Johnson and Scott Brandon and mathematician Carol Woodward, are working to develop tools that reduce dimensional requirements. They are, for example, determining which parameters are most sensitive to changes in other parameters. Mathematician Timo Bremer is working to develop a new topological method for expressing dimensionality.

A Predictive Pipeline

The collaboration's goal is a UQ computational "pipeline" that is self-adapting and self-guiding. It incorporates all data—assumptions, inputs, known errors, the relative importance of each variable on the output of the model, and approximations inherent in the physics and mathematics of the model itself—and, through a continuing series of iterations, "learns from itself." The UQ pipeline will adaptively sample. That is, it is designed to know where the most important responses and sensitivities are located in the vast field of 21 or more dimensions and select the most important sample points in that space.

According to computer scientist David Domyancic, the pipeline will save expensive computer time and ultimately will be an automated decision-making tool. Klein says, "The pipeline will advance the process of integrating theory, simulation, and experiment—a major leap forward in UQ technology."

Many of the same methodologies used successfully for stockpile stewardship are being applied to climate modeling as well as to target design for inertial confinement fusion experiments at the Laboratory's National Ignition Facility. As UQ expands into other fields under Livermore's direction, Klein hopes to establish a UQ institute at the Laboratory. "I see the work we are doing now as the first brick in the institute."

—Katie Walter

Key Words: climate modeling, predictive pipeline, uncertainty quantification (UQ).

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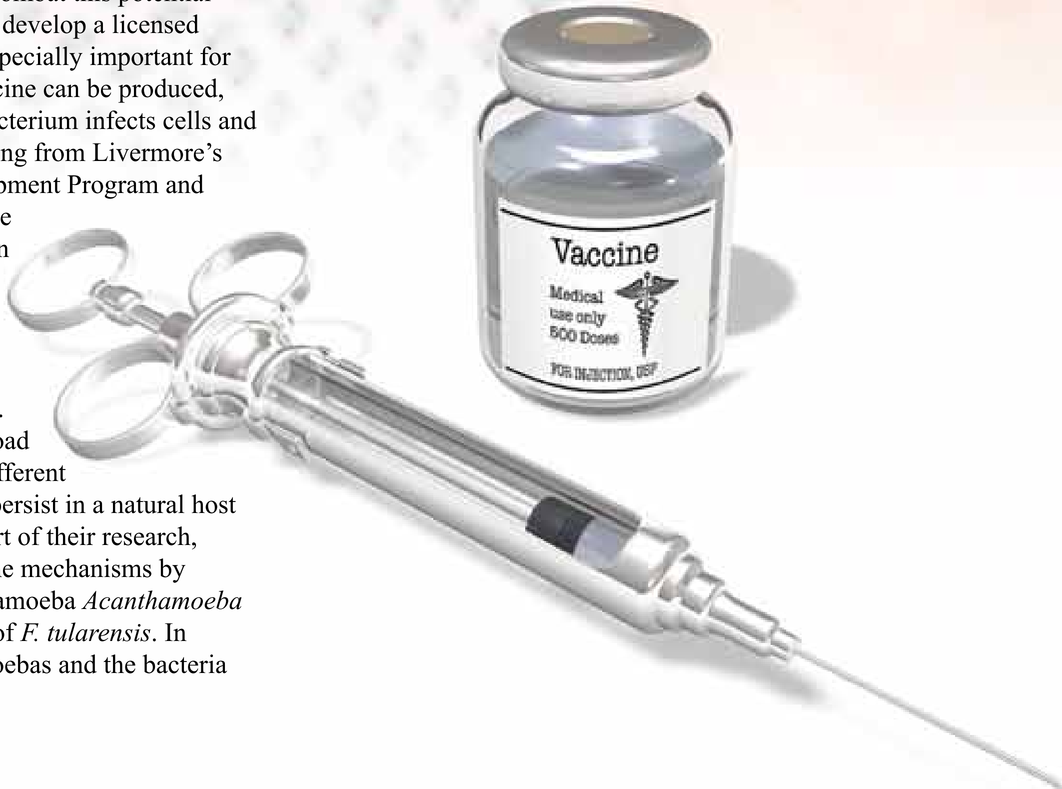
Insight into a Deadly Disease

COMPARED with plague and anthrax, tularemia is less well known to the general public, but recent outbreaks and its potential as a bioterrorism agent have brought the disease into the limelight. Sometimes called rabbit fever, tularemia primarily infects small- to medium-size mammals such as hares, prairie dogs, and rodents. However, the disease can be spread to humans through contact with infected animals, bites from ticks and deerflies, or inhalation of the airborne bacteria. Early symptoms of the disease are similar to the flu but can develop into serious, acute conditions of the glands, intestines, and respiratory system, including life-threatening pneumonia. To make matters worse, although antibiotics can be used to effectively treat the disease, the amount of time available for therapeutic intervention can be fairly short, typically three to five days if bacteria are inhaled.

Tularemia is caused by the bacterium *Francisella tularensis*. Four subspecies of *F. tularensis* are currently recognized, and several strains within these subspecies are highly virulent, with as few as ten organisms causing infection. Tularemia's virulence and ability to be aerosolized raise concerns that the bacterium could be used as a bioterrorism agent. To combat this potential threat, scientists have ramped up efforts to develop a licensed vaccine for the disease, which would be especially important for military personnel. However, before a vaccine can be produced, scientists must first understand how the bacterium infects cells and what causes it to be so virulent. With funding from Livermore's Laboratory Directed Research and Development Program and the National Institutes of Health, Livermore immunologist Amy Rasley, in collaboration with scientists at Livermore and several other research institutions across the U.S., has made substantial progress toward deciphering the complex cross talk that occurs between *F. tularensis* and host cells.



F. tularensis can infect an extremely broad range of hosts, including more than 200 different animals, but how the bacterium is able to persist in a natural host environment is not well understood. As part of their research, Rasley and colleagues set out to identify the mechanisms by which a potential bacterial reservoir—the amoeba *Acanthamoeba castellanii*—supports the different strains of *F. tularensis*. In doing so, they gained insight into how amoebas and the bacteria interact and the process by which the bacteria survive. The team also identified several novel *F. tularensis* proteins that may be key to the bacteria's survival in the environment as well as in human immune cells.

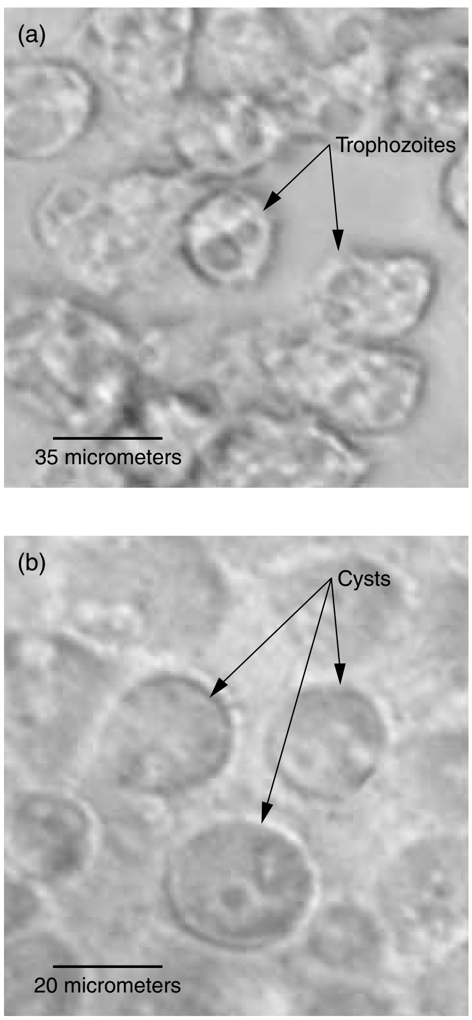
Survival of the "Cyst-est"

Reservoirs are organisms that can harbor bacteria without being killed by them, thus allowing the bacteria to exist in the environment. *A. castellanii* is a known reservoir for a number of pathogens and typically exists in an aqueous host environment. One of the ways an organism, such as the amoeba, can protect itself from adverse environmental conditions is through a process called encystment. When an amoeba (or other unicell organism) encounters unfavorable conditions, such as lack of nutrients or shifts in pH or temperature, it undergoes a morphological change. Trophozoites (protozoan) within the organism transform from mobile forms into immobile, compact cysts—a process that requires extensive protein degradation.

These cysts allow the amoebas to remain in a dormant state until more favorable conditions return. "Once encysted, amoebas are incredibly resistant to temperature and osmolarity shifts, chemical disinfectants, and antibiotics," says Rasley. The Livermore team hypothesizes that the ability of *F. tularensis* to induce amoebic encystment is an essential mechanism ensuring the bacterium's survival in the environment.

In previous studies, an attenuated strain of *F. tularensis* was shown to infect *A. castellanii*, but these studies excluded pathogenic strains of the bacterium. Rasley's team took this research one step further, infecting amoebas with subspecies of *F. tularensis* having varying degrees of virulence. The team observed that fully virulent strains induced rapid encystment within *A. castellanii*. "Typically the encystment process takes 12 to 72 hours," says Rasley. "We found that when we infected amoebas with virulent *F. tularensis*, encystment occurred within just 2 hours."

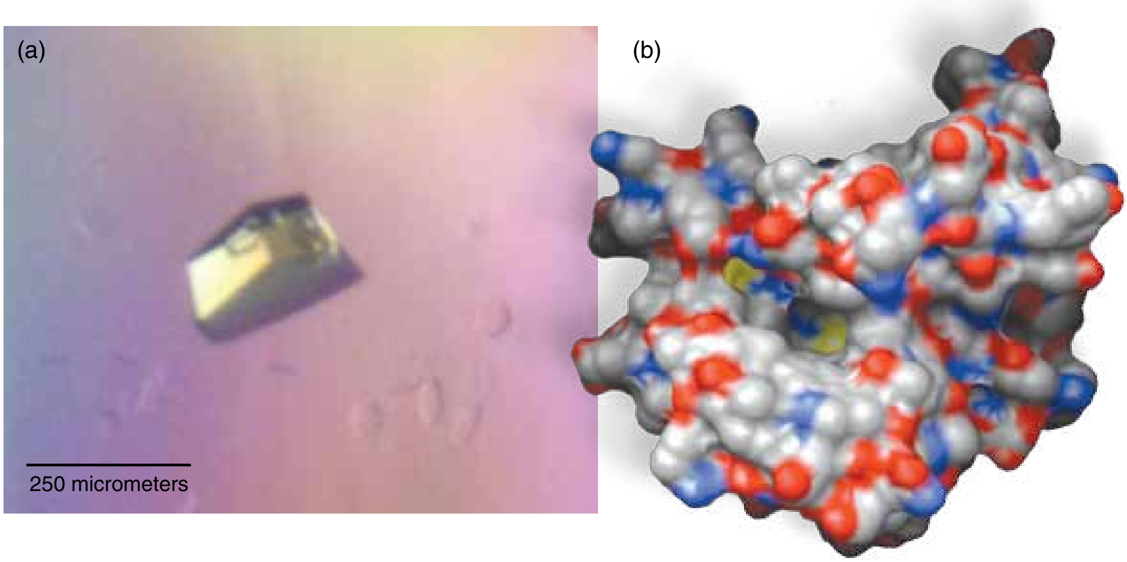
The team's next step was to determine the physical processes that allowed encystment to occur. Amoebas and bacteria were placed in a specialized transwell plate with a filter that separated the bacteria from the amoeba and prevented direct contact between them. Similar to the way a spaghetti strainer allows water to pass through but keeps the pasta contained, the filter permits anything soluble to traverse the boundary, but stops the bacteria. Interestingly, encystment occurred despite the amoeba's relative isolation from the bacteria, suggesting that cell-to-cell contact was not required and that likely secretions from the amoeba or the bacteria were traversing the filter and causing the encystment. To test this theory, the team added some of the spent culture medium from amoeba–*F. tularensis* cocultures to unexposed amoebas, yielding similar results.



(a) *Acanthamoeba castellanii* trophozoites move freely in culture under favorable conditions. (b) However, within two hours of infection with virulent strains of *Francisella tularensis*, amoebas become immobile and form cysts.

Identifying the Culprit

Each experiment provided another piece of the puzzle as Rasley and her team came closer to seeing the big picture of how *F. tularensis* manages to infect and survive within host cells. "After results showed that some agent within the liquid medium was causing the encystment, we wanted to know if the agent was proteinlike in nature," says Rasley. Spent media from amoeba–*F. tularensis* cocultures were then boiled or treated with an enzyme to break down protein structure. This process changed the properties of proteins within the organisms, rendering them inactive. "We then ran the same test as before, and no encystment occurred," says Rasley. "Therefore, we suspected that the agent must be a protein."



Novel *Francisella tularensis* proteins may provide insight into how the bacteria survive in host cells. (a) A Livermore team is characterizing a crystal of one of the proteins believed to be involved in amoeba encystment. (b) The crystal's x-ray diffraction pattern was used to solve the protein's structure. Yellow depicts the active site pocket.

Using high-performance liquid chromatography, the team separated the medium into four fractions based on size. "We identified the fractions that had activity and analyzed a sample of the peptide mixture with mass spectrometry to distinguish which proteins were present," says Rasley. In total, five amoeba proteins and seven novel *F. tularensis* proteins were identified. "Interestingly," says Rasley, "the seven *F. tularensis* proteins were present only in the amoeba– *F. tularensis* coculture and were secreted only in the presence of the amoeba."

The seven *F. tularensis* proteins are now undergoing further tests to characterize their structure and properties, and the team has already obtained a complete crystal structure for one of them. Through this research, the team has identified key genes encoding the proteins that may be responsible for the formation of amoebic cysts. When tested, genetically mutated bacteria missing these genes were unable to induce encystment and failed to survive in human immune cells.

Building the Foundation

Inside the human body, *F. tularensis* attacks macrophages, immune cells that function as a first line of defense against infection. Amoebas can be thought of as an early environmental macrophage. Thus, amoeba–*F. tularensis* interactions may give us some information about how virulence evolved. Altogether, Rasley and her group tested 13 strains of *F. tularensis*, five of which had high levels of encystment. "We did have some variability among the individual strains, which suggests more than one environmental reservoir may exist for *F. tularensis*," says Rasley.

Although it can take decades to create a licensed vaccine for commercialization, this research provides some fundamental data regarding how *F. tularensis* and host cells interact, which is the first step in the process. "Before a vaccine can be developed for clinical trials, we have to fully understand the pathology of the disease and determine at what stage to intervene," says Rasley. Research like this, although time-consuming, is definitely worth it, providing insight into the progression of a deadly disease and helping to safeguard the nation against potential bioterrorism threats.

—*Caryn Meissner*

Key Words: Acanthamoeba castellanii, amoeba, bioterrorism, encystment, Francisella tularensis, host cell, pathogen, tularemia, vaccine.

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Return to Rongelap

LIVERMORE scientists are at the forefront of an extensive 30-year effort to return the native population of Rongelap Atoll in the Marshall Islands to their home island. The population was displaced to a neighboring atoll following radioactive fallout from a U.S. nuclear test detonated in 1954 on Bikini Atoll, approximately 112 kilometers west of Rongelap. In 1957, the U.S. government resettled the islanders back on Rongelap. However, in 1985, they relocated to Mejetto Island on Kwajalein Atoll because of the community's concerns about lingering radioactive contamination and its potential health effects.

Radioecologist Terry Hamilton of Livermore's Physical and Life Sciences Directorate leads the restoration and resettlement effort through the Laboratory's Marshall Islands Dose Assessment and Radioecology Program. The program, which is under the Department of Energy's (DOE's) Office of Health, Safety, and Security, develops comprehensive assessments of radiological conditions on the island, recommends remediation activities for contaminated sites, and assesses the effectiveness of those efforts.

In recent years, as a part of this ongoing effort, Livermore scientist Bill Robison and Hamilton have calculated the expected radiation doses for people resettling on Bikini, Enjebi (Enewetak Atoll), and Rongelap islands. The results have shown that cesium-137, which has a half-life of 30 years, would account for 98 percent of the total radiation doses to the returning population, and specific steps have been identified to significantly reduce the dosage. Cesium-137 is one of the long-lasting radionuclides generated from nuclear testing.

"People could possibly resettle on Bikini based on the data we're getting from the remediation and resettlement effort at Rongelap," Hamilton says. Bikini and Enewetak atolls were ground zero for the U.S. nuclear tests. "If this remediation strategy is pursued, we estimate that the natural background dose combined with the nuclear-test-related dose on the islands of Bikini, Enjebi, and Rongelap would be less than the typical background dose in the United States or Europe."

Times Past

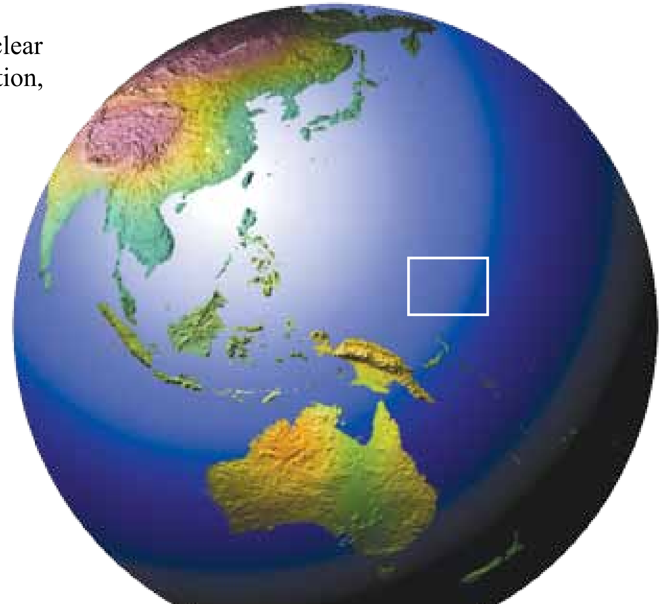
Immediately following World War II, the U.S. created a Joint Task Force to develop a nuclear weapons testing program. The task force examined several possible locations, including the Atlantic Ocean, the Caribbean, and the Central Pacific. The coral atolls in the northern Marshall Islands had many advantages—stable weather conditions, few inhabitants to relocate, and isolation with hundreds of kilometers of open ocean, where trade winds were likely to disperse radioactive fallout.

Between 1945 and 1958, 67 nuclear tests were conducted on Bikini and Enewetak atolls and adjacent regions within the

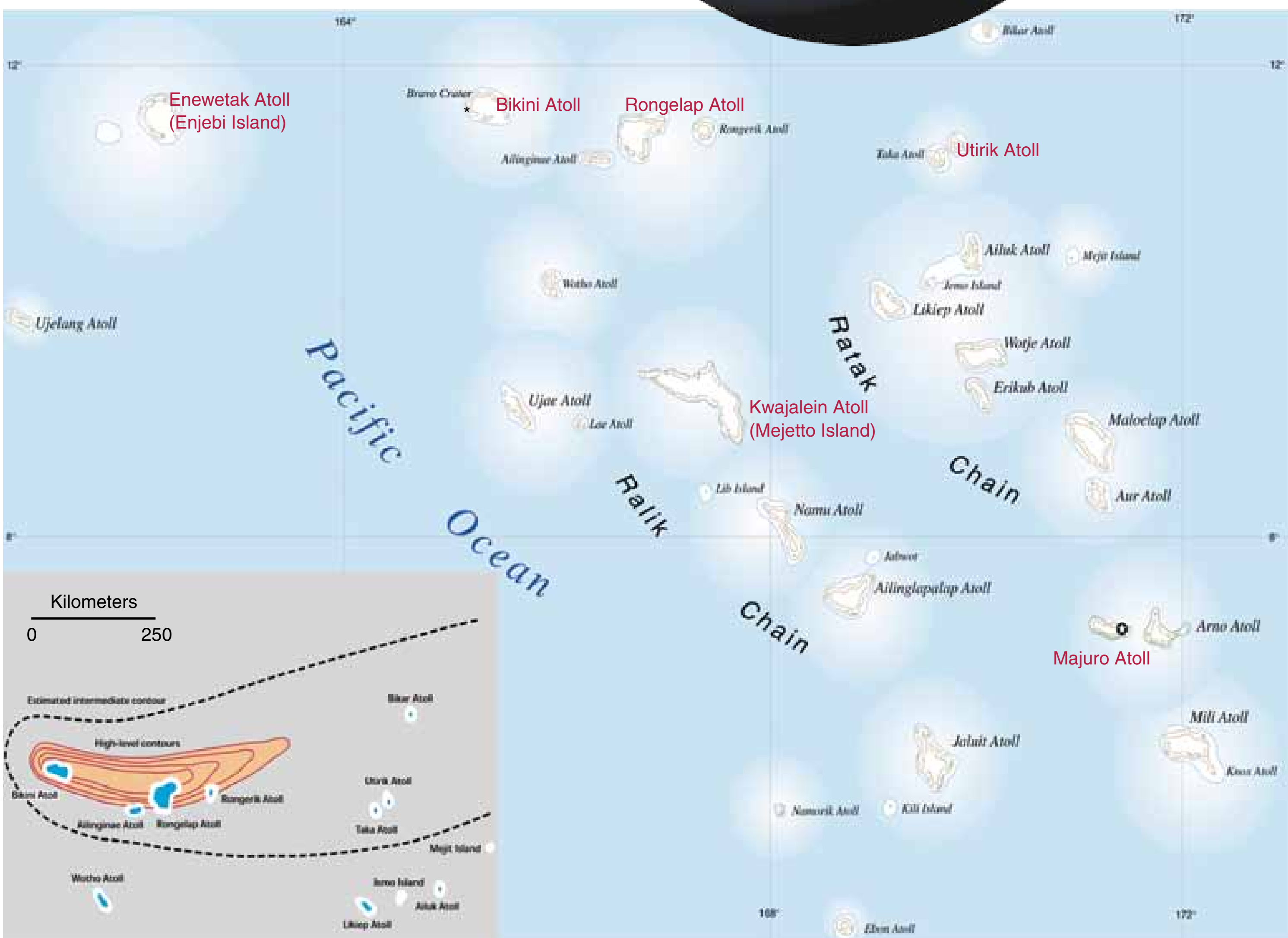
Republic of the Marshall Islands. The U.S. conducted 24 nuclear tests at Bikini Atoll with a total yield, or energy from detonation, of 76.8 megatons. The hydrogen bomb device detonated on March 1, 1954, at Bikini Atoll—dubbed Castle Bravo—had an estimated yield of 15 megatons. Castle Bravo was significantly more powerful than scientists had predicted, and it was the primary source of radioactive contamination of Bikini, Rongelap, and Utirik atolls. The resulting debris cloud rose over 15,000 meters high, which led to widespread fallout contamination over inhabited islands.

Restoring Health to the Islands

The first in a series of long-term remediation experiments began on Bikini Island during the late 1980s to evaluate potential techniques to reduce the uptake of cesium-137 into plants. Researchers found that adding



Following detonation of the 1954 Castle Bravo nuclear test on Bikini Atoll, high-altitude winds carried the debris cloud toward Rongelap Atoll. The radioactive fallout pattern is shown in the lower left inset.



potassium fertilizer to agricultural fields reduces the cesium-137 concentration in edible fruits by about 95 percent. They also found that potassium increases the growth rate and productivity of some food crops with no adverse environmental impacts.

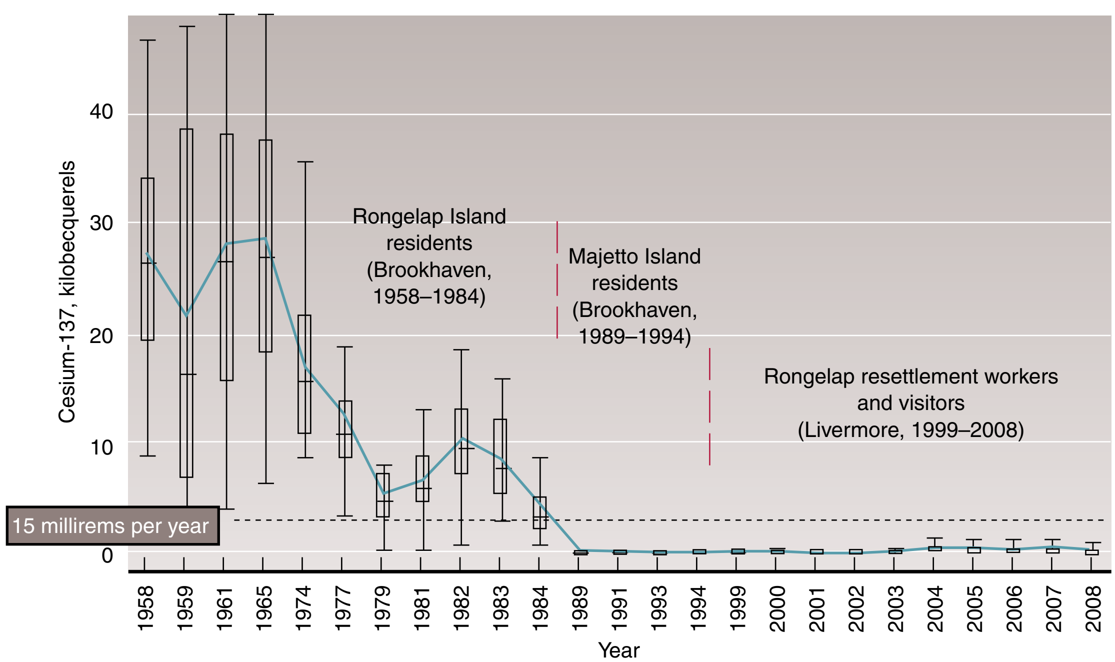
On Bikini Island, a large-plate lysimeter collects water from soils to determine the concentration of radionuclide contaminants present in that water. Lysimeter studies are providing data on the rainfall removal rate of cesium-137 from surface soils.

The team's research showed that rain transports a portion of the cesium-137 below ground, where it eventually mixes with ocean water. The rate of this loss process is much faster than the loss by radioactive decay.

According to Hamilton, a combination of treating crops with potassium and removing the top 25 centimeters of soil around houses and community buildings prior to new construction is a viable remediation strategy for resettlement. The replacement of contaminated surface soil around the village and housing areas with crushed-coral fill helps minimize external exposure rates in areas where people spend most of their time. Successful resettlement efforts on Rongelap could lead to similar efforts for the northern Marshall Islands of Bikini Atoll and affected islands at Enewetak Atoll.

In 1996, a resettlement agreement between the U.S. and the Rongelap Atoll Local Government was approved. Under this agreement, DOE is tasked with formulating a plan to monitor the effectiveness of cleanup activities and develop expertise in radiological protection monitoring among local residents. To this end, DOE is encouraging the local atoll communities to assume shared responsibilities for implementing radiation surveillance monitoring programs for resettled and resettling populations in the northern Marshall Islands. Together, DOE and local atoll governments have developed individual radiological surveillance programs in whole-body counting and plutonium urinalysis to track and assess radiological doses from residual fallout contamination.

This graph shows the history of internally deposited cesium-137 in adult males from Rongelap Island from 1958 to 1994 and for resettlement workers and visitors on the island from 1999 to 2008 as measured by Brookhaven and Lawrence Livermore national laboratories. In 1985, the people of Rongelap re-evacuated to Mejetto Island on Kwajalein Atoll.



Whole-Body Counting

Permanent whole-body counting facilities have been established on Enewetak, Rongelap, and Majuro islands. They are operated and maintained by Marshallese technicians with ongoing technical support from Livermore scientists. "These facilities comprise the largest per-capita whole-body counting program in the world for members of the public," says Hamilton. "To date, we've counted about 5 percent of the Marshallese population and more than 3,000 people are in our database."

The whole-body counting systems contain large-volume sodium iodide radiation detectors that measure gamma rays emitted from radionuclides deposited in the body. Program participants sit in an oversized chair for about 15 minutes, while the detector system noninvasively scans most of their body and all of their internal organs for high-energy gamma-emitting radionuclides, such as cesium-137 and cobalt-60. Specially designed computer software converts the measurements into an annual effective dose, and participants receive the report immediately following the test.

Residents in the northern Marshall Islands are primarily exposed to residual fallout contamination by ingesting cesium-137 contained in locally grown foods, such as coconut. Whole-body counting provides a direct measure of cesium-137 in the body. Residents who receive a whole-body count showing the presence of cesium-137 can make informed decisions about their eating habits or lifestyle based on what is considered a "safe" or acceptable health risk. The annual safe dose accepted by the Marshall Islands Nuclear Claims Tribunal is 0.15 millisieverts (15 millirems) per year. This number is based on guidance from the U.S. Environmental Protection Agency. For comparison, the dose from a chest x ray is 0.10 millisieverts (10 millirems) and from a panoramic dental x ray is 0.01 millisieverts (1 millirem).

The whole-body counting program on Rongelap provides insight into the range of exposures likely to be seen in a hypothetical resident population. "What is very clear is that levels of internally deposited cesium-137 measured in resettlement workers from 1999 to 2008 are more similar to levels observed on Mejetto from 1989 to 1993 than for the resident male population living on Rongelap during the 1980s," says Hamilton.

Monitoring Plutonium with CAMS

Radioactive by-products of nuclear explosions, including plutonium, end up being deposited on the ground and residing in the soil. The primary way humans are exposed to plutonium is through inhalation of contaminated dust particles. Inhaled or ingested plutonium can eventually end up in various organs, including the lungs, liver, and bone, resulting in continuous exposure to alpha-particle radiation. Plutonium is a concern to the Marshallese people because of its long half-life (24,000 years) and persistence both in the environment and in the human body.

Plutonium urinalysis monitoring is a highly sensitive in vitro measurement technique used to determine the amount of plutonium in human urine, from which the total amount of plutonium in the body can be extrapolated. Livermore scientists developed a plutonium bioassay monitoring program for resettlement workers on Rongelap. The bioassay program included assessments of 115 resettlement workers. Many of the workers on Rongelap who provided bioassay samples were exposed to potentially high resuspension conditions associated with soil remediation. People simply living on the island would be expected to have less exposure.

Locally trained technicians collected urine samples from resettlement workers, which were sent to Livermore's Center for Accelerator Mass Spectrometry (CAMS) for analysis. At CAMS, scientists analyzed the urine samples by counting the number of plutonium atoms contained in each sample. "Under the Marshall Islands Radiological Surveillance Program, we have developed a new state-of-the-art technology for measuring the amount of plutonium in urine based on accelerator mass spectrometry," says Hamilton, who leads the effort at CAMS. "The fact that none of the workers participating in the bioassay monitoring program have elevated levels of plutonium in their urine suggests that plutonium exposure is unlikely to be an issue of concern associated with resettlement of Rongelap Island."

A Paradise Restored

"The potential social and cultural benefits of resettlement coupled with the availability of clean water and spacious housing on Rongelap, as well as access to a rich, thriving atoll ecosystem, will likely improve the general wellness of the community," says Hamilton. Information from the individual and environmental radiological surveillance programs will help Hamilton and his team provide high-quality measurement data and reliable dose assessments. It will also help build a strong technical and scientific foundation to sustain resettlement of the affected atolls.

"There is a strong interplay between science and people," says Hamilton. "Communication is the most difficult aspect of this effort, but it is also the most rewarding. I hope that we see full resettlement of Rongelap and other affected atolls in my lifetime."

—Kristen Light

Key Words: Castle Bravo nuclear test, Center for Accelerator Mass Spectrometry (CAMS), cesium-137, Marshall Islands, plutonium urinalysis, potassium fertilizer, radiation dose, radioactive fallout, Rongelap Atoll Local Government, whole-body counting.

For further information contact Terry Hamilton (925) 422-6621 (hamilton18@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

Indirect Detection of Radiation Sources through Direct Detection of Radiolysis Products

Joseph C. Farmer, Larry E. Fischer, Thomas E. Felter
U.S. Patent 7,700,041, B2
April 20, 2010
This system indirectly detects a radiation source by directly detecting radiolytic products. The radiation source emits radiation, which produces radiolytic products. A fluid is positioned to receive the radiation from the radiation source. When the fluid is irradiated, radiolytic products are produced. By directly detecting the radiolytic products, the radiation source is detected.

Explosively Driven Low-Density Foams and Powders

James A. Viecelli, Lowell L. Wood, Muriel Y. Ishikawa, John H. Nuckolls, Phillip F. Pagoria
U.S. Patent 7,707,819 B2
May 4, 2010
Hollow RX-08-HD cylindrical charges were loaded with boron and polytetrafluoroethylene (PTFE) in the form of low-bulk-density powders or powders dispersed in a rigid foam matrix. Each charge was initiated by a Comp B booster at one end, producing a detonation wave propagating down the length of the cylinder. This process crushed the foam or bulk powder and collapsed the void spaces. The PdV work done in crushing the material heated it to high temperatures, expelling it in a high-velocity fluid jet. In the case of boron particles supported in foam, framing camera photos, temperature measurements, and aluminum witness plates suggest that the boron was completely vaporized by the crush wave and that the boron vapor turbulently mixed with and burned in the surrounding air. In the case of PTFE powder, x-ray photoelectron spectroscopy of residues recovered from fragments of a granite target slab indicate that heating was sufficient to dissociate the PTFE to carbon vapor and molecular fluorine. Those products reacted with the quartz and aluminum silicates in the granite to form aluminum oxide and mineral fluoride compounds.

Awards

Livermore physicist **Omar Hurricane** of the Weapons and Complex Integration Principal Directorate received the **Department of Energy's** (DOE's) prestigious **E. O. Lawrence Award** in April 2010. The award honors midcareer scientists and engineers for exceptional contributions in research and development supporting DOE's National Nuclear Security Administration and its mission to advance the national, economic, and energy security of the U.S.

Hurricane, a program leader whose work involves thermonuclear secondary design, was honored for his efforts in national security and nonproliferation at the Laboratory. He has led a multidisciplinary team that worked on a difficult technical issue involving two vastly different areas of physics. Much of Hurricane's research is classified.

The award came with a citation signed by Secretary of Energy Steven Chu, a gold medal bearing the likeness of Ernest Orlando Lawrence (cofounder of the Laboratory), and $50,000.

The Laboratory's **Lisa Poyneer** was inducted into the **Alameda County Women's Hall of Fame** in the science category on April 17, 2010. She joins seven other current or past Livermore employees to be selected for this honor. Poyneer was recognized for her work in adaptive optics and the development of the Gemini Planet Imager (GPI), which will be the world's most powerful astronomical adaptive optics instrument.

Taking images of planets around other stars is an incredibly challenging task. Poyneer's groundbreaking research was essential in winning the $24 million contract for the Livermore-led international team that is building the instrument. GPI's adaptive optics system, using algorithms developed by Poyneer, will provide up to 100 times better performance than current systems. Poyneer is an internationally recognized expert in her field, giving invited talks at conferences and publishing widely. Her work will directly enable a new era in the imaging of extrasolar planets.

A **team of computer security specialists** from Lawrence Livermore, Pantex Plant, and the Defense Information Systems Agency (DISA) won **first place** in a **national laboratory cyber competition** held during the February 2010 **Tracer FIRE 2 Workshop** in Los Alamos, New Mexico. Now in its second year, Tracer FIRE is a hands-on workshop designed to educate, test, and encourage collaboration among cyber-incident response teams from national laboratories and government agencies.

During the competition portion of the workshop, 11 cross-laboratory teams competed for two days in challenges and puzzles that tested their skills in malware reverse engineering, network forensics, host forensics, cryptography, social engineering, and hidden-data discovery. The winning team was co-led by **Adam Sealey** and **Erwin Lopez** and included **Steve McManus**, **Matthew Myrick**, **John Townsend**, and **Willem Verschuur** from Lawrence Livermore as well as Patrick Avery, Susan Carter, and Jeremy Scott from Pantex and David Gainey from DISA.

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

The species may be a good candidate for being the transition between the southern African ape-man *Australopithecus africanus* and either *Homo habilis* or even a direct ancestor of *Homo erectus*. The two hominid specimens lived in the area between 2.3 and 1.5 million years ago. The *Au. sebida* fossils are encased in water-laid sediments that were deposited along the lower parts of what is now a deeply eroded cave system. They were buried together in a single debris flow that petrified soon after deposition in a cave inaccessible to scavengers.

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Biofuel Combustion Drives Alternative Fuel Search

Lawrence Livermore scientist Charles Westbrook and Sandia National Laboratories researcher Nils Hansen for the first time examined the characteristic aspects of the chemical pathways in the combustion of potential biofuels. In collaboration with an international research team representing Germany, China, and the U.S., Westbrook, Hansen, and former Sandia postdoctoral student Tina Kasper used a unique combination of laser spectroscopy, mass spectrometry, and flame chemistry modeling to explore the decomposition and oxidation mechanisms of certain biofuels and the formation of harmful or toxic emissions.

Understanding the key elements of biofuel combustion is an important step toward insightful selection of next-generation alternative fuels. Biofuels such as bioethanol, biobutanol, and biodiesel are of increasing interest as alternatives to petroleum-based transportation fuels. According to Hansen and Westbrook, however, little research has been done on the vastly diverse and complex chemical reaction networks of biofuel combustion. The team's paper appeared on the cover of the May 10, 2010, edition of *Angewandte Chemie*. Work leading to the paper was funded in part by the Department of Energy's Office of Science.

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Research Puts Teeth into Forensic Science

In a large natural disaster, such as the Haitian earthquake earlier this year, or in an unsolved homicide case, knowing the birth date of an individual can guide forensic investigators to the correct identity among a large number of possible victims. Livermore researcher Bruce Buchholz and colleagues at the Karolinska Institute in Sweden are looking at victims' teeth to determine how old they were at the time of death.

Using the Laboratory's Center for Accelerator Mass Spectrometry (CAMS), Buchholz determined that the radioactive carbon-14 (^{14}C) produced by aboveground nuclear testing in the 1950s and 1960s remains in dental enamel, the hardest substance in the body. Carbon-14 dating works because every carbon-containing molecule on Earth mirrors the level of ^{14}C in the atmosphere at the time that molecule was created: in glacial ice, tree rings, mammoth bones, and DNA. Although nuclear weapons testing was conducted at only a few locations, excess levels of ^{14}C in the atmosphere rapidly dispersed and equalized around the globe. Since 1963, as a result of a worldwide atmospheric test ban treaty, ^{14}C levels in the atmosphere have been decreasing exponentially with a mean half-life of 16 years.

The CAMS radiocarbon analysis showed that dating the teeth with the ^{14}C method would estimate the birth date to within one year. In the study, 44 teeth from 41 individuals were analyzed using racemization analysis of tooth crown dentin (a chemical process in which one amino acid is converted to its counterpart) or radiocarbon analysis of enamel. In addition, 10 of these samples were split and subjected to both radiocarbon and racemization analysis. Combined analysis showed that the two methods correlated well. This research appeared in the May 2010 issue of *Molecular & Cellular Proteomics* and was highlighted in the May 2010 forensics dedication issue of *Surface and Interface Analysis*.

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Abstract

Enhancing Confidence in the Nation's Nuclear Stockpile

Nuclear weapons are extremely complex devices, with thousands of components that must work together seamlessly to produce a nuclear detonation. Components are made of various materials such as high explosives, steel, plutonium, uranium, and plastics. Many weapons remain in the stockpile long after their design lifetimes, so experts must work to extend the lifespan of these units and understand how their constituent materials and components age. Scientists conduct a comprehensive program of weapon surveillance, laboratory experiments, and maintenance and refurbishment of components. Data from all activities are used to refine computer models, some of which serve as computational surrogates for underground testing. This combined effort, which requires chemists, materials scientists, engineers, physicists, and computer scientists, is called stockpile stewardship. An important part of stockpile stewardship is the National Nuclear Security Administration's Enhanced Surveillance Campaign, aimed at producing informed estimates about how stockpiled nuclear weapon materials and systems will likely change over the next one to two decades.

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Supporting International Treaties

Livermore scientists provide the technical expertise for treaties that ban or limit weapons of mass destruction.

Also in September

• With access to powerful supercomputers, researchers can solve more complex problems at higher resolution than has ever been possible before.

• New Livermore-developed techniques can rapidly identify biological agents in the event of an attack or contamination incident.

• Smart antineutrino detectors improve monitoring capabilities at nuclear reactors and enhance international nonproliferation efforts.

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