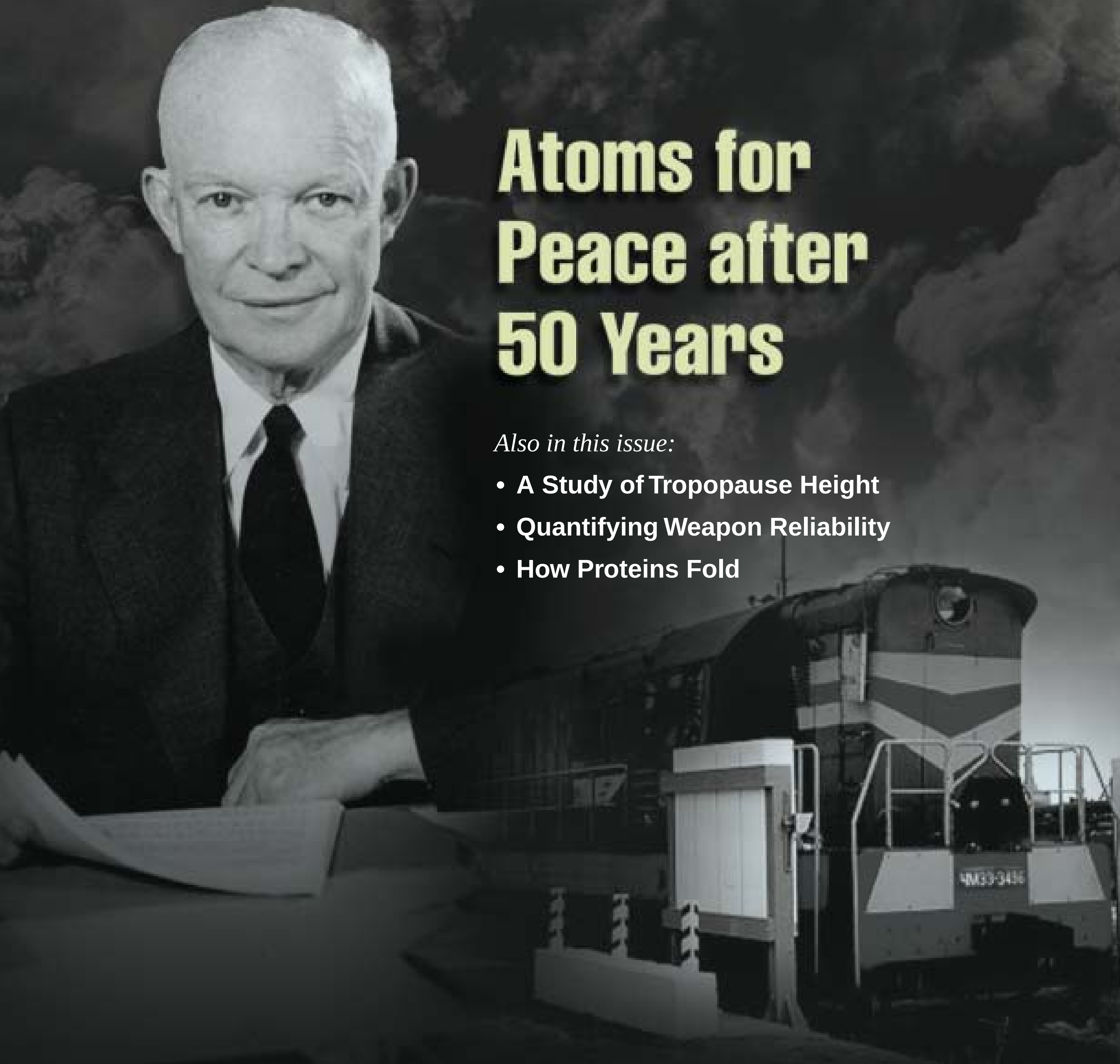
March 2004

Science & Technology
REVIEW

National Nuclear
Security Administration's
Lawrence Livermore
National Laboratory



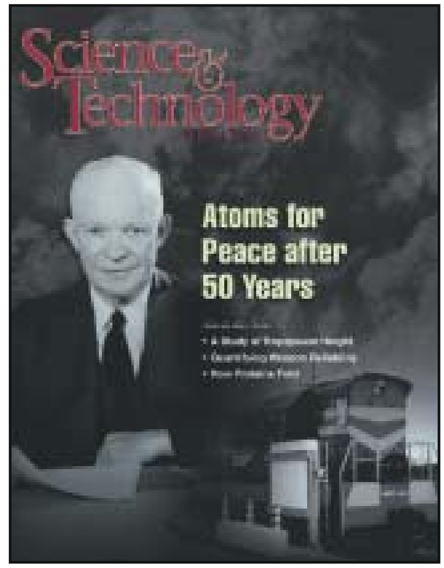
Atoms for Peace after 50 Years

Also in this issue:

- **A Study of Tropopause Height**
- **Quantifying Weapon Reliability**
- **How Proteins Fold**

About the Cover

In 1953, President Dwight D. Eisenhower (shown on the cover) presented his historic Atoms for Peace speech to the United Nations General Assembly, calling on world leaders to pursue civilian applications of nuclear technologies. Fifty years later, Livermore's Center for Global Security Research organized its 2003 Futures Roundtable around Eisenhower's initiative. At these workshops, international experts were asked to examine the advances made in nuclear technologies, especially those developed for civilian applications, and to consider what obstacles might hinder future progress. The article beginning on p. 4 discusses many of the dual-use nuclear technologies developed at Livermore, such as the radiation detector also shown on the cover.



Cover design: Amy Henke

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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Lawrence
Livermore
National
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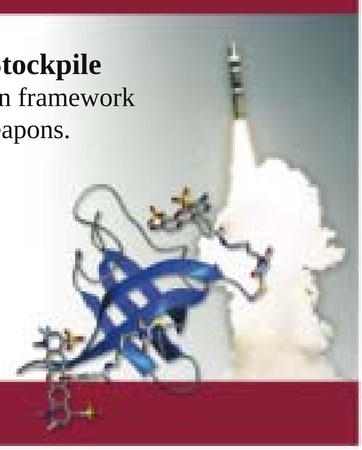

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New tools counter biological and chemical terrorism

In the November 21, 2003, issue of *Science*, three Livermore researchers discussed the recent progress in technology development to counter biological and chemical terrorism. The scientists noted that although important challenges remain, new detection systems show increased sensitivity, greater automation, and fewer false alarms.

In their paper, Pat Fitch and Dennis Imbro, who work in Livermore's Chemical and Biological National Security Program, and Ellen Raber, who leads the Environmental Protection Department, say that technologies for countering bioterrorist agents are approaching the sophistication of technologies for fighting chemical warfare agents. Nevertheless, improvements are still needed for sensors to meet the high level of sensitivity needed to protect civilians and to reduce the high rates of false alarms.

The researchers also describe a decision-making framework of four phases to guide response activities following a terrorist attack: notification, first responder, characterization, and restoration (or decontamination and remediation). During the initial notification phase, an operations center identifies an event using data from sensors and intelligence analysis as well as information on casualties. The first-responder phase is likely to include such actions as isolating or stabilizing hazardous materials or taking care of casualties. The characterization phase focuses on determining key site parameters, including time since release, extent of contamination, and potential risks to human health and the environment. The final restoration phase involves selecting site-specific decontaminating reagents, if required, and sampling to verify that all long-term environmental issues have been addressed and the solutions meet regulatory standards.

The scientists cite several reasons for the substantial improvement in biological detection. For example, polymerase chain reaction can be used to amplify DNA for rapid analysis, and the development of very specific DNA signatures for pathogens provides more accurate identification. Another factor for success is that many tests and controls can be conducted simultaneously. The researchers caution that despite these advances, technical and logistical challenges still exist to effectively prevent or combat chemical and biological terrorism.

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Another view of black hole phenomena

When most people think of black holes, they think of an area of space where matter can disappear. But that view is inconsistent with quantum mechanics.

In 1991, Laboratory physicist George Chapline suggested that this inconsistency could be avoided if the vacuum state of ordinary space–time is assumed to be a kind of superfluid. The formation of black holes would correspond to a "squeezing" of the vacuum—a quantum process roughly analogous to the compression of an ordinary fluid.

More recently, Chapline and colleagues at Stanford University have extended this idea to account for the event horizon of a black hole. They proposed that near the event horizon surface of a black hole, ordinary space undergoes a continuous phase transition to a phase with a much larger vacuum energy than the cosmological vacuum energy inferred from observations of distant supernovae. The physicists have predicted that near the surface of a black hole, matter behaves in a markedly different way from what is predicted by classical general relativity.

Black holes are generally believed to be remnants of stars that have collapsed into themselves. This gravity can pull in and obliterate objects that approach the surface. Chapline's group believes that black holes are actually extended bodies made up of "dark energy." In this view, matter doesn't disappear when it falls inside the event horizon surface of a black hole, but it can be transformed when it crosses the surface.

Chapline notes that the behavior of sound waves crossing a critical surface in a vertical column of a superfluid model provides the necessary insight into what happens to relativistic particles when they approach an event horizon. "The energy of the relativistic particles will become a quadratic function of momentum as they approach the surface," he says. "Above a certain energy, the particles will become unstable as they cross the surface."

As a result of this instability, a star falling onto the surface of a large black hole or a massive star undergoing gravitational collapse will emit pulses of radiation with characteristics that are similar to those of some cosmic gamma-ray bursts. An article about this work appeared in the July 2003 issue of *Scientific American.*

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Search for planets yields shock-wave breakthrough

A small, inexpensive interferometer developed to help astrophysicists search for planets is also being used to boost the time resolution and stability of streak cameras that record high-speed phenomena, such as those that occur in shock-wave physics experiments. The externally dispersed interferometer (EDI) was first proposed in 1998 in a project led by Livermore physicist David Erskine. The system combines the white-light velocity interferometry techniques used on the Laboratory's two-stage gas guns with an external grating spectrograph for astronomical imaging.

(Continued on p. 28.)

Rethinking Atoms for Peace and the Future of Nuclear Technology

THE Center for Global Security Research (CGSR) was established in 1996 to bring together diverse expert communities—Laboratory specialists, outside experts, government and military leaders, the business community, and other interested citizens—to help better understand the interaction of policy and technology. The hallmark of CGSR activities is the annual Futures Roundtable. The 2002 Roundtable, which coincided with Livermore's 50th anniversary, examined the horizons of science. Looking both backward and forward 50 years, the 2002 series brought together many of the Laboratory's founders with the newest generation of young scientists and engineers.

To build on the enthusiasm generated in 2002, we organized the 2003 Futures Roundtable around President Eisenhower's Atoms for Peace speech, which he presented to the United Nations General Assembly in 1953. The article beginning on p. 4 discusses the history of this initiative, advances made at Livermore in nuclear technologies over the past 50 years, and the road ahead.

Just four months after the Soviet Union detonated its first H-bomb, President Eisenhower argued in his Atoms for Peace speech that mankind ". . . must be armed with the significant facts of today's existence." A thermonuclear age had emerged, and nuclear technology would spread widely. Deterrence would not be sufficient. A step-by-step approach would be needed, including "a relationship with the Soviet Union which will eventually bring about a free intermingling of the peoples of the east and of the west—the one sure, human way of developing the understanding required for confident and peaceful relations."

Eisenhower proposed that an "international atomic energy agency" be created to accept surplus fissile material from the weapons programs of the nuclear weapons states and to "devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind. Experts would be mobilized to apply atomic energy to the needs of agriculture, medicine and other peaceful activities. A special purpose would be to provide abundant electrical energy in the power-starved areas of the world."

Eisenhower's speech presented a comprehensive vision for both military and civilian nuclear technology, outlining the nuclear dangers and opportunities. In many ways, the young multidisciplinary Laboratory founded by E. O. Lawrence and Edward Teller received a boost in its infancy because of the expansive missions inherent in pursuing atoms for peace. Synergism between weapon applications and spin-off and spin-back technologies were the natural products of this more integrated approach to nuclear weapons research. For the next 50 years, Lawrence Livermore made contributions in every area highlighted by President Eisenhower.

Today, the Cold War is over, and Laboratory scientists were among those who led the way toward "a free intermingling of the peoples of the east and of the west." Yet many of today's nuclear challenges parallel those that concerned Eisenhower. The knowledge of nuclear weapons continues to spread, and the benefits from peaceful application of nuclear technology fall well short of their potential, in part because of concerns about security and safety. Thus, the 50th anniversary of Eisenhower's speech seemed an appropriate time to examine anew the future of nuclear technology.

For the 2003 Roundtable, CGSR formed working groups of international experts to examine international security, civilian applications, and crosscutting issues such as fissile material, governance, risk assessment and public confidence, and communication. Working group leaders included former Deputy Secretary of Energy Charles Curtis; former Undersecretary of State William Schneider; John Taylor, a former vice president at the Electric Power Research Institute; and former Laboratory Director Michael May. Meetings were held at Livermore and in Washington, DC, Japan, and France.

The 2003 Futures Roundtable report (available at cgsr.llnl.gov) documents agreement and dissent, but consensus emerged on five points. First, security concerns will continue to play a central role in the debate over nuclear futures. In particular, the fundamentals of international security must be strengthened to address regional security and other motivations driving proliferation. Second, the existing nonproliferation regime must be enhanced, particularly enforcement. Third, tighter control of nuclear material is required, followed by minimization of surplus material. Fourth, a better understanding of technological opportunities is needed, and improved risk–benefit analysis must reflect the concerns of the public. Even if all these steps are taken, however, the participants concluded that, fifth, an appropriate nuclear enterprise for our age requires U.S. leadership and a clear vision, something on the scale of the 1953 Eisenhower speech.

Toward that end, the 2003 CGSR Futures Roundtable helped us to be "armed with the significant facts of today's existence."

■ Ronald F. Lehman II is director of the Center for Global Security Research.

Rich Legacy from Atoms for Peace

Livermore researchers have applied their nuclear weapons expertise to develop technologies for civilian uses.

On December 8, 1953, in an address to the United Nations General Assembly, President Dwight D. Eisenhower called upon all world leaders to move toward peaceful rather than destructive uses of nuclear technology. He said that nuclear technology "must be put into the hands of those who will know how to strip its military casing and adapt it to the arts of peace." This historic address, afterward referred to as the Atoms for Peace speech, sparked a significant research and development effort to apply nuclear technology for civilian use.

In 2003, Livermore's Center for Global Security Research (CGSR) commemorated the 50th anniversary of Eisenhower's speech by conducting a series of workshops to discuss the progress made toward the goals he outlined. (See the box on p. 8.) CGSR deputy director Eileen Vergino notes that the influence of Eisenhower's initiative can be seen in many areas. "Technologies developed in nuclear weapons programs have been applied to medical diagnostics and treatments, detectors, research tools, and power generation. Research initiatives following the spirit of Atoms for Peace also brought us the technologies needed to build confidence in the arms-control treaties that furthered détente with the Soviet Union."

At the time of Eisenhower's speech, the world was experiencing dynamic and precarious changes. China had fallen to communism; Stalin, who had consolidated the Soviet empire in Eastern Europe, had died; and the U.S. was fighting the Korean War. In 1949, the Soviet Union had tested its first fission weapon and then in August 1953, its first thermonuclear device.

Lawrence Livermore had been founded only one year earlier as the nation's second nuclear weapons laboratory. The Laboratory's primary mission was to contribute to U.S. efforts to deter Soviet aggression by more rapidly advancing nuclear weapons science and technology. The nation's strategic goal was to develop a nuclear arsenal capable of deterring any nuclear attack—which to many people during that time seemed imminent. Livermore contributed to this mission by developing the submarine-launched ballistic missile warhead, which removed a first-strike capability as a strategic military option. For the remainder of the Cold War, the U.S. and its allies relied on the nuclear weapons developed at Lawrence Livermore and Los Alamos national laboratories. And deterrence worked—no nuclear weapons were used during the Cold War.

In addition to this success, Livermore researchers began to find civilian uses for the weapons technologies they developed. Many of these products and processes—unimagined in 1953—continue to benefit society today.

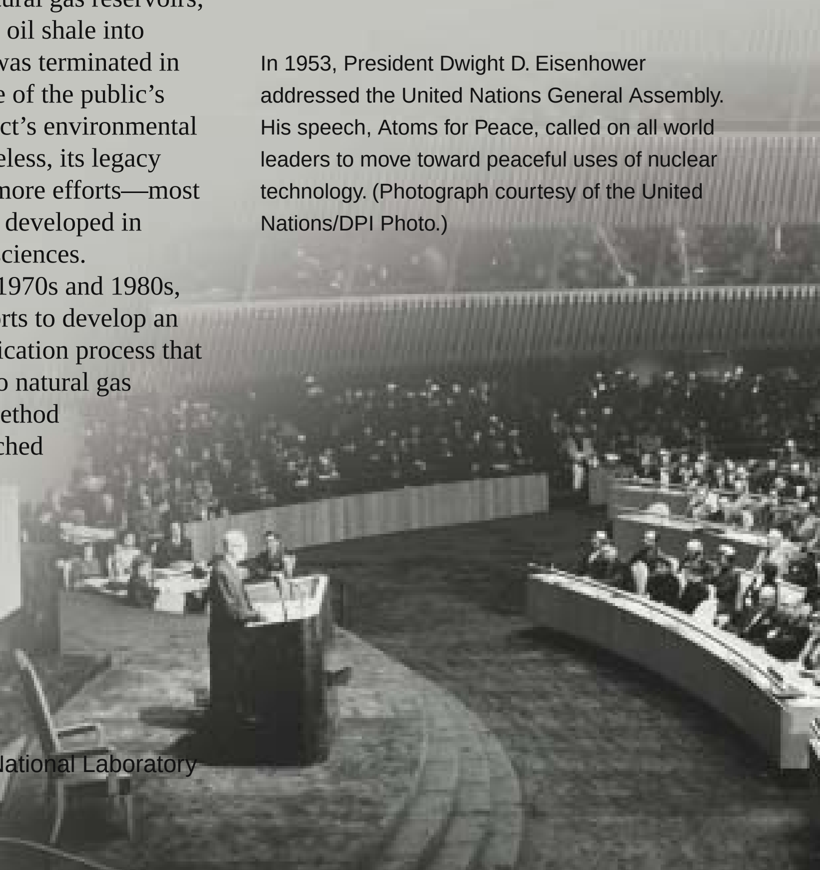
Project Plowshare and Beyond

One of the nation's earliest and most ambitious efforts to develop civilian applications of nuclear technology was Project Plowshare, which was established by the U.S. Atomic Energy Commission and Congress in 1957. Plowshare research included studies to determine whether nuclear explosives could be safely and expediently used to make harbors, canals, and dams; stimulate natural gas reservoirs; or process underground oil shale into oil. Project Plowshare was terminated in 1977, primarily because of the public's concern about the project's environmental consequences. Nevertheless, its legacy remains in many Livermore efforts—most notably in the expertise developed in atmospheric and earth sciences.

For example, in the 1970s and 1980s, Livermore pursued efforts to develop an underground coal-gasification process that converted coal beds into natural gas without mining. This method had two benefits: it reached coal that, for economic reasons, could not be accessed with surface mining techniques; and it produced a combustible gas that was easy to clean. In another Plowshare offshoot, Laboratory scientists investigated the use of nuclear explosives—and later high explosives—to fracture oil shale and liberate the oil it contained. From that research, they developed sophisticated surface-retorting techniques for converting the kerogen in shale into oil as well as the computer models to predict the natural production of oil from kerogen, which have been adopted by major oil companies worldwide.

Through these Plowshare projects, the Laboratory began to build its technology base in geosciences. As a result, Livermore has made significant contributions to ongoing studies of a proposed high-level nuclear waste repository at Yucca Mountain, Nevada. For more than 25 years, Laboratory scientists and engineers have combined their expertise in nuclear materials, geologic science, and computer modeling to help develop safe and secure methods for storing the radioactive wastes produced by nuclear power plants.

The Plowshare projects also expanded the Laboratory's efforts to understand nuclear fallout. Building on this expertise,

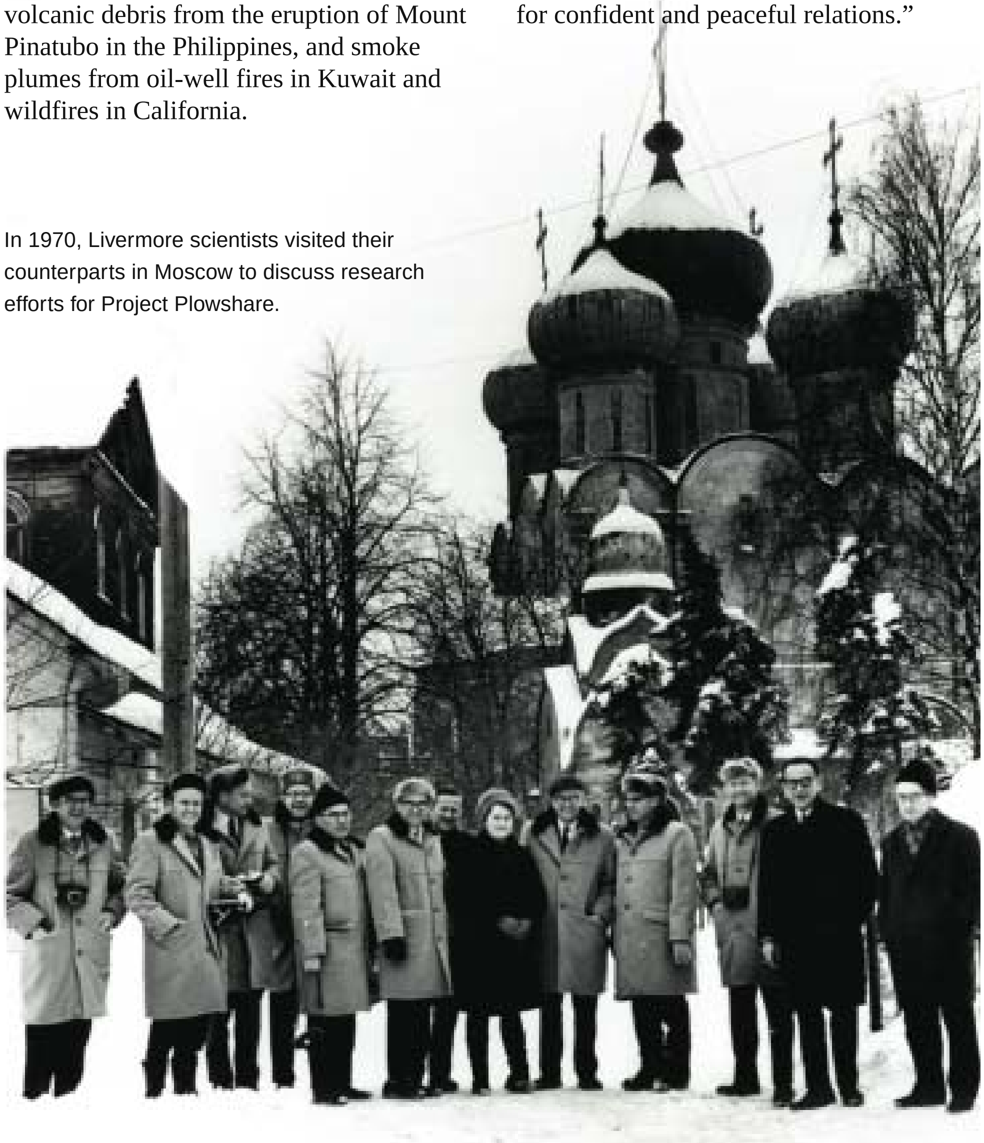


In 1953, President Dwight D. Eisenhower addressed the United Nations General Assembly. His speech, Atoms for Peace, called on all world leaders to move toward peaceful uses of nuclear technology. (Photograph courtesy of the United Nations/DPI Photo.)

Livermore developed the Atmospheric Release Advisory Capability (ARAC) as an emergency response service for the federal government. ARAC's original mission was to estimate the fate of radionuclides in the event of actual or potential radioactive releases. In 1979, the National Atmospheric Release Advisory Center (NARAC) at Livermore opened ahead of schedule in response to the nuclear power plant emergency at Three Mile Island in Pennsylvania. Since then, NARAC has provided emergency-response assistance by tracking airborne releases from the Chernobyl nuclear power plant, volcanic debris from the eruption of Mount Pinatubo in the Philippines, and smoke plumes from oil-well fires in Kuwait and wildfires in California.

Cooperating with the Soviets

In the 1950s, a chief concern for world leaders was the growing tension between the dominant political philosophies symbolized by the U.S. and the Soviet Union. President Eisenhower recognized that the two nuclear powers had to work together to diffuse a potential conflict. In his Atoms for Peace speech, he thus proposed modest steps to "initiate a relationship with the Soviet Union which will eventually bring about a free intermingling of the peoples of the east and of the west—the one sure, human way of developing the understanding required for confident and peaceful relations."



In 1970, Livermore scientists visited their counterparts in Moscow to discuss research efforts for Project Plowshare.

Magnetic fusion energy was the first research area in which U.S. and Soviet nuclear scientists cooperated. Livermore scientists had already been working in this area even before Eisenhower's speech. Afterward, they began to collaborate with Soviet, British, and other American scientists to study controlled fusion reactions as a method for power generation. Results from that research were presented at the 1958 Atoms for Peace Conference in Geneva.

The Cold War lasted another 30 years, but more areas of cooperation opened up. The two superpowers negotiated new treaties that limited nuclear testing and reduced their nuclear arsenals. To ensure that the treaties could be enforced, government agencies called on Livermore and Los Alamos scientists to provide technical support during the negotiations.

The Laboratory also began to research methods for monitoring nuclear explosions. From those efforts, which began in the Vela Program, scientists developed technologies to detect nuclear explosions whether they were detonated at the Earth's surface, underground, in space, or at high altitude. Nuclear explosion monitoring remains an important research activity at the Laboratory. Current efforts entail developing databases, methodologies, algorithms, software, and hardware to improve monitoring capabilities around the world. Technical support of arms-control negotiations also continues to be an integral part of Livermore's overall mission. Today, experts at the Laboratory provide technical assistance to the Department of Energy (DOE) and its National Nuclear Security Administration (NNSA) on treaty verification, and they analyze technical issues associated with nuclear arms-control measures.

A turning point in U.S.–Soviet relations came in 1988 with the Joint Verification Experiment (JVE). For the JVE, each nation agreed to allow the other to take verification measurements, including hydrodynamic yield, during one nuclear experiment conducted at each host country's nuclear test site. A U.S.–Soviet collaboration involving nuclear experiments was unprecedented and showed how far the two nations had come in working together.

The first JVE event, Kearsarge, was conducted on August 17, 1988, at the Nevada Test Site (NTS). Soviet scientists who were escorted to NTS not only observed U.S. scientists and engineers preparing for an underground nuclear experiment but also recorded measurements during the event. Then on September 14, the Shagan Event was conducted at the Soviet Union's Semipalatinsk Test Site. As with the Kearsarge Event, U.S. scientists observed the operations and recorded measurements.

The measurement technique used for the JVE, called CORRTEX, was developed at Los Alamos using concepts that originated at Livermore. This technique measures the speed of the shock wave produced by a nuclear explosion and then correlates that speed to the nuclear yield produced in the explosion.

"The JVE was an extraordinary success," says Bob Schock, a U.S. participant in the JVE who now is a CGSR senior fellow and director of the center's Atoms for Peace project. "Professional relationships were formed among Livermore and Russian scientists that remain strong today. It marked the beginning of the end of the Cold War."

Treaties Call for Better Detectors

In 1953, President Eisenhower foresaw that "the knowledge now possessed by several nations will eventually be shared by others, possibly all others." In response to this potential threat, he recommended that the U.S. accelerate its efforts to develop nuclear detection systems. Since then, the Laboratory has developed an array of radiation detection systems to support various arms-control treaties. One such treaty, the 1987 Intermediate-Range Nuclear Forces Treaty, allowed the U.S.

A simulation of smoke dispersion from a fire at a tire disposal pit in Tracy, California, is superimposed on an aerial photograph taken a few hours after the fire started.

U.S. and Soviet flags fly side by side atop the experiment tower at the Nevada Test Site during the first of two Joint Verification Experiments in 1988.

Trains leaving and entering Astrakhan on the Caspian Sea are monitored for nuclear materials as they pass between radiation detectors.

and the Soviet Union to measure radiation from the other nation's nuclear warheads.

To develop more accurate diagnostic equipment for this treaty, Livermore opened the Radiation Measurement Facility (RMF) in 1988. The RMF has hosted several international experiments, including a demonstration in 1997 of potential technologies to verify the Trilateral Initiative. Formed in 1996, the Trilateral Initiative is a collaboration of Russia, the U.S., and the International Atomic Energy Agency (IAEA) to ensure that fissile material removed from dismantled warheads not be reused for weapons. (IAEA was established in 1957 as the world's Atoms for Peace organization under the United Nations and is responsible for verifying that nations comply with their nonproliferation agreements.)

Such radiation measurements, which are taken to verify that a country complies with an arms-control treaty, can be intrusive and can reveal aspects of a nuclear weapon's design—details that are among the most closely guarded secrets of nuclear weapons states. To help protect this information, Livermore scientists designed two systems that measure radiation without revealing warhead designs. The first system, called the template-matching method, compares the radiation signature from an inspected item with a known standard for a weapon or component of the same type. The second system, called the attribute measurement method, characterizes an inspected item to determine whether the item possesses one or more of the attributes of nuclear weapons and their components.

Another area of Livermore detector research is aimed at surmounting the difficulties encountered when fissile materials are shielded, as they are in nuclear warheads. Many detectors are designed to operate in passive mode, collecting air samples and characterizing background radiation to determine whether the telltale gamma rays emitted by fissile materials are present. To detect shielded materials, Livermore scientists are working on active detection techniques. These techniques induce radiation, for example, by bombarding a shielded container with neutrons or energetic photons. Samples are then analyzed to determine whether they contain highly enriched uranium (HEU). This technology also may be useful for homeland security. It is being adapted for use at ports and customs inspections, where investigators need improved tools to prevent the clandestine smuggling of nuclear material.

Other Livermore-designed detectors are being used in a U.S.–Russian project to ensure that HEU from dismantled nuclear

Where Scientists and Policy Makers Meet

The Center for Global Security Research (CGSR) at Lawrence Livermore brings together international experts in science, technology, national security, and policy to explore the ways in which science and technology intersect with policy development. Such interactions help both scientists and policy makers understand these issues so they can work toward common goals. "Think tanks abound," says Eileen Vergino, the center's deputy director, "but few of them have Livermore's concentration of experts in nuclear weapons, laser, biotechnology, energy, and other related fields."

To foster in-depth discussion of common issues and goals, CGSR sponsors workshops, research fellowships, and independent analyses, which have included participants from the past and current U.S. Administrations, Congress, and the Departments of Defense, Energy, and State as well as their international counterparts. For example, past workshops have focused on security and the technology-driven threats to the U.S. and its allies and on deterrence in response to new threat scenarios.

In November 2003, CGSR held a two-day symposium entitled, "Atoms for Peace after 50 Years: New Challenges and Opportunities." This symposium concluded a series of workshops at which scientists and policy makers discussed the progress made toward goals President Dwight D. Eisenhower outlined in his Atoms for Peace speech, which he delivered to the United Nations General Assembly in 1953. "In our spring 2003 workshops, we asked participants to examine both the benefits and risks of nuclear technology—whether it is used for national security or civilian applications," says Vergino. Participants were also encouraged to discuss the crosscutting issues, such as nuclear waste and disposition, environmental protection, regulations, management of nuclear systems, and most importantly, public confidence in the safety and reliability of these technologies.

Speakers at the symposium included Paul Longsworth, deputy administrator for the National Nuclear Security Administration, and Susan Eisenhower, granddaughter of the late President Eisenhower and chairperson of the Eisenhower Institute. In her presentation, Eisenhower said, "The genie is already out of the bottle," and she encouraged attendees to search for synergetic uses of nuclear technology that provide national security and civilian benefits. CGSR's final report is available online at cgsr.llnl.gov.

warheads is blended down to low-enriched uranium, which can be used to power commercial nuclear reactors. Livermore is also exploring a concept for detectors that can verify the origin of weapons-grade plutonium.

New Challenges after the Cold War

When the Cold War ended, a major international concern was the status of nuclear materials and weapons from the former Soviet Union. The U.S. has worked with Russia to ensure that weapons-grade nuclear materials do not get into the wrong hands. Livermore-designed detection systems are now located at some of the most important nuclear institutes in Russia, such as the All-Russian Scientific Research Institute of Technical Physics in Snezhinsk, a facility similar to Lawrence Livermore. Another program is helping customs officials in Russia to install nuclear detection equipment across that nation's 20,000 kilometers of borders. A U.S.–Russian team has equipped Moscow's Sheremetyvo International Airport with radiation detection equipment, including pedestrian portals to monitor departing passengers. Similar pedestrian- and vehicle-monitoring portals have been set up at border sites (see the figure on p. 8).

Both the U.S. and Russia are committed to reducing their nuclear arsenals. In the early 1990s, these efforts were given additional impetus when the Nuclear Non-Proliferation Treaty (NPT) was about to expire. The NPT called for signatory nations without nuclear weapons to forgo acquiring them. In exchange, these nations would have access to peaceful applications of nuclear technologies. Meanwhile, nations with nuclear weapons agreed not to share their weapons technology with others and to pursue negotiations in good faith to end the nuclear arms race at the earliest possible date. In negotiations to extend the NPT, the nonnuclear signatory nations wanted the five nuclear signatories—the U.S., Russia, United Kingdom, France, and China—to demonstrate more visible progress toward nuclear disarmament. The five nations eventually agreed to cease nuclear testing, and in 1995, the NPT was extended indefinitely.

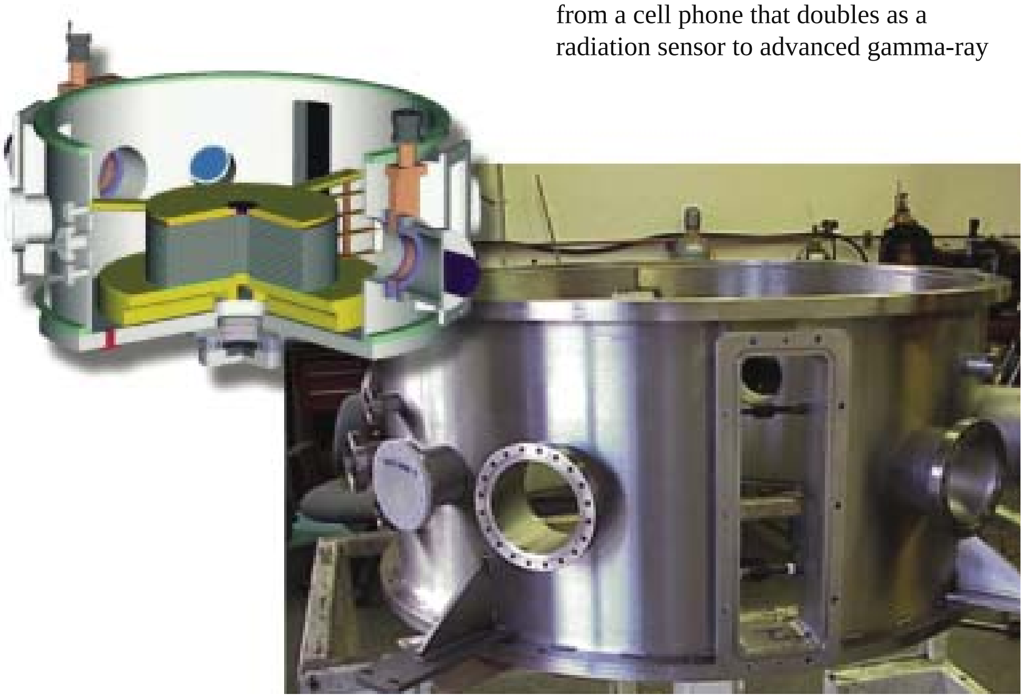
In the absence of nuclear testing, the nation needed another approach to ensure the safety and reliability of its nuclear deterrent. As a result, in 1996, DOE established the Stockpile Stewardship Program, to provide the tools and technologies scientists need to better understand the physical interactions involved in nuclear weapons and how component aging might affect weapon reliability. The challenge of stockpile stewardship has led to recent advances in many research areas at the Laboratory, including physics, chemistry, materials science, and engineering.

For example, DOE launched the Accelerated Strategic Computing Initiative (ASCI) to develop the high-performance computers and advanced software needed to simulate weapon performance more accurately. Now called the Advanced Simulation and Computing Program, ASCI places the NNSA laboratories at the forefront of scientific computing. Lawrence Livermore is now home to ASCI White, a supercomputer that can process 12.3 trillion operations per second (teraops). The Laboratory is also preparing for the delivery of ASCI Purple, which will be capable of up to 100 teraops. Novel computer architectures with still greater capabilities are being developed. (See *S&TR*, June 2003, pp. 4–13.)


The Adaptable Radiation Area Monitor (ARAM), a portable radiation monitoring system, can detect small amounts of radioactive materials from a distance.

Terascale computing offers the potential to revolutionize scientific discovery. It can lead to unprecedented levels of understanding in many areas of physics, including climate and weather modeling, environmental studies, and the design of new materials.

Another cornerstone of the Stockpile Stewardship Program is the National Ignition Facility (NIF). (See *S&TR*, September 2003, pp. 4–14.) In December 2002, NIF achieved "first light" when its first four laser beams were activated. Then in May 2003, the project set a world record for laser performance when NIF produced 10.4 kilojoules of ultraviolet laser light. When this 192-beam laser facility is fully operational, it will generate 1.8 megajoules of ultraviolet light. With NIF's unique capabilities, scientists can explore the world of high-energy-density physics, delving into the inner workings of nuclear weapons, astrophysical phenomena, and materials under extreme conditions.



Livermore is addressing the feasibility of a small proton therapy accelerator—a device for radiation treatment that can more accurately target cancer tumors without harming healthy tissue.

Detectors for Homeland Security

With the increased number of terrorism incidents worldwide, the U.S. government needs new tools for improving homeland security, and Livermore scientists and engineers have responded to that call. In April 2003, Livermore opened the Radiation Detection Center, which coordinates more than a dozen projects for detecting clandestine nuclear materials. The center's research involves more than 200 Laboratory employees from eight directorates and Livermore's Homeland Security Organization.

Laboratory physicist Ken Sale says, "We are adapting tools originally used for weapons testing to solve homeland security problems. Many of the constraints we have are the same, but the environments are different." For example, detection systems for homeland security must address the possibility that weapons of mass destruction or weapons materials could be brought into the U.S. inside maritime cargo containers or driven across U.S. borders.

The detectors being developed range from a cell phone that doubles as a radiation sensor to advanced gamma-ray spectrometers. One Livermore system stores a radiation detector on buoys placed at the entrance of marinas, ports, and waterways. (See *S&TR*, January/February 2004, pp. 19–22.) Researchers have also developed handheld, electromechanically cooled germanium detectors, such as RadScout and CryoFree/25. (See *S&TR*, September 2003, pp. 2 and 24.) Both of these detectors achieve precisions previously found only in a laboratory and do not require heavy, bulky equipment to cool the germanium.

More recently, scientists unveiled the Adaptable Radiation Area Monitor (ARAM) for homeland security (see the figure on p. 9). ARAM is a portable system that can detect small amounts of radioactive materials from a distance. When radioactive material is detected, ARAM photographs the area, collects high-resolution spectral data for analysis, and rapidly sends the information to a first responder. Another system being developed uses a network of correlated radiation detectors and cameras to locate and track radioactive or nuclear material in vehicles moving at high speeds. Researchers are also measuring the physical properties of nuclear materials so they can improve the fidelity of the computer calculations used to model detector designs.

Although the primary use of these technologies will be to locate nuclear materials and protect against acts of terrorism, they also can be used to verify compliance with arms-control agreements and to improve diagnostics for NIF, environmental monitoring, astrophysics, and medical applications.

Advanced Medical Technologies

Livermore's expertise in nuclear technology has helped scientists understand the potential health risks of human exposure to chemicals and radiation. Livermore began its biomedical research in 1963, in an effort to measure an individual's exposure to radiation. This research area continued to grow and is now a Laboratory directorate, Biology and Biotechnology Research Programs (BBRP). BBRP has made significant advances in the study of human radiation biology and biotechnology. BBRP research has aided organizations such as the Radiation Effects Research Foundation (RERF), which monitors the health of people from Hiroshima and Nagasaki who survived the atom bombs dropped on those cities in August 1945. The RERF study—possibly the largest study ever undertaken in human epidemiology—has given the world a realistic assessment of radiation risk.

Livermore researchers have developed several biological dosimeters, or biodosimeters, to detect and measure changes in human cells from ionizing radiation. The glycophorin-A (GPA) human mutation assay can measure subtle distinctions between normal and mutant red blood cells. After the 1986 Chernobyl nuclear accident, the GPA assay was used to screen cleanup workers for exposure. (See *S&TR*, September 1999, pp. 12–15.) It is now used extensively to study genetic damage in human populations that have been exposed to potentially mutagenic agents.

Another biodosimeter, chromosome painting, is used to fluorescently label small pieces of DNA. Laboratory scientists first developed this process to identify reciprocal translocation—one of the distinguishing effects of radiation damage to DNA. In reciprocal translocation, the ends of two chromosomes break off and trade places with each other. With chromosome painting, scientists see and count translocations between two differently painted chromosomes and thus determine a person's likely prior exposure to ionizing radiation.

Much of BBRP's research focuses on better understanding how different doses of radiation affect human cells. One project is studying the cellular effects from exposure to low doses of radiation, such as those received from medical procedures or in certain occupational areas. (See *S&TR*, July/August 2003, pp. 12–19.) Another project recently demonstrated that cells exposed to low-level ionizing radiation will activate genes that specialize in repairing damaged chromosomes, membranes, and proteins and thus counter cellular stress. Livermore scientists also found an adaptive response in human cells, whereby a cell that is pretreated with a tiny dose of ionizing radiation will better withstand a later, much higher dose, and they identified cellular changes that occur in the mammalian brain after low-dose radiation exposure. The results from all of these studies have useful applications, for example, in setting exposure limits for employees at radioactive waste cleanup areas and for people undergoing various medical procedures.

One notable innovation in biotechnology research at Livermore comes from adapting weapons technology to a civilian application. PEREGRINE, a treatment-planning program for radiation beam therapy, couples Livermore's storehouse of radiation transport data with powerful simulation tools and desktop computers. It can be used to diagnose cancers and treat tumors that have metastasized. (See *S&TR*, May 1997, pp. 4–11; April 2001, pp.15–17.) Another cancer-treatment system, called MINERVA, allows physicians to track targeted molecular radionuclides and determine exactly where a drug is distributed in the body. (See *S&TR*, July/August 2003, pp. 4–11.)

Technologies being developed for underground subcritical tests at NTS may also lead to a compact proton accelerator for radiotherapy treatment of deep-seated tumors. One design breakthrough is a dielectric wall accelerator being developed for the NTS x-ray source. This dielectric wall can handle the high electric field stresses generated by the 250-megavolt machines used for radiotherapy. Livermore researchers have already tested a millimeters-thick dielectric wall sample, which withstood an electric field of 100 megavolts per meter. They are now exploring this technology for use in a proton accelerator only 3 meters long. (See the figure on p. 10.) If successful, this technology would allow an oncologist to target radiation more directly to a cancer tumor while avoiding healthy tissue.

Maintaining the Legacy for Peace

Fifty years after President Eisenhower's landmark speech, the world is vastly different, but the challenge he identified remains—managing the risks of nuclear technology while obtaining its benefits. With its recent focus on Atoms for Peace, CGSR has helped to examine the gap between the scientists who are developing nuclear technologies and the policy makers who must safeguard them. By working together, these two communities contribute to Eisenhower's legacy, which continues a Laboratory tradition—providing innovative technologies to enhance national security and meet other enduring national needs.

—Gabriele Rennie

Key Words: Adaptable Radiation Area Monitor (ARAM), Advanced Simulation and Computing (ASCI) Program, Atoms for Peace, biodosimetry, Center for Global Security Research (CGSR), Joint Verification Experiment (JVE), National Atmospheric Release Advisory Center (NARAC), Project Plowshare, proton therapy, Radiation Detection Center, Radiation Measurement Facility (RMF).

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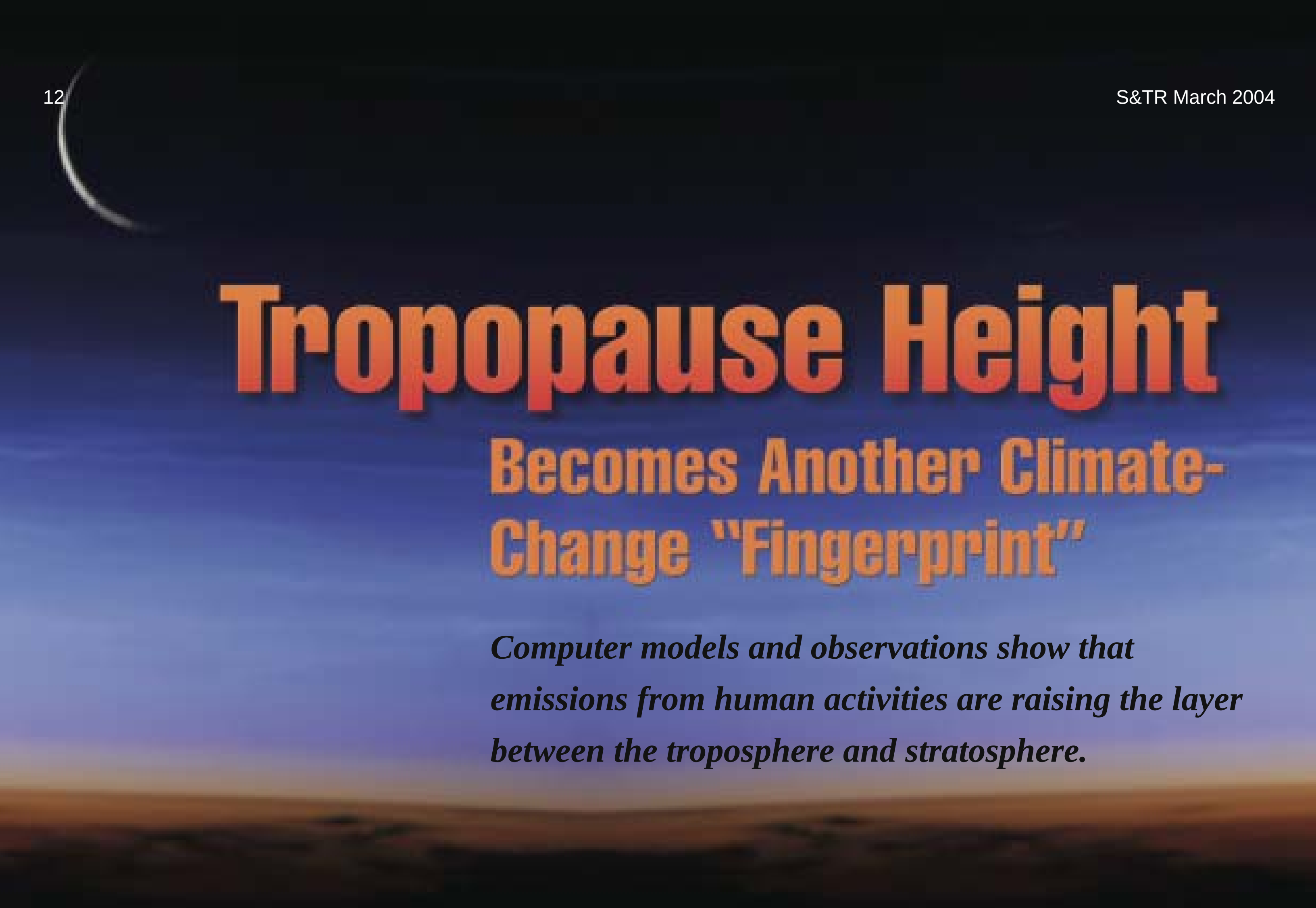
President Eisenhower's Atoms for Peace speech is available at: www.eisenhower.utexas.edu/atoms.htm.

CGSR's report on the 2003 Futures Roundtable is available at: cgsr.llnl.gov.



Tropopause Height

Becomes Another Climate-Change "Fingerprint"

Computer models and observations show that emissions from human activities are raising the layer between the troposphere and stratosphere.

THE scientific puzzle of the nature and causes of climate change is highly complex. Now, an international team of scientists, led by researchers from Lawrence Livermore, has added another piece to this puzzle. The research team has discovered that emissions from human activities are largely responsible for a significant increase in the height of the tropopause—the boundary between the turbulent troposphere, which is the atmosphere's lowest layer, and the more stable stratosphere that lies above it.

The team's results show that human-induced (anthropogenic) changes in well-mixed greenhouse gases, which are fairly evenly distributed in the atmosphere, and ozone, a greenhouse gas that is found in higher concentrations in the stratosphere, are the primary causes of the approximately 200-meter rise in the tropopause that has occurred since 1979. In their research, team members used advanced computer models of the climate system to estimate changes in the tropopause height that likely result from anthropogenic effects. They then searched for, and positively identified, the model-predicted "fingerprints" in observations of tropopause height change.

The research team reported these findings in the July 25, 2003, issue of *Science*. The team included Livermore scientists Benjamin Santer, Karl Taylor, and James Boyle as well as researchers from Lawrence Berkeley National Laboratory, the National Center for Atmospheric Research (NCAR), the Institut für Physik der Atmosphäre in Germany, and the University of Birmingham in the United Kingdom. The Department of Energy's (DOE's)

Environmental Sciences Division funded the U.S. participation in the two-year study.

The tropopause height research is part of Livermore's long-standing effort to study and model global climate change. (See *S&TR* July/August 2002, pp. 4–12.) Santer, who leads the research team, is a member of Livermore's Program for Climate Model Diagnosis and Intercomparison (PCMDI). PCMDI develops methods and tools for diagnosing, validating, and comparing the global climate models used for predicting climate change. Such predictions are computationally demanding calculations that could not have been performed without the recent advances in supercomputing technology.

"Years ago, we were fortunate to get one calculation of a climate-change prediction," says Michael Wehner, an atmospheric scientist at Lawrence Berkeley National Laboratory and a member of the research team. "Today, we are able to perform these ensemble calculations because of the progress coming from DOE's Climate Change Prediction Program. DOE made a substantial investment in this program, both in model development at NCAR and in unclassified computer centers such as the National Energy Research Scientific Computing Center at Berkeley. That investment has paid off."

Sensitive to Temperature

The tropopause lies about 18 kilometers above the Earth's surface at the equator in the summer and 8 kilometers above the poles in winter. Tropopause height is sensitive to temperature changes in the troposphere and stratosphere. Warming the troposphere or cooling the stratosphere tends to increase tropopause height. Conversely, cooling the troposphere or warming the stratosphere lowers tropopause height. (See the box below.)

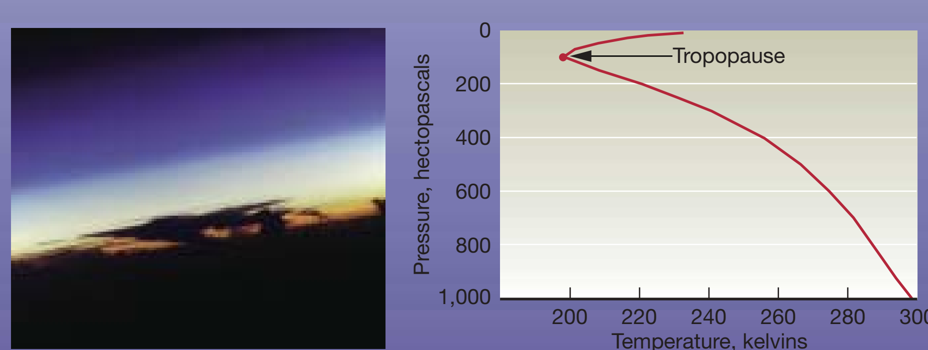
Climate is influenced by many natural and anthropogenic factors. These "forcings" of the climate system can have different effects on tropospheric and stratospheric temperatures and hence on tropopause height. For example, well-mixed greenhouse gases, such as the

Earth's Atmosphere: A Short Primer

The Earth's atmosphere can be divided into several distinct layers. The lowest layer of the atmosphere is called the troposphere, which begins at ground level and extends to 8 kilometers at the poles and to 18 kilometers near the equator. The troposphere contains up to 75 percent of the mass of the atmosphere and almost all the atmospheric water vapor. Often turbulent, it is the home to such weather systems as hurricanes, tornadoes, and thunderstorms. The troposphere is characterized by temperatures that generally decrease with increasing height.

Above the troposphere lies the stratosphere, a relatively stable layer of the atmosphere. The stratosphere extends to about 50 kilometers in altitude. An important feature of the stratosphere is the ozone layer, which protects the Earth by absorbing much of the ultraviolet radiation from the Sun. There is considerable evidence that industrial chlorofluorocarbon compounds are depleting the ozone layer, so these chemicals are being phased out under the terms of an international treaty. The stratosphere is characterized by an overall increase of temperature with increasing height.

The tropopause, which is situated at the upper boundary of the troposphere and the lower boundary of the stratosphere, marks the limit of most weather systems. Its height is sensitive to the changes in atmospheric temperature caused by both natural and human factors. Previous studies of weather balloon data have shown that the tropopause has risen about 200 meters since 1979. The Livermore-led research is a first attempt to understand the possible causes of this height increase.



The troposphere is characterized by temperatures that generally decrease as altitude increases and atmospheric pressure decreases. Situated at the upper boundary of the troposphere and the lower boundary of the stratosphere, the tropopause marks the limit of most weather systems. Anvil-shaped thunderstorm clouds (left) are pushed up against the tropopause. (Photograph courtesy of the National Aeronautics and Space Administration.)

carbon dioxide produced from burning fossil fuels, simultaneously warm the troposphere and cool the stratosphere. Both effects increase tropopause height. The depletion of stratospheric ozone by chlorofluorocarbons cools the stratosphere, which tends to raise the tropopause. The sulfate aerosols produced by burning fossil fuels lower the tropopause by cooling the troposphere. Volcanic aerosols injected into the stratosphere during massive eruptions also lower the tropopause because they absorb incoming solar radiation, thus warming the stratosphere and cooling the troposphere.

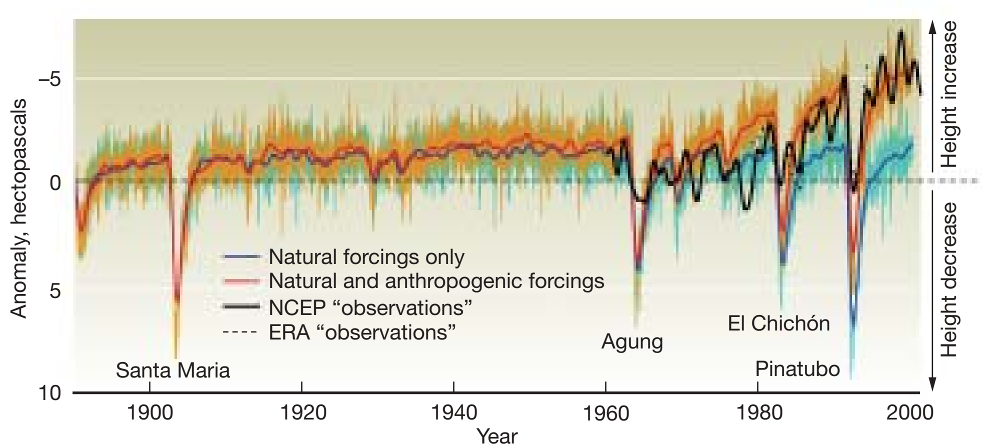
According to Santer, direct observations from weather balloons and reanalyses—optimal combinations of weather observations and numerical weather forecasts—show that the tropopause has risen about 200 meters since 1979. "Previous work had documented an overall increase in tropopause height," he says, "but ours is the first detailed study of the possible causes for this increase." The innovative aspect of the Livermore-led research was its use of climate models to estimate the individual contributions of different forcing mechanisms to overall tropopause height changes.

The tropopause can be defined in different ways based on changes in the thermal, chemical, or dynamic properties of the atmosphere with increasing altitude. The team used a standard thermal definition of the tropopause to track changes in its height. In practical terms, this standard defines the tropopause to be close to the level where atmospheric temperature stops decreasing with altitude, a characteristic of the troposphere, and starts increasing with altitude, a characteristic of the stratosphere.

Parallel Supercomputers Required

The team used the DOE Parallel Climate Model (PCM), a three-dimensional (3D) global climate model designed for parallel supercomputers (machines using many processors in tandem). PCM was developed jointly by NCAR and Los Alamos National Laboratory, and it incorporates the latest

Climate is changed by both natural and human mechanisms. Natural mechanisms include (a, b) changes in solar irradiance and (c) the amount of volcanic dust in the atmosphere. Human mechanisms include changes in (d) aerosol particles from burning fossil fuels and biomass. (Photographs courtesy of the [a–c] National Aeronautics and Space Administration and [d] National Oceanic and Atmospheric Administration.)



Simulations with the Parallel Climate Model show that human-caused changes in tropopause height are greater than those from natural effects alone. Major volcanic eruptions tend to decrease tropopause height while human activity tends to increase it. The modeling results are consistent with observational data from the National Center for Atmospheric Research and the National Center for Environmental Prediction (NCEP) and from the European Centre for Medium-Range Weather Forecasts (ERA). Maximum and minimum values for (light orange) natural and anthropogenic forcings from four realizations and (light blue) natural forcings only, also from four realizations.

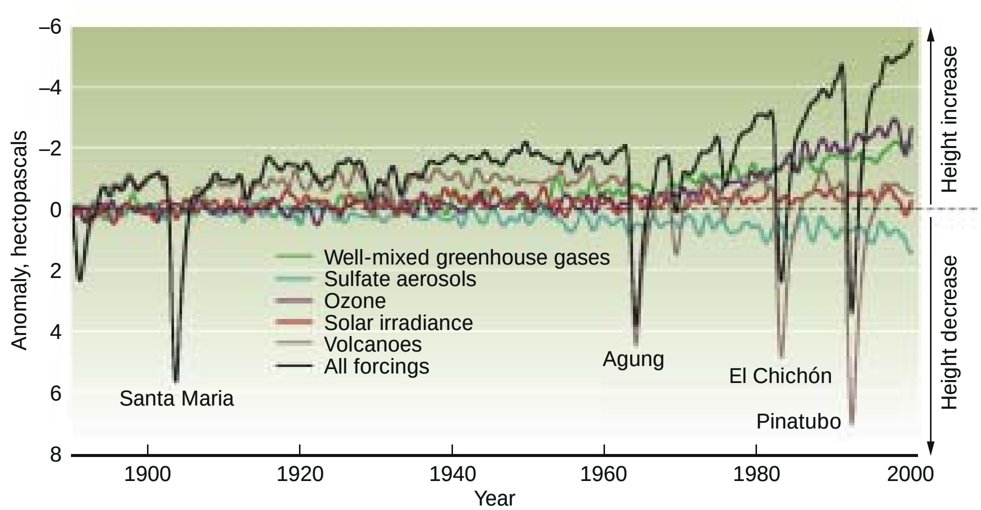
scientific understanding of the physical process at work in the Earth's atmosphere, oceans, and surface. The PCM calculations were performed at NCAR, Lawrence Berkeley's National Energy Research Scientific Computing Center (NERSC), and Oak Ridge National Laboratory.

The researchers looked at five different forcings—two natural and three human-related—that influence tropopause height. The anthropogenic forcings were changes in well-mixed greenhouse gases, the direct scattering effects of sulfate aerosols (see *S&TR*, September 2002, pp. 4–12), and ozone. The two natural forcings were changes in solar radiation and volcanic aerosols.

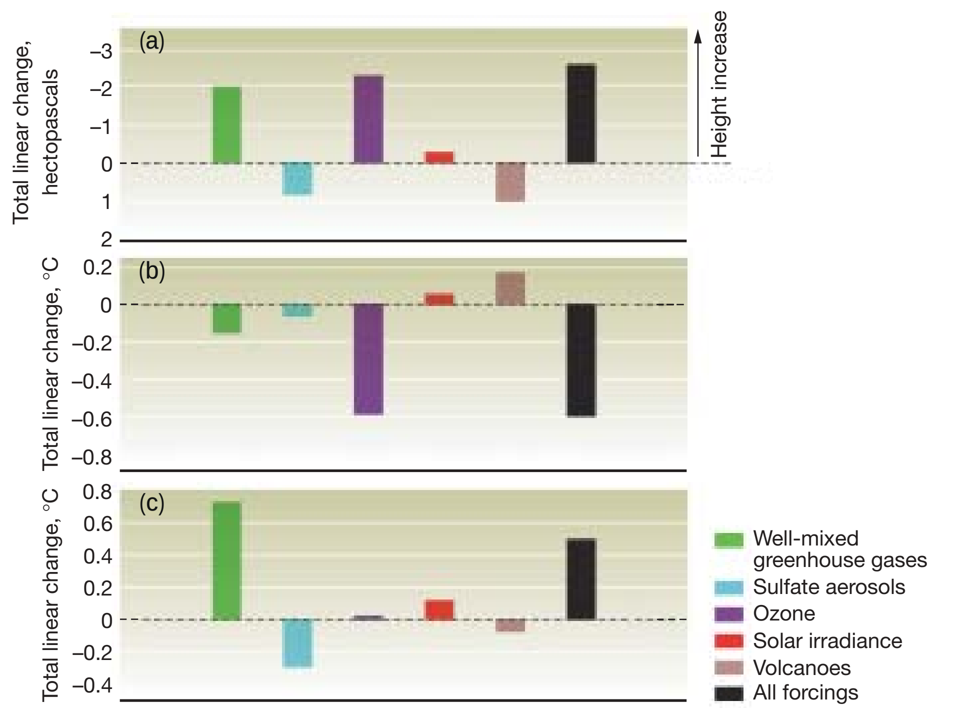
To isolate the key factors causing the height increase, the researchers analyzed the individual effects of these five factors. For each set of PCM calculations, they changed the levels of one forcing and held the others constant. For example, in one set, concentrations of well-mixed greenhouse gases were varied according to best estimates of their historical changes, while the other four forcings were held at preindustrial levels. In addition to these individual forcing experiments, various combinations were run, such as simultaneous variation of all five factors and variation of only the natural factors. All of the simulations covered the period 1890 to 1999.

"Because the PCM group performed such a comprehensive, structured array of experiments," says Santer, "we can isolate and quantify the effects of different forcings, and ask whether the climate response to these forcings is linear." He points out that it's rare for researchers to be able to study how individual factors affect global climate change—such a large array of simulations requires thousands of hours of supercomputer time.

To improve estimates of the true climate response to each forcing, the team performed four realizations of each climate-change experiment and started



Simulations reveal the relative contributions of different forcings to changes in tropopause height. Well-mixed greenhouse gases and ozone are the most important factors in raising the height of the tropopause.



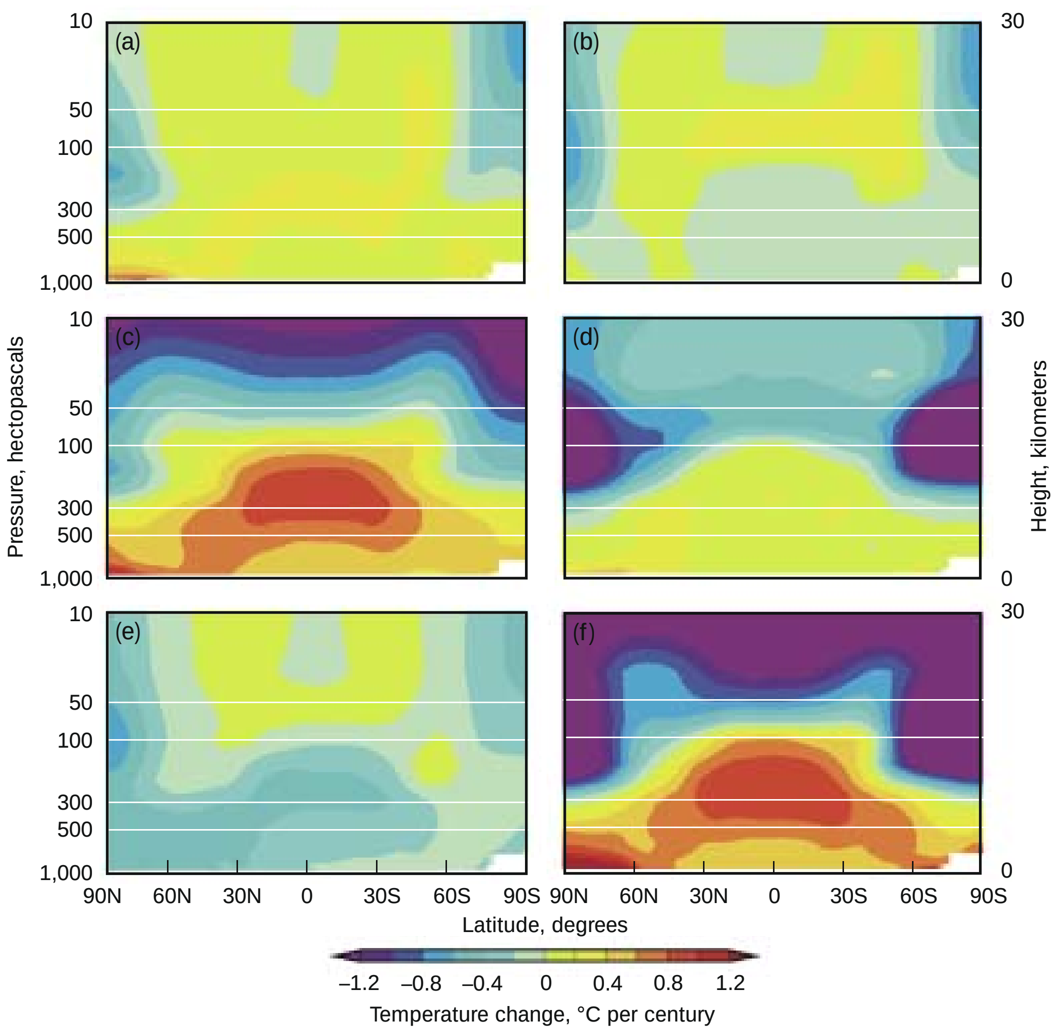
Relative contributions of different forcings to changes in (a) tropopause height and the temperature of (b) the stratosphere and (c) the troposphere. Human-induced changes in well-mixed greenhouse gases and ozone account for most of the height increase. Ozone acts by decreasing the stratospheric temperature, while well-mixed greenhouse gases influence tropopause height by raising tropospheric temperature. Both cooling the stratosphere and warming the troposphere tend to push up the tropopause.

each realization with slightly different initial conditions of the atmosphere and oceans. In addition, a 300-year control run was performed, in which all five forcings were fixed at preindustrial values. This control run provided information about the internal variability that naturally occurs in the climate system—that is, the fluctuations displayed by the system when all of the forcing changes are absent.

Nature Not a Major Culprit

Two of the simulations—the one incorporating all natural and anthropogenic forcings and the other involving only the two natural forcings—show only a small overall increase in tropopause height from 1890 to about 1965. However, from 1965 to 1999, the tropopause height increases markedly when all five factors are varied in the simulation, but not when only natural factors are varied. (See the bottom right figure on p. 14.) "These simulations clearly showed that in the 'PCM world,' the increase in tropopause height over the last two decades of the 20th century could not be caused by the Sun and volcanoes alone," says Santer.

Instead, the simulations with individual forcings indicate that human-induced changes in ozone and well-mixed greenhouse gases are responsible for about 80 percent of the tropopause height changes over the 20th century. (See the figures on p. 15.) Says Santer, "Our best understanding is that the recent tropopause height increase is due to two factors: warming of the troposphere, which is primarily caused by increasing concentrations of well-mixed greenhouse gases, and cooling of the stratosphere, which is caused mainly by depletion of stratospheric ozone."



Results from the Parallel Climate Model show fingerprints of the estimated temperature change from 1890 to 1999 for five natural and anthropogenic forcings, given as a function of latitude and altitude: (a) solar irradiance, (b) volcanoes, (c) well-mixed greenhouse gases, (d) ozone depletion, (e) sulfate aerosols, and (f) all five individual forcings varied in concert. The fingerprints are distinctly different. For example, the fingerprint for ozone depletion shows maximum cooling of the stratosphere in the Southern Hemisphere, where most ozone depletion has occurred. The sulfate aerosol fingerprint indicates that tropospheric cooling is greater in the Northern Hemisphere, where industrial production of sulfate aerosols is greater, than in the Southern Hemisphere.

Comparing Models to Observations

The concept of fingerprinting is a key aspect of studies seeking to unravel the multiple causes of climate change. Fingerprinting is an effective tool because each climate forcing mechanism has its own distinctive signature in climate records. Just as no two individuals have thumbprints with identical patterns of whorls and ridges, so no two climate forcings have identical 3D patterns of temperature change, as shown in the figure on p. 16.

Climate models such as PCM estimate the full geographic and altitudinal structure of the fingerprints that arise from different forcings. For example, when all five forcings are varied, the PCM simulation produces a fingerprint of tropopause height change with pronounced geographic structure. In this simulation, the largest height increases occur at high latitudes in the Southern Hemisphere, where ozone depletion is most pronounced.

To validate the simulation, the team then searched for this fingerprint in reanalysis data. Reanalyses are useful because they combine data from numerical weather forecasts with direct weather observations from balloons, ships, satellites, aircraft, and ground stations. "We don't have enough tropopause height data from direct observations to piece together a globally complete picture of tropopause height change," explains Santer. "We use weather forecast models to fill in the gaps." The reanalyses, the product of considerable scientific effort, give a spatially complete picture of the changes in global climate over the past two decades.

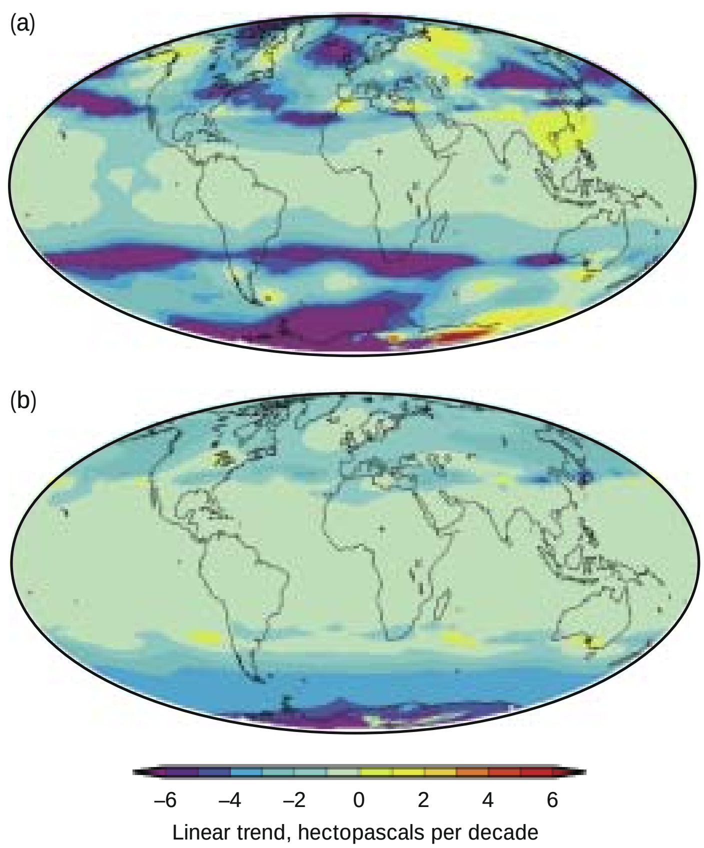
The team used two sets of reanalysis data to determine whether choosing a particular set of observations would affect the results. The first reanalysis was produced jointly by NCAR and the U.S. National Center for Environmental Prediction (NCEP). The second was from the European Centre for Medium-Range Weather Forecasts (ERA). The atmospheric temperature profiles in these data sets were used to calculate tropopause height. The start date chosen for monitoring height changes was 1979, the beginning of the ERA data and what the team considered the more reliable portion of the NCEP reanalysis.

Using a standard signal-detection method, the team was able to identify the PCM tropopause height fingerprint in both the NCEP and ERA reanalyses. Tropopause height increased markedly in both reanalyses, as it had in the PCM calculations that varied all five forcings. In the reanalyses, the smallest changes occurred in the tropics, and the largest increases were near the poles, particularly in the Southern Hemisphere.

This fingerprint is first apparent in the reanalysis data in 1988, just 10 years after the assumed start of monitoring, and becomes more apparent over time. Its early detection reflects the large atmospheric changes that have occurred over the past two decades. "By detecting this fingerprint in the reanalyses," says Santer, "we have considerable confidence in our ability to attribute tropopause height changes to the combined effects of anthropogenic and natural forcings."

Another Fingerprint

The height of the tropopause provides another fingerprint of human effects on climate, and Santer says it deserves further scientific attention. Previous fingerprints of Earth's changing climate have been evident in surface temperatures, ocean heat



(a) Patterns of tropopause height change (from 1979 to 1999) found in the reanalysis data from the National Center for Atmospheric Research and the National Center for Environmental Prediction resemble (b) those for the same period in the Parallel Climate Model simulation in which five climate forcings were varied simultaneously. Both the simulation and the reanalysis data showed increases in tropopause height, with the smallest changes occurring in the tropics and the largest increases toward the poles, particularly in the Southern Hemisphere.

content, polar ice cover, and atmospheric pressure patterns. "What we're now seeing with the rising tropopause and warming troposphere is that many different aspects of the climate system are telling us a consistent story—human activities are altering the Earth's climate. All of these changes are consistent with our scientific understanding of how the climate system *should* be responding to anthropogenic forcings. They are not consistent with the changes we would expect to occur from natural forcings alone."

Santer acknowledges that both reanalyses and computer climate models will always have deficiencies, so there will always be uncertainties in model-predicted tropopause height fingerprints, in observed estimates of tropopause height changes, and in scientists' understanding of the relative contributions of natural and anthropogenic factors to such changes. To lessen these uncertainties, the Livermore researchers are repeating their study—this time using data from more recent second-generation reanalyses, combined with improved weather forecast models and more sophisticated data assimilation systems. Climate scientists are also excited about the high-quality data on atmospheric temperature profiles that can now be obtained with Global Positioning System (GPS) technology. GPS data can provide an independent source of information on observed tropopause height changes.

The Livermore researchers now want to test the robustness of their findings, and they have several research options. One is to examine whether their results are sensitive to the number of atmospheric levels used in the calculations of tropopause height changes. The climate models and reanalyses the team originally used archived temperatures from 17 to 19 atmospheric levels, and the resolution of the temperature data near the tropopause was fairly coarse. "One concern we have," says Santer, "is that the calculations might produce different estimates of tropopause height changes if the vertical temperature gradients used in our models and reanalysis data were more detailed." Preliminary results indicate that the sensitivity to vertical resolution is relatively small, but this result must be verified with extended high-resolution climate model simulations. The computational resources available at Livermore and at NERSC provide excellent resources for performing such calculations.

Clearly, the change in the tropopause is another piece to help solve the complex climate-change puzzle.

—Arnie Heller

Key Words: Department of Energy's Parallel Climate Model (PCM), global warming, National Center for Atmospheric Research (NCAR), Program for Climate Model Diagnosis and Intercomparison (PCMDI), stratosphere, tropopause, troposphere.

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The article in* Science *can be found at: www.sciencemag.org/cgi/content/full/301/5632/479.

Output from these and other related climate models is available at: www.nersc.gov/projects/gcm_data.

A Better Method for Certifying the Nuclear Stockpile

LAWRENCE Livermore and Los Alamos—the two national laboratories that designed the nuclear systems in U.S. nuclear weapons—are working together to develop an improved methodology for verifying the performance of these systems and for presenting those data in a common format. Known as quantification of margins and uncertainties (QMU), this methodology draws together the latest data from simulations, experiments, and theory to quantify confidence factors for the key potential failure modes in every weapon system in the stockpile.

The assertion that the nuclear explosive package in a weapon performs as specified is based on a design approach that provides an adequate margin against known potential failure modes. Weapons experts judge the adequacy of these margins using data from past nuclear experiments, ground and flight tests, and material compatibility evaluations during weapons development as well as routine stockpile surveillance, nonnuclear tests, and computer simulations.

"With QMU, we're still examining margins against potential failure modes," says Charles Verdon, who leads A Program in Livermore's Defense and Nuclear Technologies (DNT) Directorate. "But now the assessment of these margins relies much more heavily on surveillance and computer simulations than in the past and therefore must be more rigorous and quantifiable."

The Confidence Factor

A confidence factor for a component or system is defined as the performance margin divided by the uncertainty in evaluating that margin. For a nuclear weapon, if the confidence factor for each potentially significant failure mode is greater than or equal to 1, the overall system can be considered safe and reliable.

$$\text{Confidence factor, CF} = \frac{\text{Margin}}{\text{Uncertainties}}$$

If CF $\geq$ 1, then system is considered safe and reliable.

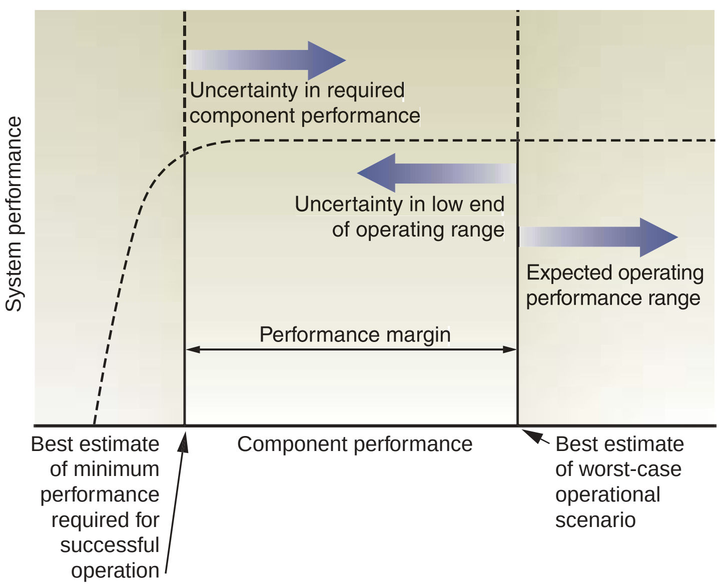
A nuclear warhead or bomb is designed to operate successfully at a performance level that is slightly lower than the level defined for the worst-case scenario of potential operating conditions. (See the figure on p. 20.) In defining the worst-case scenario, weapons experts consider numerous events that may occur during a weapon's lifetime, such as extremely cold atmospheric temperatures, vibration, or tritium decay between a gas-transfer-system exchange—any one of which could reduce weapon performance. The difference between these two levels—minimum required performance for successful operation versus the best estimate of the worst-case performance—constitutes the performance margin.

Many variables affect how a weapon will actually perform. Some of these variables, such as changes that alter the structural integrity of the weapon's outer casing or the behavior of plutonium as it ages, give rise to uncertainties about the best estimates of the minimum performance and the worst-case scenario for operation. Technical uncertainties are the root cause of such variables. For example, the equation of state for plutonium, which is arguably the most important material in the nuclear weapons stockpile, is not yet well understood when it is at the high-temperature and -pressure conditions that exist during a nuclear explosion. (See *S&TR*, January/February 2004, pp. 12–14.)

According to Kent Johnson, DNT chief of staff, reducing these technical uncertainties drives Livermore's continuing quest to understand the multitude of weapon constituents through experiments and simulations. "As our understanding increases, uncertainties may also increase for a while," he says, "but ultimately, we expect uncertainties to decrease considerably."

Today, no new nuclear weapons are being developed, and those in the current stockpile are being maintained beyond their originally planned lifetimes. To ensure the performance of these aging weapons, Livermore and Los Alamos take a survey–assess–refurbish approach to evaluating the stockpile. QMU, the methodology being used in the assessment part of this approach, helps weapon scientists identify where and when they must refurbish a weapon system. QMU is also proving useful for deciding whether the designed refurbishments are adequate.

Routine surveillance of stockpiled weapons has been a feature of weapon maintenance for decades, and it continues today. A more aggressive approach to surveillance under the National Nuclear Security Administration's (NNSA's) Stockpile Stewardship Program examines individual components to understand the aging process and its effects, if any, on overall performance. Nonnuclear tests at the Contained Firing Facility at Livermore's Site 300, at the Joint Actinide Shock Physics Experimental Facility at the Nevada Test Site, and soon at the National Ignition Facility at Livermore—all three of which were developed since nuclear testing ceased—are critical for scientists to better understand how materials behave during a nuclear explosion. In addition, Livermore's terascale supercomputer ASCI White, one of the largest in the world, provides the computing power needed for high-resolution simulations that incorporate most of the physical interactions that occur during a nuclear explosion.



An example of the relationship between the performance of a component and the overall nuclear weapon system. Uncertainties at both ends of the performance margin may reduce the margin. Numerical simulations, nonnuclear tests, data from past underground experiments, and the latest theory are combined to quantify technical uncertainties (the sum of the magnitude of the two uncertainty arrows) and the performance margin.

QMU pulls together all of this information—plus the latest physics theory and useful historic nuclear-test data—to arrive at quantifiable information with which decisions can be made about weapon certification or to answer questions about any weapon or weapon component in the stockpile. In 2001, QMU was successfully applied in the certification process for the W87 Alt342, the major refurbishment of the W87 nuclear weapon that was pursued through the warhead's life-extension program.

The goal is to fully integrate QMU into the nation's formal Annual Assessment of the entire stockpile of nuclear weapons. Each year, the directors of Livermore, Los Alamos, and Sandia national laboratories sign a letter to the President stating whether the weapon systems designed by each laboratory meet all safety, reliability, and performance requirements. By using QMU methodology, the laboratories will have a common framework for all of the necessary evaluations that comprise the Annual Assessment.

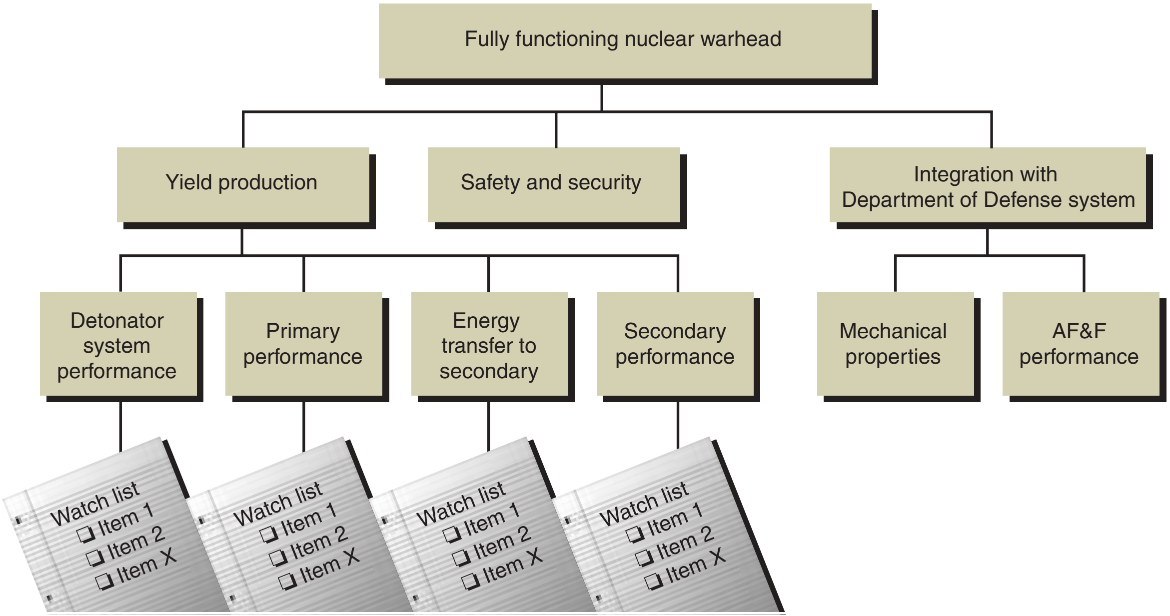
Making QMU Work

To implement the QMU process for a Livermore-designed weapon in the stockpile, weapon scientists first identify a set of components on which to focus in-depth analysis. Teams of experts define watch lists of credible failure modes and performance issues. For example, they are concerned with how current weapons will perform at extreme temperatures and whether component aging will affect performance. They also watch for such conditions as detonator deterioration and metal corrosion.

"The things on the list are the ones that keep us awake at night," says Verdon. "We want to know what parts might be approaching the edge of the performance margin, particularly if there are variables that could affect performance even more. Then we know that our scientists are working on the truly sensitive issues. During this continuing process, we must also stay vigilant for the unexpected."

For weapons that are being modified to prolong their life in the stockpile, new engineering features and proposed changes receive the same scrutiny. In these life-extension projects, scientists must determine quantitative answers to questions such as: Are the proposed changes a good idea? Does a modification fix the problem it was designed to solve? Does the modification introduce other problems?

Experts have developed a taxonomy of uncertainties for which scientists are always on the lookout. They are known, known-unknown, and unknown-unknown uncertainties. One example of a known uncertainty is the structural integrity of the weapon's casing. Engineering details are well known, but vibration during flight may crack the case and cause contents to be rearranged.



The first step in quantifying margins and uncertainties for a warhead or bomb designed by Livermore is to identify a watch list of potential failure modes and issues.

This known uncertainty can be accommodated through design by building in large margins but perhaps at some weight penalty.

A known unknown is, for example, the equation of state for plutonium at conditions critical to weapon performance. In this instance, scientists "know what they don't know" and are working to fill in the gaps in their knowledge. That way, they can use their models with confidence to address such issues as the effects of age or manufacturing changes.

An unknown unknown is one in which researchers "don't know they don't know." An example is an anomaly in data from past underground nuclear experiments. Several tests of a weapon gave the same result, but another, whose parameters appeared to be similar, provided an unexpected result. "We don't know why it happened," says Johnson, "and we need to figure it out." High-fidelity experiments, simulations, and data from past underground tests help scientists move the known-unknown and unknown-unknown uncertainties into the known uncertainties category, thus reducing overall uncertainty. Confidence factors would then increase, unless the new results indicated that margins had been overestimated.

An essential component of this process is open and critical evaluation of results. Workshops, peer reviews, joint evaluations with Los Alamos personnel, and senior advisory panels are all venues for exchanging ideas and expertise. Equally important is that the team determining the final confidence factors for a component is not the same team that developed the original watch list for it.

Livermore's second life-extension project for a warhead is under way now. The design team responsible for refurbishing all W80 warheads in the stockpile is using the QMU process to ensure that all credible failure modes have been considered and properly addressed. "The goal is to demonstrate through tests and calculations the set of confidence factors greater than one that are needed for certification of the W80 in 2008," says Johnson.

Into the Future

QMU has proved to be an excellent tool for addressing a range of concerns related to the existing stockpile. In addition, it may eventually be applied to other responsibilities of NNSA's weapons program. Pits, which include the inner shell of plutonium in the primary part of a weapon, change slowly with age as plutonium decays, perhaps reducing the margin for proper performance of the primary. The U.S. does not currently have a pit production facility for replacing existing pits. Is a dedicated production facility needed? And if so, by what date?

These questions cannot be answered definitively yet, but QMU will play a role in formulating the answers.

—*Katie Walter*

Key Words: quantification of margins and uncertainties (QMU), Stockpile Stewardship Program.

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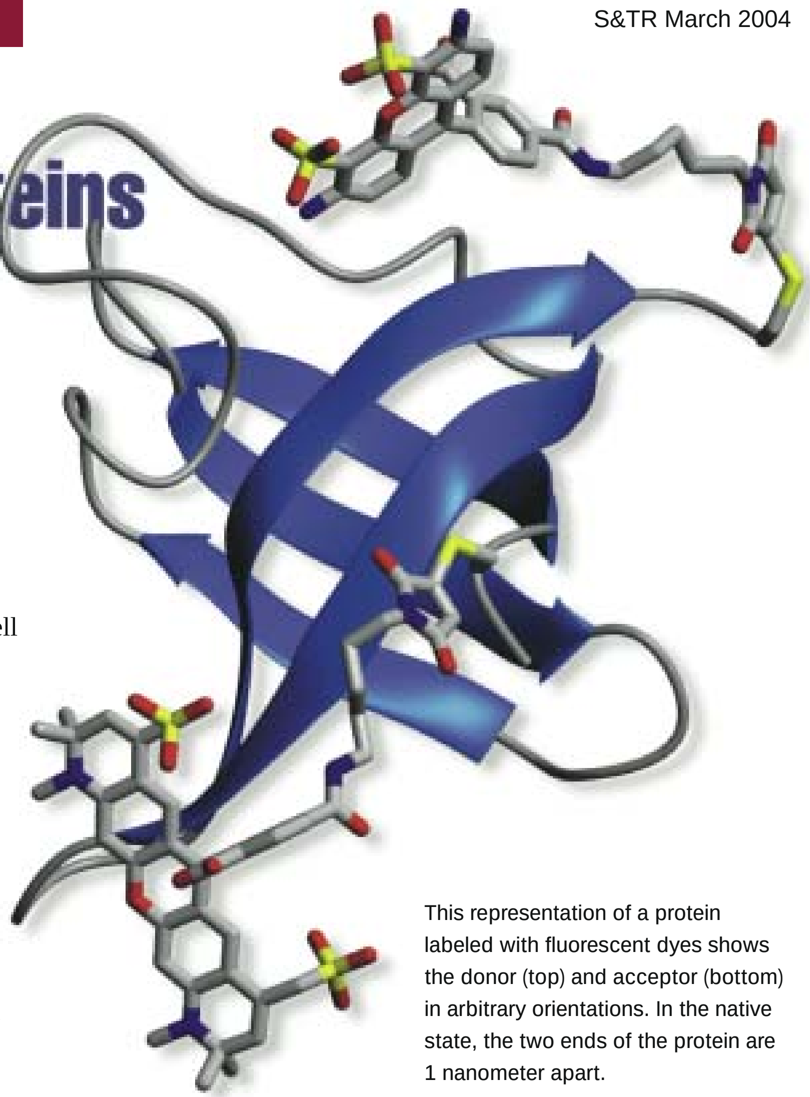
Observing How Proteins Loop the Loop



This representation of a protein labeled with fluorescent dyes shows the donor (top) and acceptor (bottom) in arbitrary orientations. In the native state, the two ends of the protein are 1 nanometer apart.

THE stretched-out lazy chains of amino acids forming the proteins that make life will, with the right chemical prodding, suddenly twist and tie into loopy, intricate three-dimensional shapes, like a complicated shoelace. And not just any shape will do: A backward twist or a wrong knot can cause something to go horribly wrong. A misfolded protein can poison the surrounding cells, leading to diseases such as Alzheimer's and mad cow as well as some cancers.

To better understand this process, Livermore physicist Olgica Bakajin worked with scientists from the Laboratory of Chemical Physics at the National Institute of Diabetes and Digestive and Kidney Diseases, which is part of the National Institutes of Health, and the Physikalische Biochemie at Universität Potsdam in Germany, to develop a method for investigating protein folding one molecule at a time. Their observations are the first of protein-folding kinetics on the single-molecule level. Using a microfluidic mixer they developed, the scientists were able to look at a protein at defined times after the folding reaction began and, for the first time, isolate a short-lived "collapsed state."

"The team is interested in how a protein goes from a random coil to its functional folded form," says Bakajin. "With our instrument, researchers will come closer to understanding this process and be able to study many different proteins to come up with some general rules about how proteins fold."

Detect the Subtlest Fold

Bakajin designed and built the mixer with support from Livermore's Laboratory Directed Research and Development Program. The device includes microchannels for introducing various solutions, a region for mixing protein and chemicals, and a chamber that allows researchers to record data. The microchannels, 8 to 50 micrometers deep and 5 to 50 micrometers wide, are cut into the surface of a silicon wafer. A solution consisting of protein and denaturant, which keeps the protein structure "relaxed" and unfolded, is fed into the center channel. A buffer is then fed into the two outer channels, to dilute the denaturant and allow the protein to fold. Compressed air drives the solutions through the channels at a specified flow rate. When the solutions contact each other, they mix, dilute the denaturant, and within a few tens of milliseconds, initiate the protein-folding reaction.

To demonstrate the performance of the mixer, the researchers used a "cold shock" protein from the bacterium *Thermotoga maritime*, a thermophile organism that lives in some hot springs. This particular protein, notes Bakajin, has two recognized stable states: folded and unfolded. For this experiment, the team labeled each end of the protein with fluorescent dye. When the protein is excited by 488-nanometer laser light, one dye molecule, called the donor, emits light at a specific wavelength. The other dye molecule, called the acceptor, absorbs the donor light and then emits light of a different wavelength.

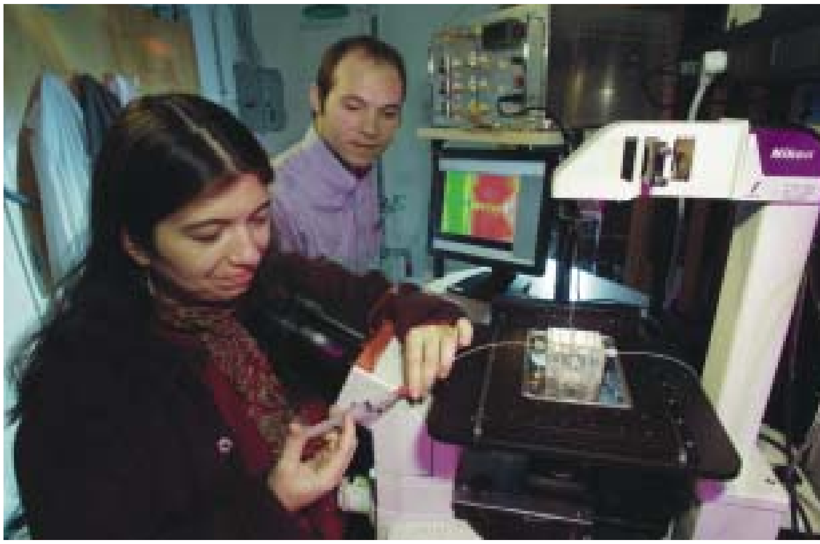
Bakajin explains, "If the two dye molecules are far apart—such as when the protein is in its relaxed, unfolded state—not much donor energy reaches the acceptor. If the two molecules are close—that is, when the protein is folded—more of the donor's energy reaches the acceptor, and the intensity of the acceptor's emitted light increases. So the ratio of emission between these two molecules tells us how far apart the dye molecules are and lets us know the state of the protein."

In the mixing region, once the denaturant is diluted, the protein begins to fold. The 488-nanometer laser beam is positioned downstream to illuminate a section of the observation channel that has been marked at specific intervals. Because the protein mixture flows down the tube at a known velocity, each mark corresponds to a particular time delay after mixing. Photon detectors aimed at these marked areas collect data in millisecond intervals as individual molecules pass by. In this way, the team was able to collect data on the status of individual protein molecules and determine whether a molecule was folded or unfolded. "Before now," says Bakajin, "no one has been able to look at individual proteins under nonequilibrium conditions in this manner."

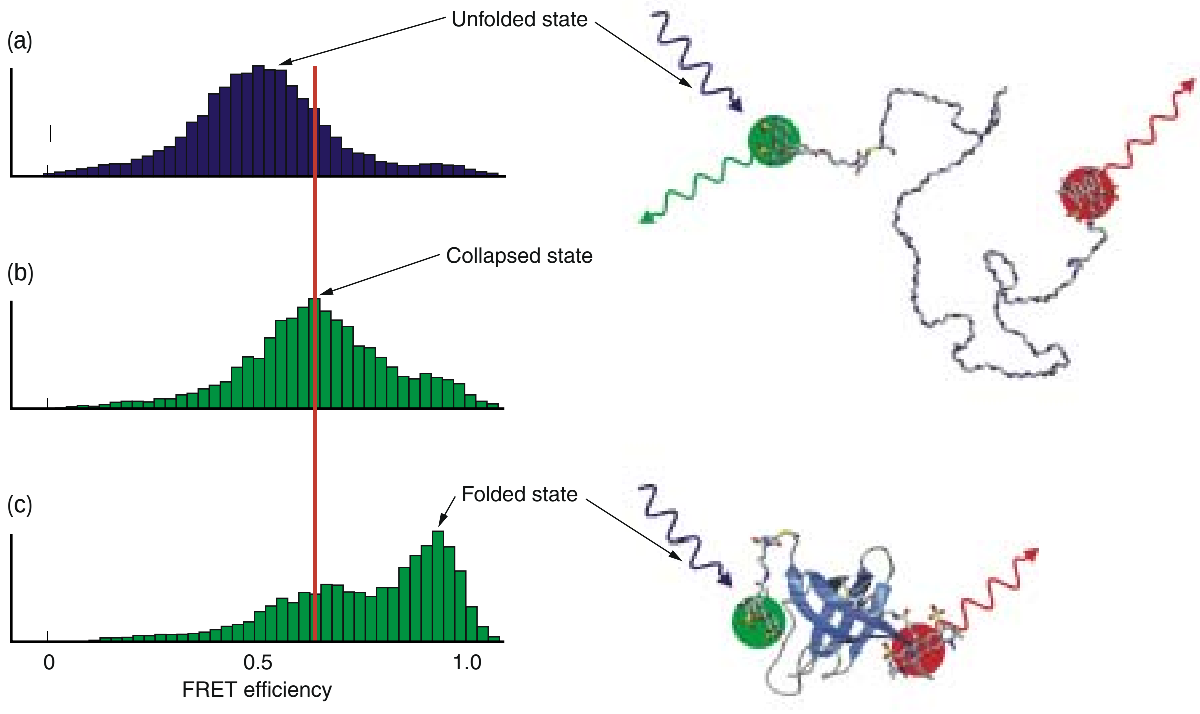
From these data, the team identified a short-lived, interim state between the unfolded and folded state. The interim state is apparent at 100 milliseconds—the time of the team's first observation. In this state, the molecule has become more compact or collapsed, but it is still in a random coil and not in its functional folded state. Bakajin notes that no one has directly observed and isolated this collapsed state before. "In principle, we should be able to study the properties of this very short lived state because it is separated from the folded state in our experiments."

The signals for each state—the initial unfolded, uncollapsed state; the interim collapsed state; and the final folded state—are quite different. Each is characterized by a different transfer efficiency—the rate that energy is transferred from the donor to the acceptor. The processes of collapse and folding can also be distinguished from each other. As shown in the figure below, the peak shifts from the lower transfer efficiency that corresponds to the unfolded, uncollapsed state to a higher efficiency, which corresponds to the collapsed state. During folding, the population of the collapsed state decreases while the population of the folded state increases. These changes alter the peak heights, which correspond to the protein-folding states, but the position of the peaks remain the same.

The microfluidic device that Bakajin and her colleagues developed allows scientists to monitor protein-folding kinetics in millisecond snapshots. But to clarify some of the faster events, scientists want to take measurements on time scales



Olgica Bakajin (left) and David Hertzog characterize the microfluidic mixers at Livermore's Biosecurity and Nanosciences Laboratory.



Histograms of the Forster Resonance Energy Transfer (FRET) efficiency, E_m, which is used to measure protein folding. As the fluorescent donor and emitter molecules move closer to each other, E_m increases, and higher E_m means more folded proteins. The red line shows the mean value for E_m in the unfolded state after mixing. (a) Protein is in equilibrium at the start of the experiment—most of the observed molecules are unfolded. (b) At 100 milliseconds, the peak has shifted, showing that the ends are closer together, but they are not folded. This is the interim, or collapsed, state. (c) By 1 second, E_m indicates that most of the proteins are in the folded state.

that are 1,000 times shorter. Present technology does not allow observation of single molecules at these extremely short time scales because the single dye molecules simply don't emit photons fast enough. Such measurements can be done by looking at many molecules at the same time, but for scientists to observe events on the microsecond scale, the protein-folding reaction must be initiated within that time frame.

To solve this problem, David Hertzog, a mechanical engineering graduate student at Stanford University, is working with Bakajin on a new microfluidics device that mixes reagents and initiates protein-folding reactions in microseconds. In this device, fluids travel as fast as 1 meter per second through a 10-micrometer-wide channel. Because of the tiny dimensions, miniscule amounts of protein are sufficient to perform measurements: 10 microliters is enough to run experiments continuously for 3 hours. Researchers are also working to improve the mixing time and background levels of the mixers for single molecule observations. Instead of using a tiny observation window of glass—which fluoresces and introduces some background photons—they are experimenting with windows of fused silica.

Predicting with Precision

To get a better handle on how the various parts of the string fold, says Bakajin, scientists plan to insert the donor and acceptor dye molecules in different areas of the protein strings. Another experiment researchers want to perform is to introduce mutations into the proteins or cut off parts of the chain and then see how those changes affect the folding process. The hope is that, given a sequence of amino acids and a specific environment, researchers will be able to predict not only a protein's final shape but also how it got there.

"This is important information for understanding and eventually treating diseases that result from misfolded proteins and for such ventures as creating designer drugs," says Bakajin. "Researchers believe that the folding process sometimes becomes derailed in the collapsed or interim states due to increased temperatures or acidity or other such factors. The Laboratory will be part of bringing this understanding to light through its novel microtechnology."

She points out that this project is also an example of how Livermore researchers collaborate with scientists and organizations outside the Laboratory, to develop technology that will also be useful for other Livermore projects. "Microfluidics is crucial for developing miniature detectors and sensors of all kinds," says Bakajin. "Such devices will be used not only in basic science research but also for homeland security applications. This project is just one of the opportunities we have to contribute to basic science using microfluidic technologies developed at Livermore."

—Ann Parker

Key Words: amino acids, fluorescence detection, microfluidics, protein folding kinetics.

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Patents and Awards

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

Patents

Thin Film Transistors on Plastic Substrates with Reflective Coatings for Radiation Protection

Jesse D. Wolfe, Steven D. Theiss, Paul G. Carey, Patrick M. Smith, Paul Wickboldt
U.S. Patent 6,642,085 B1
November 4, 2003
Fabrication of silicon thin-film transistors (TFTs) on low-temperature plastic substrates using a reflective coating so that inexpensive plastic substrates may be used in place of standard glass, quartz, and silicon-wafer-based substrates. These TFTs can be used in large-area, low-cost electronics, such as flat-panel displays, and in portable electronics, such as video cameras, personal digital assistants, and cell phones.

Polyacrylamide Medium for the Electrophoretic Separation of Biomolecules

Ramakrishna S. Madabhushi, Stuart A. Gammon
U.S. Patent 6,646,084 B2
November 11, 2003
A polyacrylamide medium for the electrophoretic separation of biomolecules. The polyacrylamide medium comprises high-molecular-weight polyacrylamides (PAAm) with a viscosity average molecular weight of 675 to 725 kilodaltons, which were synthesized by the conventional redox polymerization technique. Capillary electrophoresis of BigDye DNA sequencing standard was then performed using this separation medium. A single base resolution of about 725 bases was achieved in about 60 minutes in a noncovalently coated capillary with an internal diameter of 50 micrometers, an effective length of 40 centimeters, and a field of 160 volts per centimeter at 40°C. The resolution achieved when this formation is used to separate DNA is much superior (725 bases versus 625 bases) and faster (60 versus 75 minutes) than when the commercially available PAAm is used under identical conditions. The formulation method for synthesizing PAAm is straightforward and simple, and it does not require cumbersome methods such as emulsion polymerization to achieve very high molecular weights. Also, with this formulation, PAAm does not have to be separated from the reaction mixture before the polymer is reconstituted to a final concentration. Furthermore, the formulation is prepared from a single average-molecular-weight PAAm rather than from a mixture of two different ones.

Ruggedized Microchannel-Cooled Laser Diode Array with Self-Aligned Microlens

Barry L. Freitas, Jay A. Skidmore
U.S. Patent 6,647,035 B1
November 11, 2003
A microchannel-cooled, optically corrected, laser diode array is fabricated by mounting laser diode bars onto silicon surfaces. This approach allows for the highest thermal impedance in a ruggedized, low-cost assembly that includes passive microlens attachment without the need for lens frames. The microlensed laser diode array can be used in all solid-state laser systems that require efficient, directional pump sources with a narrow bandwidth and high-optical-power density.

Optical Probe with Light Fluctuation Protection

Luiz B. Da Silva, Charles L. Chase
U.S. Patent 6,647,285 B2
November 11, 2003
An optical probe for tissue identification includes an elongated body. Optical fibers are located within the elongated body for transmitting light to and from the tissue. Light fluctuation protection is associated with the optical fibers. In one embodiment, a reflective coating on the optical fibers reduces stray light. In another embodiment, a filler with very high absorption is located within the elongated body between the optical fibers.

Thin Film Capillary Process and Apparatus

Conrad M. Yu
U.S. Patent 6,649,078 B2
November 18, 2003
Method and system of forming microfluidic capillaries in various substrate materials. A first layer of a material such as silicon dioxide is applied to a channel etched in a substrate. A second, sacrificial layer of a material such as a polymer is deposited on the first layer. A third layer, which may be of the same material as the first layer, is placed on the second layer. The sacrificial layer is then removed to form a smooth-walled capillary in the substrate.

Silicon on Insulator Self-Aligned Transistors

Anthony M. McCarthy
U.S. Patent 6,649,977 B1
November 18, 2003
A method for fabricating thin-film, single-crystal silicon-on-insulator (SOI) self-aligned transistors. Standard processing of silicon substrates is used to fabricate the transistors. Physical spaces between the source and gate and between the drain and gate are introduced by etching the polysilicon gate material. These spaces provide connecting implants, or bridges, that allow the transistor to perform normally. After the silicon substrate processing is completed, the silicon wafer is bonded to an insulator (glass) substrate, and the silicon substrate is removed, leaving the transistors on the insulator (glass) substrate. Transistors fabricated by this method may be used, for example, in flat-panel displays.

Laser Peening of Components of Thin Cross-Section

Lloyd A. Hackel, John M. Halpin, Fritz B. Harris, Jr.
U.S. Patent 6,657,160 B2
December 2, 2003
The properties of a metal piece are altered by laser peening. The first side of the piece is laser peened using an acoustic coupling material that is operatively connected to the second side. Then the second side is laser peened using an acoustic coupling material that is operatively connected to the first side.

Passive Magnetic Bearing for a Horizontal Shaft

Richard F. Post
U.S. Patent 6,657,344 B2
December 2, 2003

A passive magnetic bearing is composed of a levitation element and a restorative element. The levitation element has a pair of stationary arcuate ferromagnetic segments located within an annular radial-field magnet array. The magnet array is attached to the inner circumference of a hollow shaft end. An attractive force between the arcuate segments and the magnet array acts vertically to levitate the shaft and in a horizontal transverse direction to center the shaft. The restorative element has an annular Halbach array of magnets, and a stationary annular circuit array is located within the Halbach array. The Halbach array is attached to the inner circumference of the hollow shaft end. A repulsive force between the Halbach array and the circuit array increases inversely to the radial space between them and thus acts to restore the shaft to its equilibrium axis of rotation when it is displaced therefrom.

Bistable Microvalve and Microcatheter System

Kirk Patrick Seward
U.S. Patent 6,663,821 B2
December 16, 2003

A bistable microvalve of shape memory material is operatively connected to a microcatheter. The bistable microvalve includes a tip that can be closed off until it is in the desired position. Once it is in position, it can be opened and closed. The system uses heat and pressure to open and close the microvalve. The shape memory material will change stiffness and shape when heated above a transition temperature. The shape memory material is adapted to move from a first shape to a second shape, either open or closed, where it can perform a desired function.

Inductrack Magnet Configuration

Richard F. Post
U.S. Patent 6,664,880 B2
December 16, 2003

A magnet configuration comprising a pair of Halbach arrays magnetically and structurally connected together are positioned with respect to each other so that a first component of their fields substantially cancels at a first plane between them, and a second component of their fields substantially adds at this first plane. A track of windings is located between the pair of Halbach arrays, and a propulsion mechanism is provided for moving the pair of Halbach arrays along the track. When the pair of Halbach arrays moves along the track and the track is not located at the first plane, a current is induced in the windings and a restoring force is exerted on the pair of Halbach arrays.

Sol-Gel Manufactured Energetic Materials

Randall L. Simpson, Ronald S. Lee, Thomas M. Tillotson, Lawrence W. Hrubesh, Rosalind W. Swansiger, Glenn A. Fox
U.S. Patent 6,666,935 B1
December 23, 2003

Sol-gel chemistry is used to prepare energetic materials (explosives, propellants, and pyrotechnics) with improved homogeneity, materials that can be cast to near-net shape, and/or those that can be made into precision molding powders. The sol-gel method is a synthetic chemical process wherein reactive monomers are mixed into a solution and polymerization occurs, leading to a highly cross-linked, three-dimensional solid network resulting in a gel. The energetic materials can be incorporated during the formation of the solution or during the gel stage. The composition, pore and primary particle sizes, gel time, surface areas, and density may be tailored and controlled by the solution chemistry. The gel is then dried using supercritical extraction to produce a highly porous, low-density aerogel or by controlled slow evaporation to produce a xerogel. Applying stress during the extraction phase can result in high-density materials. Thus, the sol-gel method can be used to manufacture precision detonator explosives and to produce precision explosives, propellants, and pyrotechnics as well as high-power composite energetic materials.

Awards

Former Laboratory Director **Bruce Tarter** has been named a **Fellow** of the **American Association for the Advancement of Science** (AAAS) under the section on Societal Impacts of Science and Engineering. Tarter is being honored for his “distinguished leadership of Lawrence Livermore National Laboratory in transforming the science base for post–Cold War national security and for sustained contributions to national science policy.” Alan Leshner, chief executive officer of AAAS and the executive publisher of *Science* magazine, called the award “a well-deserved recognition” for Tarter’s accomplishments.

Tarter served as Laboratory Director from 1994 to 2002, the second-longest tenure in Livermore’s history. During those years, he was instrumental in leading the Laboratory from its Cold War missions to its current focus on national security through science-based stockpile stewardship and nonproliferation programs.

The **American Physical Society** (APS) has selected five Laboratory physicists as **APS Fellows**.

John Castor, from the Defense and Nuclear Technologies Directorate’s AX Division, was recognized for “groundbreaking work on radiatively driven stellar winds, and contributions to the theory of opacities, equations-of-state, and radiation hydrodynamics, including national security applications in high-energy-density physics.”

Theoretical astrophysicist **Richard Klein**, also in AX Division, was selected for “pioneering contributions in computational astrophysics including star formation, radiatively driven stellar winds, instabilities in supernovae and magnetized neutron stars, and scaled laser experiments simulating strong shock phenomena in the interstellar medium.”

Giulia Galli, who leads the Quantum Simulations Group in the Physics and Advanced Technologies (PAT) Directorate, was cited for her “important contributions to the field of ab initio molecular dynamics and to the understanding of amorphous and liquid semiconductors and quantum systems.”

Erich Ormand, the acting group leader for Nuclear Theory and Modeling in the PAT Directorate, was cited for his “important contributions to nuclear structure physics, including both the ab initio shell-model calculations and the Monte Carlo approach; and for his contributions to nuclear physics as applied to the Stockpile Stewardship.”

Christian Mailhiot, who leads the Materials Science and Technology Division in the Chemistry and Materials Science Directorate, was recognized for his “outstanding contributions and scientific leadership in theoretical and computational condensed matter and materials physics, with particular emphasis on innovative discoveries related to quantum-confined semiconductor structures and high-pressure research.”

A sixth APS Fellow from Livermore, **Steven Hatchett**, was named earlier in 2003 (see *S&TR*, January/February 2004, p. 24).

Each year, no more than one-half of 1 percent of the current APS membership is recognized by their peers through election to the status of fellow. APS fellowship recognizes members who have made advances in knowledge through original research and publication, or those who have made significant and innovative contributions in the application of physics to science and technology. APS fellows also may have made significant contributions to the teaching of physics or service and participation in the activities of the society.

APS also has honored **Siegfried Glenzer** with its **2003 Award for Excellence in Plasma Physics Research**. Glenzer, who was named an APS Fellow in 2001, is group leader for Plasma Physics in the National Ignition Facility (NIF) Programs Directorate. In 2003, he became the first researcher to conduct scientific experiments in the NIF target chamber. APS honored Glenzer “for elegant diagnostics using collective Thomson scattering together with X-ray spectroscopy, which greatly advanced the understanding of the complex plasma environment in laser driven hohlraums used in inertial confinement fusion.”

Optical physicist **Gary Sommargren** has been awarded the **Lifetime Achievement Award** from the **American Society for Precision Engineering**. The lifetime achievement award is designated to those individuals who, over the span of their careers, made significant contributions to the science and discipline of precision engineering. Sommargren has devoted most of his career to solving problems in optical metrology, both at the Laboratory and at Zygo Corporation, where he worked from 1981 to 1991.

Lawrence Livermore National Laboratory has received a **Longevity Award** from the **Ombudsman Association**, the largest group representing ombuds in the U.S. and Canada. The award is given to organizations that have had an ombuds program for more than 10 years. Ombuds services have existed in some of Livermore’s organizations since the 1970s. In 1997, these services were expanded Laboratory-wide in response to employee suggestions.

(Continued from p. 2.)

The EDI can be used to precisely measure small shifts in Doppler velocity. These shifts in the wavelength of starlight are caused by the motion of a planet around a star. Light passing through the periodic fringes of an interferometer and into the spectrograph creates a moiré pattern. This moiré pattern shifts transversely in proportion to the Doppler velocity. The EDI eliminates atmospheric distortions, which can reduce the precision in Doppler or spectroscopic measurements.

In 1999, when Erskine and his team tested the system at the University of California's Lick Observatory on Mount Hamilton, they found that the EDI reduces the distortion of starlight. More recently, using information in the moiré patterns with special software, they demonstrated that the EDI can boost the spectrograph resolution at Lick by two times.

Erskine realized the EDI could also be used to improve the time resolution and stability of streak cameras, such as those used in experiments at the National Ignition Facility. Such a boost in time resolution is analogous to the increase in spectral resolution for astrophysical measurements.

Other potential applications for the EDI include high-resolution spectroscopy over a broad bandwidth, boosting the resolution and stability performance of existing spectrograph facilities, and searching for exoplanets by measuring stellar angular positions. More information on the improved spectral resolution from the EDI is available in the August 1, 2003, issue of *Astrophysical Journal Letters.*

Contact: David Erskine (925) 422-9545 (erskine1@llnl.gov).

Rich Legacy from Atoms for Peace

In 2003, Livermore's Center for Global Security Research examined the rich legacy of President Dwight D. Eisenhower's Atoms for Peace speech. In this historic speech, which he gave to the United Nations General Assembly in 1953, Eisenhower called on world leaders to move toward peaceful rather than destructive uses of nuclear technology. In the past 50 years, scientists and engineers at Lawrence Livermore have had many opportunities to contribute to this legacy by adapting expertise and technologies originally derived from nuclear weapons research for use in civilian applications that improve human health, energy, and the environment. For example, Laboratory scientists have developed energy alternatives such as converting coal beds into natural gas without mining, and they continue to explore magnetic and inertial confinement fusion as future sources of energy. The National Atmospheric Release Advisory Center at Livermore has provided emergency response assistance in events such as the Three Mile Island nuclear power plant emergency, the Chernobyl accident, and oil-well fires in Kuwait. Laboratory-developed radiation detection systems assist the U.S. and Russia in nonproliferation and stockpile stewardship of nuclear materials and enhance homeland security with an array of portable radiation detectors for various environments. Nuclear technology has also been adopted to improve medical diagnostics and treatment applications.

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Tropopause Height Becomes Another Climate-Change "Fingerprint"

An international team of scientists, led by researchers from Lawrence Livermore, has discovered that emissions from human activities are largely responsible for a significant increase in the height of the tropopause, the boundary between the troposphere and the stratosphere. The research was based on advanced climate models, which showed that human-induced changes in ozone and well-mixed greenhouse gases are the primary causes of the approximately 200-meter rise in the tropopause that has occurred between 1979 and 1999. The team used the Department of Energy's Parallel Climate Model, a three-dimensional global climate model designed for parallel supercomputers. The model-predicted patterns, or fingerprints, of tropopause height change were positively identified in reanalyses, which are combinations of observations and weather forecasts. The change in the height of the tropopause provides another fingerprint of human effects on climate.

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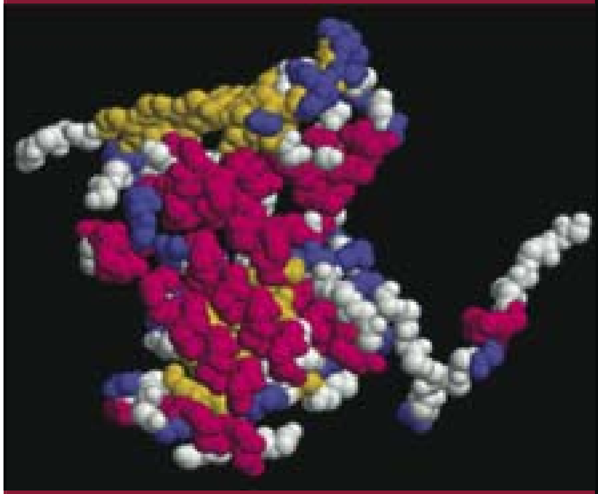
Coming Next Month

Using DNA to Detect Pathogens



Livermore scientists are developing DNA-based signatures that can be used to quickly and accurately identify lethal pathogens and counter a bioterrorist attack.

Also in April

- *An engineered barrier system for the proposed repository at Yucca Mountain, Nevada, is designed to keep nuclear waste in its place.*

- *A Livermore-developed combat simulation program has been modified for homeland security planning and training.*

- *Computer models are helping Laboratory engineers better understand the homogenous compression charge ignition engine—a fuel-efficient engine with greatly reduced emissions.*

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