Lawrence Livermore National Laboratory

2000 Annual Report

Managed by the University of California
for the U.S. Department of Energy

Lawrence Livermore National Laboratory was founded in 1952 as a nuclear weapons research facility. The Laboratory has been managed since its inception by the University of California, first for the Atomic Energy Commission and now for the National Nuclear Security Administration within the U.S. Department of Energy. Through its long association with the University of California, the Laboratory has been able to recruit a world-class workforce and establish an atmosphere of intellectual freedom and innovation, both of which are essential to sustained scientific and technical excellence. As an NNSA national laboratory with about 8,000 employees, Livermore has an essential and compelling core mission in national security and the capabilities to solve difficult, important problems.

2000 ANNUAL REPORT

Contents

NATIONAL SECURITY

PAGE 4

Providing for National Security in a Changing World **4**
- Stockpile Stewardship—Attending to Stockpile Needs 6
- Stockpile Stewardship—Modeling and Experiments 8
- Stockpile Stewardship—Greater Capabilities to Come 10
- Proliferation Prevention and Detection 12
- Response to Proliferation and Other Security Threats 14

NATIONAL NEEDS

PAGE 16

Meeting Enduring National Needs **16**
- Improving Energy Security and Environmental Management 18
- Advancing Bioscience to Improve Human Health 20
- Pursuing Breakthroughs in Science and Technology 22

SHAPING THE FUTURE

PAGE 24

Positioning the Laboratory for the Future **24**
- Secure, Safe Operations and a Good Neighbor 26
- New Capabilities through Partnerships 28
- Award-Winning Science and Technology 30
- About the Laboratory's People and Programs 32

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C. Bruce Tarter, *Director*

During especially challenging periods in Lawrence Livermore's nearly half century of service to the nation, Laboratory personnel have always responded with extraordinary efforts. Over the past two years, we faced major challenges both to our programs and to the way we operate. The Laboratory's staff responded with significant technical achievements and marked improvements in operations. Exceptional people make Livermore an exceptional national laboratory.

The Laboratory's workforce is motivated by the opportunity to advance science and technology to meet important national needs. Our multidisciplinary research and development are directed toward the Department of Energy's (DOE) mission areas—national security, energy resources, environmental quality, and science and technology. Because Livermore is one of the three national laboratories that are part of the National Nuclear Security Administration (NNSA) within DOE, national security is our defining responsibility. As an outgrowth of that responsibility, the Laboratory has unique capabilities, which we also apply to advance bioscience and address emerging issues related to energy resources and environmental management.

Livermore scientists and engineers, in collaboration with other elements of NNSA, provide the expertise that makes it possible in the absence of underground nuclear testing for the United States to maintain a safe and reliable nuclear weapons stockpile—a supreme national interest. Laboratory researchers are also working with DOE and other organizations to improve the nation's capabilities to stem the proliferation of weapons of mass destruction.

Our national security responsibilities require us to push the frontiers of science and technology. Our largest frontier project is the National Ignition Facility (NIF), which will be the world's largest laser when completed and capable of producing fusion in a laboratory setting. NIF is one of the pillars of the Stockpile Stewardship Program. It is an extraordinarily challenging undertaking that has required breakthrough development of many enabling technologies and a close partnership with many high-tech industries. Through the exceptional efforts of the NIF project team, NIF is becoming a reality. Recently, new baseline project plans for NIF were certified to Congress by General John Gordon, NNSA Administrator.

The Accelerated Strategic Computing Initiative, or ASCI, is another pillar of the Stockpile Stewardship Program. In an outstanding partnership with IBM, we now have at Livermore the world's most powerful computer, ASCI White. Livermore scientists are using the machine to vastly improve simulations of weapons physics. And as this report highlights, researchers in each of Livermore's major programs use high-performance simulation as a powerful tool for scientific discovery and engineering development.

Our staff also responded to challenges in Laboratory operations. We made numerous upgrades to security—particularly cybersecurity—to protect sensitive information, which is increasingly in electronic form. We also implemented DOE's Integrated Safety Management System in 2000, resulting in better safety practices and greater safety awareness.

Our accomplishments in 2000 are a credit to the dedicated employees at the Laboratory. This annual report exemplifies only some of their fine work. At Livermore, we are dedicated to ensuring national security and applying science and technology to the important problems of our time.

C. Bruce Tarter

2000 in Review News and

January

Adaptive Optics

The clearest images ever taken of Titan (Saturn's largest moon) and Neptune were revealed at an American Astronomical Society meeting in Atlanta. The infrared-light images were among the first taken at Hawaii's Keck II telescope after installation of Livermore-developed adaptive optics technologies that help compensate for atmospheric turbulence.

February

Energy and Environment

Director Bruce Tarter took steps to form an Energy and Environment Directorate, which merged important ongoing programs for DOE in nuclear materials management; environmental risk reduction and remediation; and energy, carbon, and climate modeling. Livermore activities in these thrust areas are closely linked to our national security mission.

March

Russian Programs

The Laboratory, Fresenius Medical Care AG, and the Avangard Foundation signed a contract for Avangard to manufacture components for kidney dialysis machines in the closed city of Sarov. This contract represents a major milestone in the United States' effort to engage a Russian nuclear weapons production facility and create civilian jobs for displaced workers.

July

ASCI White Computer

Following delivery from IBM, installation began of the world's fastest supercomputer as part of DOE's Accelerated Strategic Computing Initiative (ASCI). The ASCI White machine, capable of 12 trillion operations per second, is needed to simulate in 3D the performance of nuclear weapons. The Laboratory is at the forefront of terascale scientific computing.

August

Subcritical Experiments

Oboe 5, the Laboratory's eighth subcritical experiment, was conducted to better understand the behavior of plutonium when it is strongly shocked and how that behavior depends on the metal's age. The Oboe tests are the first to be performed inside individual confinement vessels in a reusable underground chamber at the Nevada Test Site.

September

Safety Management

After inspecting safety procedures at 25 facilities and reviewing more than 700 supporting documents, a DOE Verification Team determined that Integrated Safety Management has been effectively implemented at Livermore. Safety and security are top priority in all operations at Livermore, and we have taken steps to ensure a high level of performance in both areas.

Accomplishments at the Laboratory

April

Human Genome

The DOE Joint Genome Institute (JGI) Production Sequencing Facility announced completion of a "working draft" of the sequence for chromosomes 5, 16, and 19—DOE's responsibility in the international Human Genome Project. The JGI is made up of genome researchers from Berkeley, Livermore, and Los Alamos national laboratories.

May

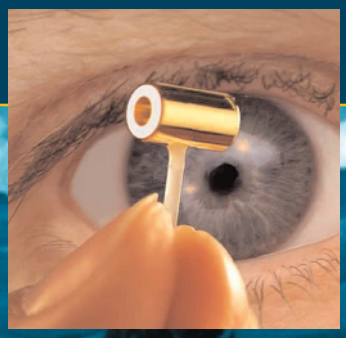
National Ignition Facility

DOE Secretary Bill Richardson announced that his interim report to Congress would define the path forward for National Ignition Facility (NIF) construction. The importance of NIF to stockpile stewardship, completion of the project's comprehensive rebaseline, and "spectacular technical successes" contributed to his decision and subsequent Congressional actions.

June

NNSA

General John A. Gordon became Administrator of the newly formed National Nuclear Security Administration (NNSA) and DOE Under Secretary for National Security. He has visited the Laboratory several times to learn more about our programs and meet staff as he sets the direction for the new agency, which brings together DOE's national security functions.



October

Health-Care Technology

PEREGRINE, a revolutionary tool for analyzing and planning radiation treatment for cancer patients, was granted clearance by the U.S. Food and Drug Administration. One of many advanced health-care technologies developed by Livermore researchers, PEREGRINE systems are being produced and marketed to the medical community by a licensee.

November

UC Contract

DOE and the University of California (UC) entered into negotiations to modify and extend UC's contract to manage the Laboratory. The contract has been extended to 2005, preserving Livermore's association with the university, which is important to intellectual vitality at the Laboratory and to recruitment and retention of a quality workforce.

December

Distinguished Science

Six Laboratory scientists earned the rank of fellow in distinguished societies—the American Physical Society and American Association for the Advancement of Science. Exceptional performance by Livermore employees and scientific and technical excellence are vital to the success of the Laboratory's research and development programs.

National Security

Lawrence Livermore National Laboratory was established in 1952 to help ensure national security through the design, development, and stewardship of nuclear weapons. National security continues to be the Laboratory's defining responsibility.

Threats to national security and global interests keep the United States actively engaged in world events at the beginning of the 21st century. The U.S. is committed to halting the spread of nuclear as well as chemical and biological weapons worldwide while maintaining sufficient nuclear forces to deter any adversary. Lawrence Livermore National Laboratory contributes to these important endeavors.

Providing for National Security in a Changing World

A Part of the NNSA

Livermore is one of the three national security laboratories that are part of the National Nuclear Security Administration (NNSA), which began operation within DOE in March 2000. With General John A. Gordon serving as its first administrator, NNSA brings together DOE's national security functions, a clear mission, and unique responsibilities.

Safe and Reliable Nuclear Weapons

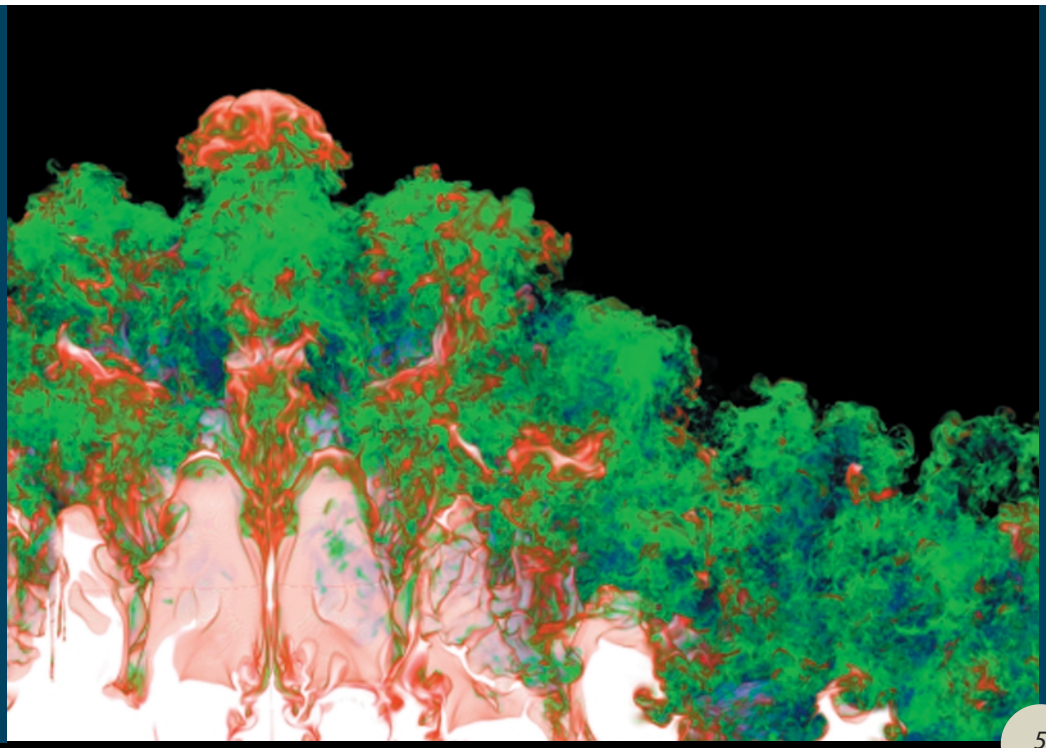
Livermore plays a prominent role in the Stockpile Stewardship Program for maintaining the safety and reliability of the nation's nuclear weapons in the absence of nuclear testing. Working with the other NNSA laboratories, we are attending to the immediate needs of the stockpile through assessments and actions based on a combination of laboratory experiments and computer simulations of nuclear weapon performance. We are also acquiring more powerful experimental and computational tools to address the more challenging issues that will arise as the nation's nuclear weapons stockpile continues to age.

Proliferation Prevention and Arms Control

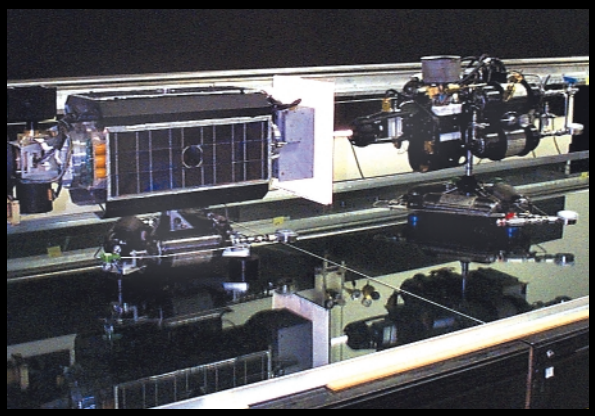
The Laboratory is addressing the dangers posed by the proliferation of

Congressional interest in stockpile stewardship remains high. The establishment of the NNSA, workforce quality and diversity, and the rebaselining of the National Ignition Facility (NIF) were priority issues for Representative Ellen Tauscher (10th District, California), a frequent visitor to the Laboratory. She and Representative Mac Thornberry (center, 13th District, Texas), both members of the House Armed Services Committee, met with Director Bruce Tarter and toured NIF (right photo) in December 1999.

High-resolution, three-dimensional (3D) scientific simulations using Accelerated Strategic Computing Initiative (ASCI) supercomputers are central to stockpile stewardship. An 8-billion-zone simulation recently revealed fine-scale physics of turbulence never seen before. The calculation generated more than 2 terabytes (2 million megabytes) of graphics data in more than 300,000 files.



nuclear as well as chemical and biological weapons through a wide spectrum of analysis and technology development activities. In addition, Livermore provides the government with technical information and assistance to support the development of national policy on nuclear weapons, nonproliferation, and arms control.



An engineering test vehicle (ETV) at Livermore demonstrates critical capabilities that future microsatellites will need to perform complex autonomous operations in the proximity of other space objects. With its novel object-tracking system and miniaturized propellant system, the ETV has repeatedly succeeded in docking with another object in dynamic experiments on an air table that simulates zero-gravity conditions.

Technology for New Security Requirements

Building on the scientific and technical capabilities needed for the Laboratory's stockpile stewardship and nonproliferation missions, Livermore develops advanced defense technologies for the Department of Defense (DoD) and other sponsors to increase the effectiveness of U.S. military forces and meet emerging national security needs.

A technician trained in handling fissile material inspects a plutonium part for an experiment at Livermore's plutonium facility. The Laboratory supports the Stockpile Stewardship Program through basic research on the properties of plutonium and surveillance of pits from Livermore-designed weapons. In leading the national plutonium immobilization program, we have developed and demonstrated hardware alternatives for plutonium storage.

As a principal participant in the nation's Stockpile Stewardship Program, Livermore is committed to maintaining confidence in the safety and reliability of the U.S. nuclear weapons stockpile. The program is extraordinarily demanding because the nuclear weapons in the stockpile continue to grow older, and we are challenged to ensure their performance and refurbish them as necessary without conducting nuclear tests.

The Stockpile Stewardship Program integrates the activities of the U.S. nuclear weapons complex, which includes Livermore, Los Alamos, and Sandia national laboratories as well as the four production sites and the Nevada Test Site.

Stockpile Stewardship—Attending to Stockpile Needs

The Laboratory's activities involve weapons systems in all three legs of the U.S. strategic triad. We are completing the Life Extension Program for the W87 ICBM warhead; we are the design laboratory for the B83 bomb; we are beginning life-extension work on the W80 cruise missile warhead; and we are an integral part of the SLBM Protection Program.

Certifying Stockpile Safety and Reliability

In April 2000, the Secretaries of Energy and Defense certified to the President that the U.S. nuclear stockpile is safe and reliable and that no nuclear tests are needed at this time. This formal annual certification, which was the fourth since the inception of the Stockpile Stewardship Program, was based on technical reviews and independent evaluations conducted by Livermore, Los Alamos, and Sandia national laboratories. It is our responsibility to provide the President with accurate assessments of the safety, reliability, and performance of each weapon system in the nation's nuclear stockpile.

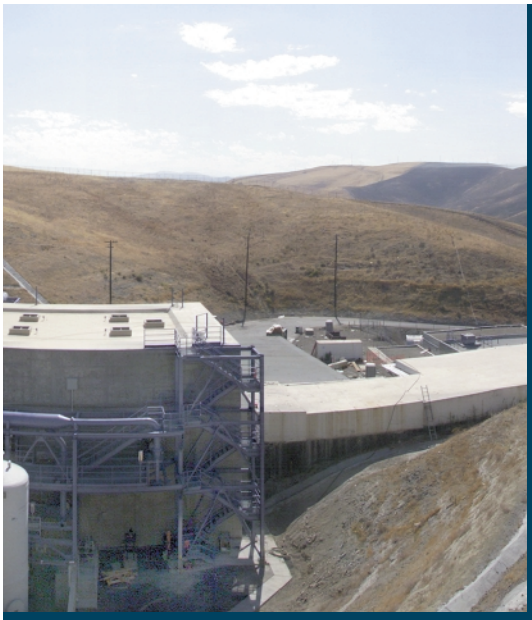
Final Certification of W87 Nears Completion

Livermore's W87 Life Extension Program, begun in late 1994, met all its major milestones. Refurbished W87s are being delivered to the Air Force after assembly at the Pantex Plant. Refurbishment of the W87 ICBM warhead (the design with the most modern safety features in the stockpile) extends the lifetime of the weapon to beyond 2025.

The Laboratory's activities are directed toward final certification of the restockpiled weapons, which is expected in 2001. In summer 2000, we finished a final set of ground tests. We also flight-tested production verification units aboard a Peacekeeper missile launched in March 2000. No additional nuclear testing of the W87 is required to assure system reliability. Assessment of nuclear performance and subsequent certification are based on computer simulation, past nuclear tests, and new aboveground experiments that address specific physics issues.

Growing Stockpile Responsibilities

Lawrence Livermore and Sandia Livermore are assuming responsibility for the W80 Life Extension



With construction completed, the Contained Firing Facility at Site 300 (left) is undergoing qualification testing to assure the facility's ability to contain debris from hydrodynamic tests of mock weapon primaries. With the flash x-ray machine (right) taking multiple images during each experiment, the facility is designed to conduct tests that use up to 60 kilograms of high explosives.

Program. The W80, designed by Los Alamos, is deployed in air-launched and sea-launched cruise missiles. Plans for this life-extension program will draw on the results of a W80 Dual Baseline study, an in-depth assessment of refurbishment options to be completed by Livermore, Los Alamos, and Sandia in FY 2001. The schedule calls for the first production unit of the refurbished warheads in FY 2006. As refurbished W80 units enter the stockpile, Livermore will be responsible for continuing evaluations of their performance. Los Alamos will retain this responsibility for W80s not yet refurbished.

In addition, pits from Livermore-designed weapons will now be thoroughly examined at facilities for handling special nuclear materials in Livermore's Superblock. These stockpile surveillance activities previously had been conducted at Los Alamos.

Reassignment of responsibilities for the W80 and pit surveillance better balances activities at the two laboratories to maintain the performance of stockpiled weapons. These new activities supplement the W87 Life Extension Program and our work with the U.S. Navy on an SLBM Warhead Protection Program. That program, now nearing completion, has been a five-year development effort by the NNSA laboratories to examine warhead pit reuse to meet the Navy's future warhead needs. Activities have included analyses, extensive ground testing, and a high-fidelity flight test conducted in April 2000 to measure flight dynamics.

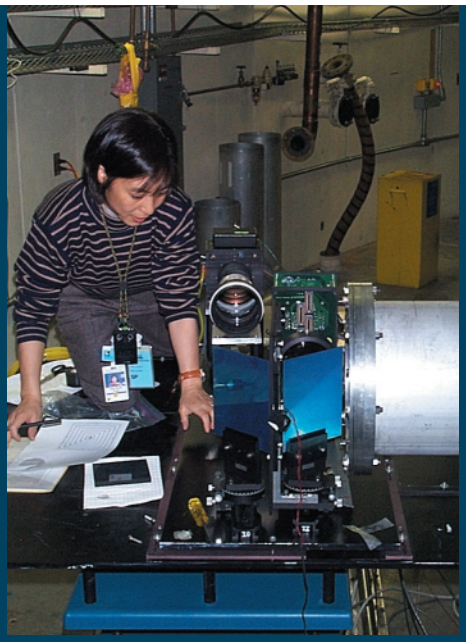
Independent Reviews of Weapon Systems

With publication of Livermore's W76 Dual Revalidation Report in April 2000, the Laboratory completed its responsibilities in a four-year-long reevaluation of the W76 SLBM warhead. The dual revalidation consisted of assessments by Los Alamos, which designed the warhead, and Livermore, which pursued extensive experimental and computational work to evaluate W76 performance.

In the absence of nuclear testing, the nation increasingly must rely on independent assessments by the NNSA laboratories—whose expert judgment is supported by computational models and experimental tools—to ensure the safety and reliability of weapons in the stockpile.

At Livermore's Hardened Engineering Test Building, specialists from the two laboratories prepare a drop test to validate the shock load performance of the Los Alamos–designed B61 earth-penetrator bomb.

Decisions and actions about the stockpile must be grounded in experimental reality. In the past, that reality included nuclear testing. Now, we ensure stockpile performance using laboratory experiments and computer modeling to achieve a much more sophisticated understanding of the underlying physics and engineering issues.



A Livermore physicist checks an imaging station and Laboratory-designed detectors at the end of the proton beamline at the Los Alamos Neutron Science Center. Together with Los Alamos scientists, we are exploring the possibility of using protons instead of x rays to create radiographic images for studies of nuclear weapons.

Stockpile Stewardship—Modeling and Experiments

At Livermore, this two-stage gas gun accelerates projectiles to speeds of 8 kilometers per second to produce in a target a shock wave that is millions of times atmospheric pressure. We are bringing the Joint Actinide Shock Physics Experimental Research (JASPER) Facility into operation at the Nevada Test Site. With JASPER, researchers will perform important gas-gun experiments using uranium and plutonium targets.

Subcritical Experiments Study Plutonium

We successfully completed six of the eight planned subcritical experiments that compose the Oboe series, including four tests in 2000. Conducted in an underground tunnel at the Nevada Test Site, these highly instrumented experiments provide data on the behavior of plutonium when it is strongly shocked and how that behavior differs depending on the plutonium's age. These tests, which complement simulations and laboratory experiments, help us understand how aging-related changes in plutonium affect the performance of stockpiled weapons.

Because we want to achieve test conditions, high explosives are detonated next to samples of plutonium. No critical mass is formed in the process, so no nuclear fission chain reaction occurs as it would in a nuclear detonation. Tests are instrumented with high-speed diagnostics, including a laser-based system that obtains holographic images of plutonium ejecta flying out from the shocked surface at the moment of explosion. The film images, when projected with a laser, allow experimenters to see in 3D a cloud of plutonium and analyze the size, shape, and velocity of the particles.

The Oboe tests are the first to be performed inside individual confinement vessels. Personnel enter the underground test chamber to retrieve films and data after the test, once the chamber is determined to be free of contamination. The use of vessels for subcritical experiments is significantly reducing costs. Previously, each subcritical experiment took a minimum of one year to field and rendered unusable all diagnostic equipment in the test chamber.

A Better Model of High-Explosive Detonation

By linking two previously separate physics models, Livermore scientists now have a much better capability to simulate the detonation of high explosives. One of the codes, CHEETAH, models the chemical kinetics and thermodynamics involved in a detonation. Developed at the Laboratory with support from both DOE and DoD, CHEETAH is widely used within the defense community to evaluate new high explosives. CHEETAH is

Equipment typically used for making subway tunnels (left) carves out Livermore's underground test facilities. In a finished alcove (right), Livermore and Bechtel Nevada workers lower a package of plutonium and explosives into the heavily instrumented containment vessel for an Oboe subcritical experiment.

linked to the ARES hydrodynamics code. In the resultant simulation, as ARES determines the motion of the materials, CHEETAH provides at each time step the state of chemical reactions and equation-of-state data for the relevant intermediate and reaction products, which affect subsequent hydrodynamic performance.

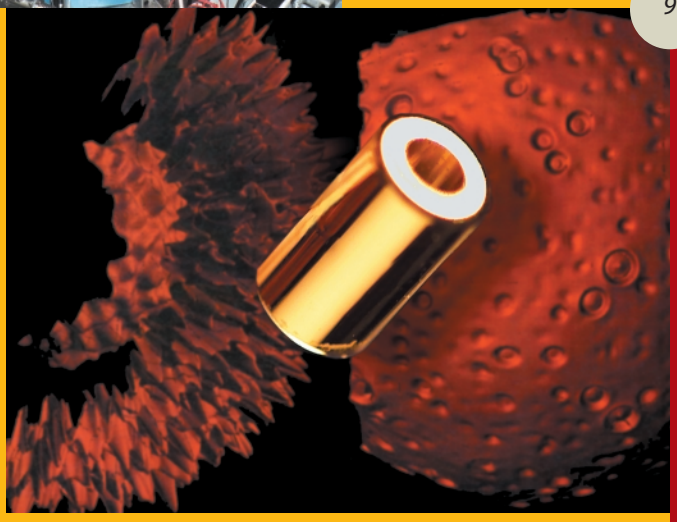
Better data increase the accuracy of the simulation models. Experiments are being performed to obtain improved equation-of-state data for the materials—such as carbon dioxide—produced by high-explosives detonation. Researchers used Livermore's diamond anvil cell to study carbon dioxide at extreme conditions and, in the process, created two forms of solid carbon dioxide never seen before in the laboratory.

3D Weapons Physics Simulations

Increasingly sophisticated 3D simulations of weapons physics are being made possible by successively more powerful computers, which have been installed at the Laboratory as part of the DOE's Accelerated Strategic Computing Initiative. Three-dimensional simulation is critically important: nuclear explosion phenomena are seldom symmetric because of aging and manufacturing variations.

Livermore researchers achieved a major milestone in the Stockpile Stewardship Program in late 1999 with the first-ever 3D simulation of a nuclear-weapon primary explosion. The next step in the full-system modeling of weapon performance is a 3D simulation of the thermonuclear burn of a weapon secondary. Such work is in progress using the ASCI White supercomputer.

In addition to the codes developed to simulate nuclear weapon performance, the Laboratory has developed the HYDRA code, which was used in 2000 to simulate in 3D the performance of targets that might be used in the National Ignition Facility to achieve ignition and thermonuclear burn. The simulations were run on 1,680 processors of the Blue Pacific computer using a mesh of more than 16 million zones. HYDRA was also used to model the results of hydrodynamic instability experiments performed on the Laboratory's Nova laser and the University of Rochester's Omega laser.



In a 3D HYDRA simulation using over 16 million zones, we studied the growth of hydrodynamic instabilities due to surface roughness in a target capsule for the National Ignition Facility. Two surfaces of constant density (left) are shown prior to thermonuclear ignition; a contour of the rebounding shock at ignition time is on the right. A typical NIF capsule is shown in the foreground.

The greatest challenges in stockpile stewardship lie ahead, as weapons continue to age. Success depends on bringing into operation vastly improved scientific capabilities, which will be used by our experienced nuclear weapons designers to train the next generation of stockpile stewards, who will rely on the new tools. At Livermore, we are acquiring powerful supercomputers to better simulate weapons performance, and we are constructing the National Ignition Facility to perform needed thermonuclear physics experiments.

Stockpile Stewardship—Greater Capabilities to Come

In 28 tractor-trailer trucks from Poughkeepsie, New York, the IBM ASCI White supercomputer—the world's fastest and most powerful—was delivered to the Laboratory during summer 2000. The machine is powered by 8,192 IBM RS/6000 processors and covers an area the size of two basketball courts. ASCI White has enough memory to hold six times the entire book collection of the Library of Congress.

World's Most Powerful Computer

In summer 2000, Livermore became home to the world's most powerful supercomputer with the delivery from IBM of ASCI White, which is capable of performing over 12 trillion operations per second (12 teraops). The ASCI White machine was acquired through the Accelerated Strategic Computing Initiative (ASCI), a key component of the Stockpile Stewardship Program. ASCI is rapidly advancing the state of the art in computers, modeling techniques, and data-management tools needed to simulate the performance of nuclear weapons.

ASCI White is based on the next-generation IBM processor, node, and switch technology. It has 512 nodes, each with 16 processors. Exceeding its contractual performance requirements, the machine is about three times faster than Livermore's Blue Pacific computer, which was used to perform the first-ever 3D simulation of an exploding nuclear weapon primary. About 100,000 times more powerful than a typical desktop computer, ASCI White provides over 12 terabytes (trillion bytes) of main memory and over 147 terabytes of global disk space.

The advanced computing capabilities made possible by ASCI move us closer to the goal of performing full-scale simulations of weapons performance based on first-principles physics without resorting to simplified models. These new capabilities—on smaller, unclassified systems—offer future unprecedented levels of understanding in climate and weather modeling, environmental studies, the design of new materials, and many areas of physics.

NIF Plans Revised as Construction Continues

Construction continued at Livermore on the National Ignition Facility (NIF) as the NIF project team developed a rebaselined plan for finishing the project. The new baseline plan was validated and approved by DOE in September. It calls for laser operations to begin in FY 2004 and completion of the project in FY 2008.

Conventional construction for NIF is essentially completed, and installation of the laser beampath infrastructure is under way. The 118,000-kilogram target chamber, a 10-meter-diameter aluminum sphere, has been installed, leak-tested, and prepared for additional shielding. Mounted on the chamber's outer surface will be hundreds of diagnostic instruments and 48 final optics assemblies that will convert the laser pulses from infrared to ultraviolet and focus the light precisely on a target the size of a BB-gun pellet.

The NIF project was rebaselined to enhance the planned method of assembling and integrating the lasers and to ensure that strict beampath cleanliness requirements would be met. The NIF project team contracted with experts from industry to implement plans for installing laser components, and the team took steps to greatly improve project management.

In parallel, exceptional progress was made on many technical fronts. In September 2000, DOE's Energy Systems Acquisition Advisory Board approved the new NIF baseline, and the Secretary of Energy submitted his certification of the NIF project plans to Congress. The Secretary of Energy's Advisory Board (SEAB) also concluded that the corrective actions undertaken by the NIF project team together with the revised cost and schedule baseline in the Secretary's report to Congress are sufficient to permit the NIF project to be completed as planned.

Construction activities in 2000 bring the conventional facilities to 95 percent completion—both for the optics assembly building and the stadium-size laser building with its laser and capacitor bays, laser-beam switchyards, and target bay. The NIF integration management and installation contractor is making great progress installing the enclosures for the laser beams and support systems. Over 1,000 tons of beampath infrastructure were in place by January 2001. The design of line-replaceable units—modular components that constitute the special laser, target, and optical equipment—is nearly complete, and more than 1,000 laser glass slabs meeting NIF specifications have been produced.

With the world's most powerful laser in NIF, many fundamental processes of thermonuclear ignition and burn soon will become accessible for laboratory study and analysis. By focusing its energy on a BB-size target for a few billionths of a second, NIF will generate in experiments the temperatures and pressures needed to validate weapons-physics computer codes and address important issues of stockpile stewardship.

The development of improved methods for manipulating and interpreting terabytes of data is an important focus of ASCI. Livermore researchers test the usefulness of new visualization tools—a novel desktop display and "data gloves" that allow the user to reach out and seemingly move and examine images.

Design is completed for the Terascale Simulation Facility, which will house Livermore's next supercomputer after ASCI White. The $89-million facility will include a computer complex with about an acre of floorspace as well as office space for a growing staff of computer and physical scientists who support ASCI.

The proliferation of nuclear, chemical, and biological weapons, collectively referred to as weapons of mass destruction (WMD), is of grave concern to U.S. security. We are tackling the problem of proliferation across the entire spectrum of the threat, from preventing proliferation at the source, to detecting and reversing proliferant activities, to responding to the threatened or actual use of such weapons.

Proliferation Prevention and Detection

Livermore's Center for Global Security Research (CGSR) organized and hosted the After Globalization Conference attended by Vice Admiral Arthur Cebrowski (left photo, left foreground) and Former Secretary of State George Shultz (right foreground). CGSR Director Ronald Lehman (right photo, center) was a principal participant in the formal dedication of the Open Computing Center at Snezhinsk, Russia.

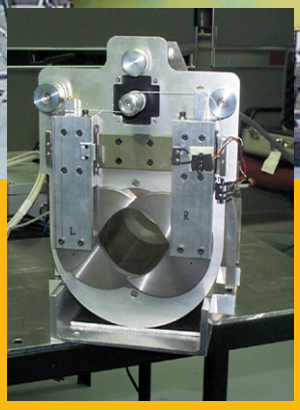
Reducing the Russian Nuclear Threat

Since the early 1990s, the U.S. and Russia have engaged in a range of negotiations designed to reduce the danger from nuclear weapons. Issues have included shutting down plutonium-producing reactors, monitoring nuclear stockpiles, inspecting stored nuclear material, and disposing of excess plutonium. Many of these negotiations have floundered on the shoals of the classified information that would need to be exchanged in order to verify the agreements.

As a way out of this impasse, Livermore and Los Alamos developed the concept of an information barrier—a set of hardware, software, and procedures—to allow measurements on classified objects but prevent classified information from being revealed to inspectors. We demonstrated such a system to Russian scientists and security specialists in August 2000 at Los Alamos. The Fissile Material Transparency Technology Demonstration consisted of measurements on a number of unclassified authentication sources as well as measurements on a weapon component. The extremely successful demonstration is enabling valuable headway on this difficult but essential treaty-monitoring issue of exchanging just the required information.

Through the DOE's Material Protection, Control, and Accounting (MPC&A) program, we are working to improve the security of Russia's weapons-usable nuclear materials. Livermore leads MPC&A project teams at Chelyabinsk-70, Sverdlovsk-44, the Bochvar Institute, and Krasnoyarsk-45. We are also working with the Northern and Pacific Fleets of the Russian Navy to enhance the protection of the nuclear fuel for their nuclear-powered vessels. This work involves direct interactions with the Russian Ministry of Defense, an activity that would have been inconceivable during the Cold War.

Livermore researchers examine the Russian-designed and -built plutonium oxide salt washer that is being tested for use in the U.S. plutonium disposition program. We are helping make nuclear materials more secure in the United States and worldwide.



Detectors, positioned on either side of a container with an unseen sample, can identify the presence of plutonium in retired weapons and determine whether the plutonium is newly manufactured or aged. A tungsten alloy shutter (inset) is a key system feature that helps to ensure that only unclassified information is provided to observers.

Assisting Conversion at Russian Nuclear Complex

Downsizing the Russian nuclear complex is a high-priority U.S. national security goal. However, such downsizing will eliminate the jobs of thousands of Russian weapons workers. To accelerate the downsizing process, the U.S. and Russia have launched the Nuclear Cities Initiative to create self-sustaining civilian jobs for displaced workers in the closed nuclear cities of Sarov, Snezhinsk, and Zheleznogorsk.

Livermore leads the DOE team working with Snezhinsk and its various civilian entities to develop commercial enterprises. For example, we have a contract with SPECTR-Conversion to develop improved technologies for oil-well-casing perforators. In November 2000, the Strela Open Computing Center was dedicated. This center will facilitate the ability of Western firms to tap Sneshinsk's expertise in computer programming, software development, and scientific computations for commercial applications.

We are also working with the Avangard Foundation (the commercial element of the Avangard Electro-mechanical Plant at Sarov) and Fresenius Medical Care AG (the world's largest provider of products and services for individuals with chronic kidney failure) to develop a manufacturing center at Sarov for dialysis machines and disposable products. Contracts were signed in March 2000, and fences were moved in June to enable work activities outside Avangard's high-security area. Several hundred former weapons workers will eventually be employed in this enterprise. This collaboration is a major milestone in U.S. efforts to engage a Russian weapons production facility.

Remote Sensing for Proliferation Detection

Chemicals associated with the various stages (research and development, production, testing, storage, use) of weapons of mass destruction are released into the environment at levels that may be detectable by technical means. Remote detection of these chemical signatures would provide clues that, in conjunction with other sources of information, could be used to infer the nature of the activities that generated them. We are developing optical remote-sensing techniques for detecting, identifying, and quantifying signatures of the proliferation or use of weapons of mass destruction.

For example, we have developed a hyperspectral infrared imaging spectrometer (HIRIS) for passive remote sensing of chemical signatures. The system was flown in several successful challenging flight campaigns this past year. The data from these flights are being used to refine the HIRIS remote gas analysis software and models and to further validate the instrument's performance.

We leverage Laboratory capabilities to provide technology, analysis, and expertise for DOE and DoD in such areas as biodefense, counterproliferation analysis, missile defense, solid-state lasers, advanced conventional munitions, and energetic materials. We also work with the Justice, Treasury, and Commerce departments to improve the nation's ability to prevent and mitigate terrorist use of mass-destruction weapons.

Response to Proliferation and Other Security Threats

Fast, Accurate, and Portable Biodetectors

Livermore is a major participant in DOE's Chemical and Biological National Security Program and has developed unique instruments that dramatically advance biodetection capabilities. Our Handheld Advanced Nucleic Acid Analyzer (HANAA) was originally developed for use on the battlefield or in the event of a terrorist attack. It also has broader civilian health uses. It is the first truly portable DNA analysis instrument suitable for real-time identification of bioagents in the field.

Biodetectors require unique antibodies or DNA sequences to identify and characterize pathogens. We are developing a comprehensive array of such signatures to support a wide range of biological detection capabilities. We are working with the Centers for Disease Prevention and Control (CDC) to validate these signatures for use by the public health community. Collaborating with Los Alamos National Laboratory, we developed DNA signatures for *B. anthracis* (anthrax) and *Y. pestis* (plague) and transferred these to CDC for final multiagency validation. We are now developing signatures for additional pathogens.

Livermore's Atmospheric Release Advisory Capability's Emergency Operations Center mobilizes to model an atmospheric release. Models use real-time meteorological data to calculate the dispersal of released aerosols or particulate matter. We have integrated ARAC's capabilities into Livermore's CAPS and JTOPS programs to provide analytical support to emergency responders in the event of a chemical or biological attack.

Technology to Support Military Operations

The Counterproliferation Analysis and Planning System (CAPS) enables users to analyze a proliferator's weapons production capabilities end to end and to assess interdiction options and corresponding consequences. Developed at Livermore, CAPS has been widely accepted by the defense community. In the Defense Planning Guidance for 2000, the Secretary of Defense named CAPS as the preferred counterproliferation tool to be used by the nation's armed services.

In August 2000, we used CAPS to provide crisis management support to naval operations in the Navy 3rd Fleet Limited Objective Experiment-Zero, held at sea and near Point Magu in southern California. This exercise demonstrated the full integration of the Atmospheric Release

Developing DNA signatures involves microbiologists, molecular biologists, biochemists, geneticists, and computer experts. Here, biomedical scientists work to distinguish DNA of various species of virulent organisms.

The Laboratory's JCATS team won an award (also see p. 30) from DoD's Defense Modeling and Simulation Office for modeling conflict on scales ranging from a handful of fighters in an urban security operation to battles between units of thousands with tanks, aircraft, and submarines.

Advisory Capability (ARAC) into CAPS, whereby users can incorporate real-time meteorological and plume data for consequence analysis.

We are leveraging CAPS, hyperspectral imaging activities, and our entity-level combat simulation model (Joint Conflict and Tactical Simulation, or JCATS) to design the Joint Total Operational Planning System. JTOPS aims to provide military planners with a tool to integrate real-time critical intelligence into mission planning. Elements of the JTOPS concept were successfully tested in the Navy 6th Fleet Battle Experiment-Golf, held in Italy during March 2000. JCATS provided a virtual battlefield context for the exercise. Planners also used pre-scripted hyperspectral data to monitor operation of a hypothetical WMD facility and "reached back" to the Laboratory through CAPS to obtain technical information on selected targets and to evaluate the consequences of attacking selected areas.

Technologies for Air and Missile Defense

In support of the Army's Space and Missile Defense Command, the Laboratory is working with industrial partners to develop a 100-kilowatt (average power) solid-state laser to be deployed on a mobile battlefield platform. Such high-power laser systems are leading candidates for an enhanced air-defense capability. In 2000, we brought into operation a 10-kilowatt prototype laser and tested its effectiveness in damaging selected materials. This laser will be delivered to the High-Energy Laser Strategic Test Facility (HELSTF) at White Sands Missile Range in May 2001.

Also during 2001, we will begin work on a submodule of a 100-kilowatt diode-pumped laser that is to be delivered to HELSTF in 2003.

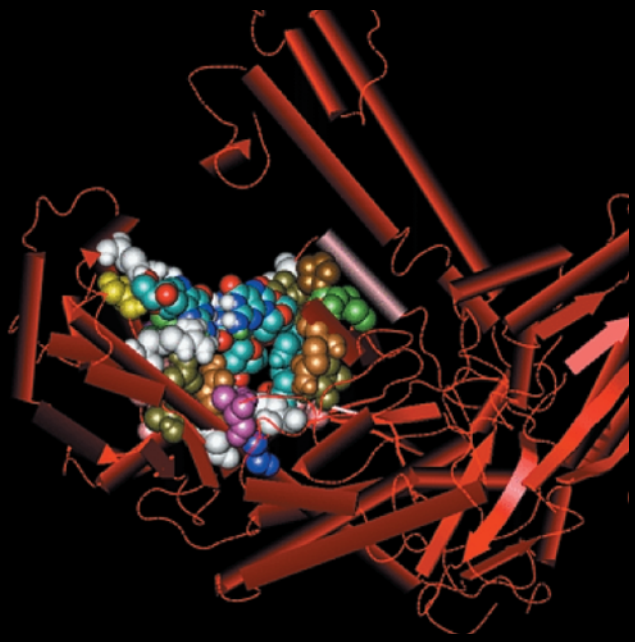
We are contributing to missile defense with the Remote Optical Characterization Sensor Suite (ROCSS). In experiments conducted in the High Explosive Applications Facility (HEAF), ROCSS successfully detected chemical seedant in a high-explosive environment such as would exist after a missile intercept. The goal is to provide battlefield commanders with a tool to determine if an intercepted hostile warhead was carrying chemical or biological agent.

We are working with the DoD to improve the capability of low-velocity cruise missiles to penetrate hard targets. Our new multicharge precursor warhead consists of a cluster of small charges with a single large charge in the back. It is designed to efficiently create a large hole for the cruise missile to fly through virtually unimpeded (right).

National Needs

As a national laboratory with state-of-the-art research facilities and capabilities, Livermore can respond to a broad range of important national needs. Applying the Laboratory's special skills to diverse problems leads to cross-fertilization of ideas and helps to sustain the multidisciplinary base needed for national security work. We have wide-ranging capabilities in applied science and technology, many specialized research facilities, and unique expertise in selected areas. Livermore emphasizes challenges with the potential for high-payoff results, which means our work often entails significant scientific and technical risk. We focus on the critical, enduring missions of DOE and program areas that reinforce our national security work.

Meeting Enduring National Needs



This DNA polymerase is from the scalding-water bacterium *Thermus aquaticus*. The precision and thermal stability of this enzyme is key to PCR (polymerization chain reaction), the technology that has enabled the Human Genome Project and other biotechnologies supported by DOE. Through simulations as well as experiments, we are learning how such polymerases make perfect copies of DNA during the cell-division process. The interaction of DNA and protein, in the region depicted by space-filling atoms, is the focus of our study.

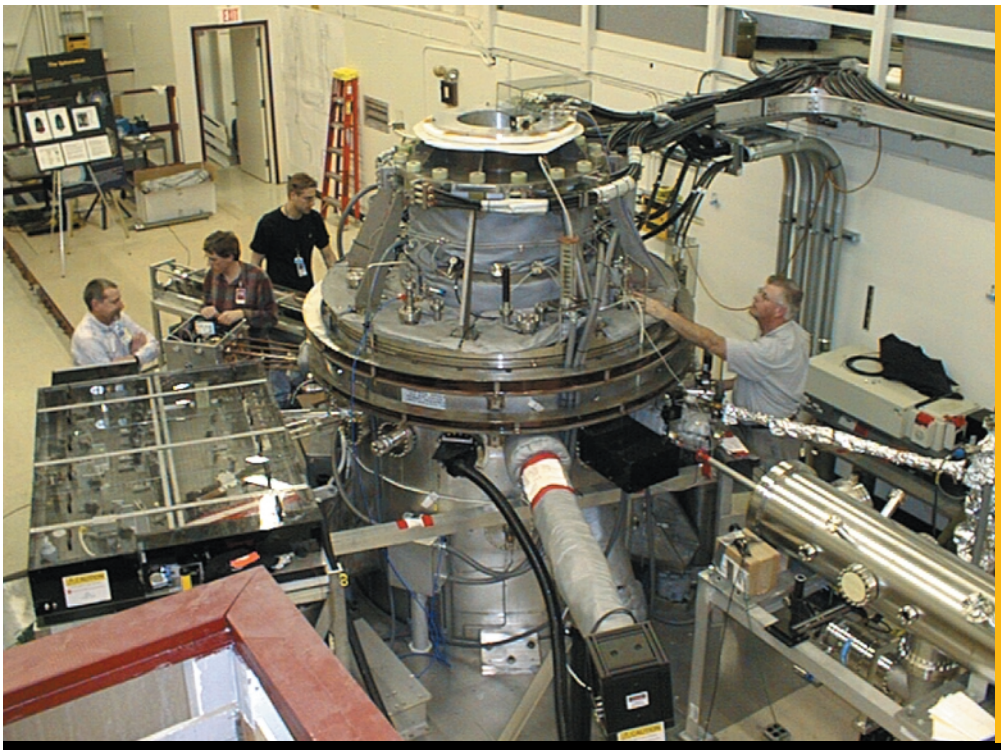
Energy and Environment

Livermore's energy and environment program contributes to providing the scientific and technological basis for secure, sustainable, and clean energy resources for the U.S. and to reducing environmental risks. Significant technological advances as well as broad cooperation among institutions are required to reach these goals. Our efforts focus on three critical areas in which the Laboratory can make a significant difference.

Nuclear materials management is an enduring mission of DOE because the Department will be responsible for a vast array of nuclear materials for generations to come. We are a key contributor to nuclear materials management through various activities at the Laboratory.

Carbon management is another focus of our research because of the world's growing demands for energy and the historically high atmospheric concentration of greenhouse gases. We are pursuing technologies for energy generation and usage in areas where the Laboratory has special expertise. Through efforts such as our significant contributions to global climate modeling, we are also developing a better understanding of the environmental consequences of energy generation and usage that drive technology selection and implementation.

In addition, we are developing technologies to characterize and remediate contaminated groundwater faster and more cost efficiently than previously possible. We have extremely sensitive techniques for determining the mutagenic and carcinogenic potency of chemical pollutants.



In its second year of operation, the Sustained Spheromak Physics Experiment is achieving high electron temperatures and generating valuable data to help improve plasma simulation codes. Our goal is to understand and optimize energy confinement in the spheromak and, if results are promising, develop a larger follow-up experiment.

Bioscience and Biotechnology

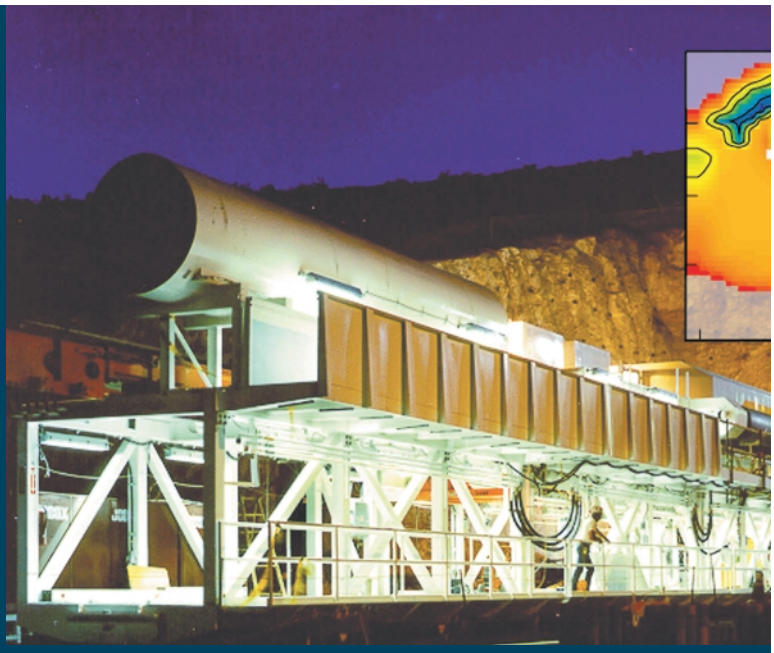
The Laboratory's research advances human health through efforts in genomics, disease susceptibility and prevention, and improved health care and medical biotechnology. Research activities in biology, biotechnology, and health care fit well in the Laboratory's technology-rich environment. A cross-fertilization of ideas and talents provides our bioscientists access to the latest technologies in physical sciences and engineering. Conversely, bioscientists at Livermore make significant contributions to national security activities and other major programs.

Fundamental Science and Applied Technology

We pursue initiatives that have the potential for major advances and reinforce research areas that are strong at the Laboratory. Many projects, sponsored by DOE's Office of Science and other customers, take advantage of the unique research capabilities and facilities at Livermore. Other work, supported by Laboratory Directed Research and Development funding, extends the Laboratory's capabilities in anticipation of new mission requirements.

Astrophysics technology development at Livermore has included adaptive optics for the Keck II telescope in Hawaii, where images of Neptune and Titan (Saturn's largest moon) were taken (middle and bottom images). We also developed ultraprecise grating arrays for spectrometers on the X-Ray Multi-Mirror Newton Observatory that was launched in December 1999. One early color-coded x-ray image (top) from the observatory shows the Large Magellanic Cloud, a small companion galaxy to the Milky Way.

Livermore's activities in energy and environmental science support DOE priorities for enhancing the nation's energy security, developing and making available clean energy, cleaning up former nuclear weapon sites, and finding a more effective and timely approach to nuclear waste disposal.



Improving Energy Security and Environmental Management

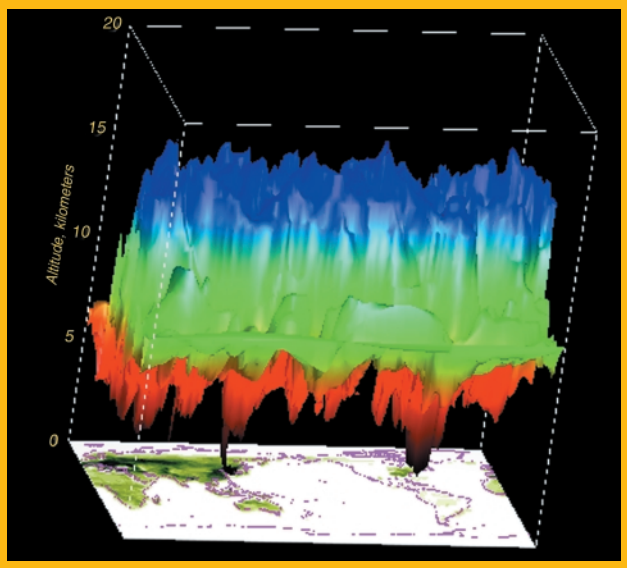
Waste Storage for the Millennia

Yucca Mountain, at the Nevada Test Site, is the nation's potential site for a high-level nuclear waste repository. The Laboratory is helping DOE to address some of the major scientific challenges in nuclear waste storage. We are making major contributions toward the selection of materials for the waste package and engineered barrier, pioneering the analysis of how heat affects the mountain. Livermore researchers led the preparation of three of the nine Process Model Reports—for the waste package, engineered barrier system, and near-field environment. Completed in 2000, these reports provide the basis for the Secretary of Energy's site recommendation to the President.

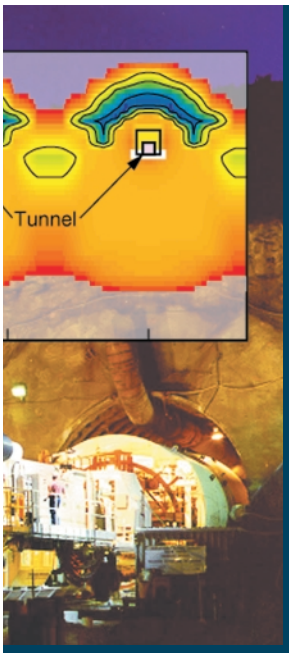
Scientists need to know whether geologic responses over thousands of years could cause the waste packages to corrode and release radioactivity. We have been testing the materials for making waste storage containers and researching the site's geology to accurately predict the effect on nearby geology of the heat from the buried wastes. In addition, using Livermore's supercomputers, we have constructed a code to simulate the geologic evolution of the repository for 100,000 years or more. The code is being used to predict the temperature evolution surrounding the buried nuclear waste and the possible means by which water will enter the repository's tunnels over the eons.

Deep Ocean Sequestration of Carbon

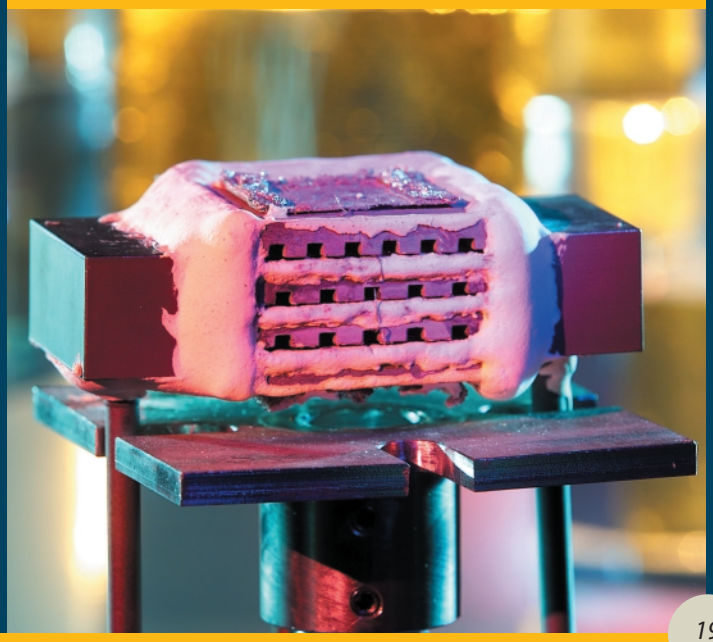
The Laboratory co-directs DOE's Center for Research on Ocean Carbon Sequestration (DOCS) and leads its efforts in numerical simulation. Researchers are investigating



Atmospheric chemistry models are an important part of global climate simulations. Livermore modeling results show that in various locations, ozone in the lower stratosphere, which is typically in 100-parts-per-billion concentrations, is transported to near-surface altitudes.



Detailed models of waste packages and the surrounding geology are used in simulations of the long-term evolution of tunnels at Yucca Mountain. A cross section through two tunnels shows the formation of domes of low-porosity rock above hot (pink) waste packages of spent nuclear reactor fuel after about 500 years. Fractures in the rock are irreversibly sealed, preventing water from entering the tunnel.



Tests of a 3-x-5-inch, three-cell stack of solid-oxide fuel cells developed by Laboratory researchers achieved record-setting power density (over 1 watt per square centimeter), generating 61 watts of peak power. The fuel-cell design incorporates the benefits of thin-film processing techniques that reduce manufacturing costs and should help bring the technology to commercialization.

ways that fossils can be burned without releasing into the atmosphere carbon dioxide (CO_2), a greenhouse gas that contributes to global warming. CO_2 is produced by the burning of fossil fuels, and the use of coal, oil, and gas are mainstays of the U.S. economy, supplying about 85 percent of the nation's energy needs.

Because the deep ocean is able to store additional CO_2, DOCS is examining the effectiveness of various strategies to sequester carbon in the ocean. One possibility is the storage of CO_2 in deep underwater geologic reservoirs. As part of the DOE effort, the Laboratory is developing criteria for identifying subsurface geologic formations useful for sequestration. Researchers are also developing a first-cut model of CO_2 injection and sequestration processes.

Improved Climate Modeling

Improved simulations of the global climate are needed to better understand the changes in Earth's climate that may be caused by human activities. The ever-increasing speed of Livermore's supercomputers is making it possible to "push the envelope" of global climate simulations and the science behind it. Future high-resolution global climate simulations should lead to improved predictions of future climate—not just future weather—on both global and regional scales.

In one study, detailed models of the troposphere and stratosphere were combined to examine how natural and human-made emissions of chemical species may alter the distribution of ozone and, more important, how these regions interact. We found that at various geographic locations (such as northeastern United States and eastern China), stratospheric ozone is being transported to altitudes near Earth's surface. These results indicate that atmospheric ozone chemistry—in both the stratosphere and troposphere—must be considered in any quantification of global surface ozone distributions.

Fuel-Cell Breakthrough

We are improving the design of solid-oxide fuel cells with the goal of making the technology an attractive option for clean and efficient power generation for the 21st century. By applying their materials science expertise, Livermore researchers are developing a very-high-power-density prototype that operates at a temperature low enough so that more affordable materials and manufacturing technologies can be used. In 2000, we built and tested a prototype modular fuel cell consisting of a stack of three single cells. For the stack, we obtained a power density of 1.05 watts per square centimeter at 800°C, a result for a stack of cells that is at least 50 percent higher than previously reported.

Working with academia, industry, and government, we leverage the Laboratory's capabilities in the physical and engineering sciences to conduct research of national importance in bioscience and biotechnology. Livermore pursues technical innovations in genomics, disease susceptibility identification, and health care.

Advancing Bioscience to Improve Human Health

"Working Draft" Human Genome Sequence

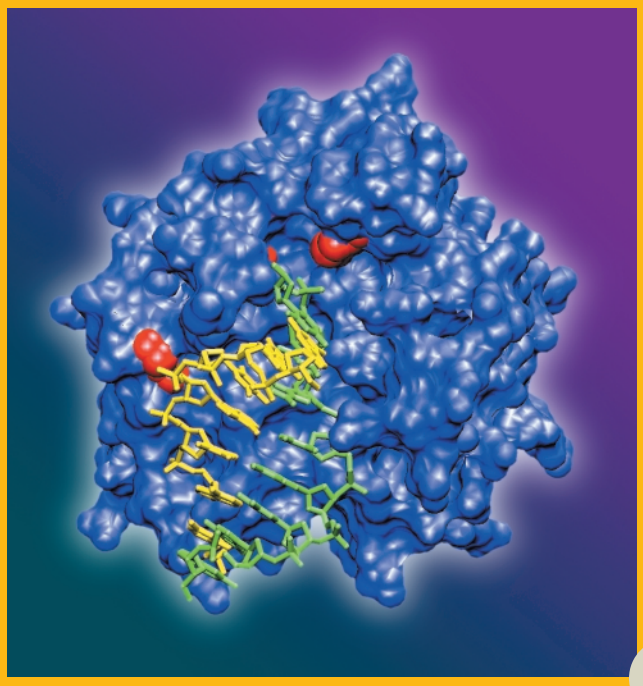
Livermore researchers were on hand in Washington, D.C., in June 2000 to announce the completion of a draft version of the complete DNA sequence of the human genome. For members of the DOE's Joint Genome Institute (JGI), this task involved identifying and placing large fragments of DNA in the proper order to cover three of the human chromosomes (5, 16, and 19) and determining the DNA sequence of the fragments. JGI met its goal by completing its assigned portion of the draft prior to April. The draft consists of very-high-quality sequence data (less that 1 error for each 10,000 bases) in large regions across the 3 chromosomes. Work is continuing to finish sequencing each chromosome to higher quality and continuity.

In the Laboratory's efforts to sequence the human genome, researchers' resourcefulness and the use of robots speeded up the process of decoding DNA. Completion of the Joint Genome Institute's draft sequence was announced in April 2000, a year ahead of the original schedule.

Joint Genome Institute Finishes Microbe Month

October 2000 was named Microbe Month at the JGI when, during the month, draft sequences of 15 bacterial genomes were produced, each ranging from 2 to 7 million bases in size. This is a rate of better than 1 genome for every 1.5 working days. The microbes selected were a diverse group of organisms, having important implications for the economy and the environment. Among the organisms sequenced was *Xylella fastidiosa*, a pathogen carried by the "sharpshooter" insects currently making headlines by infecting California's

We are using a new accelerator mass spectrometer in biomedical collaborations with researchers from around the world to begin to solve many challenges in studies using carbon-14—from examining the way humans metabolize vitamins to developing new cancer diagnostic tests.



Supercomputers have established new standards for size and accuracy in the chemical modeling of biological processes. We are studying the dynamics and structure of DNA and repair mechanisms. Here, a model is shown of Ape1, a DNA-repair protein, and amino acids among a strand of DNA (yellow and green strands).

grape crop. Another intriguing organism, *Prochlorococcus marinus*, is thought to be the most abundant organism on Earth and plays a major role in carbon sequestration. Scientists worldwide can now access sequence data on these organisms to advance their research.

Cooking Method Lowers Carcinogen Levels

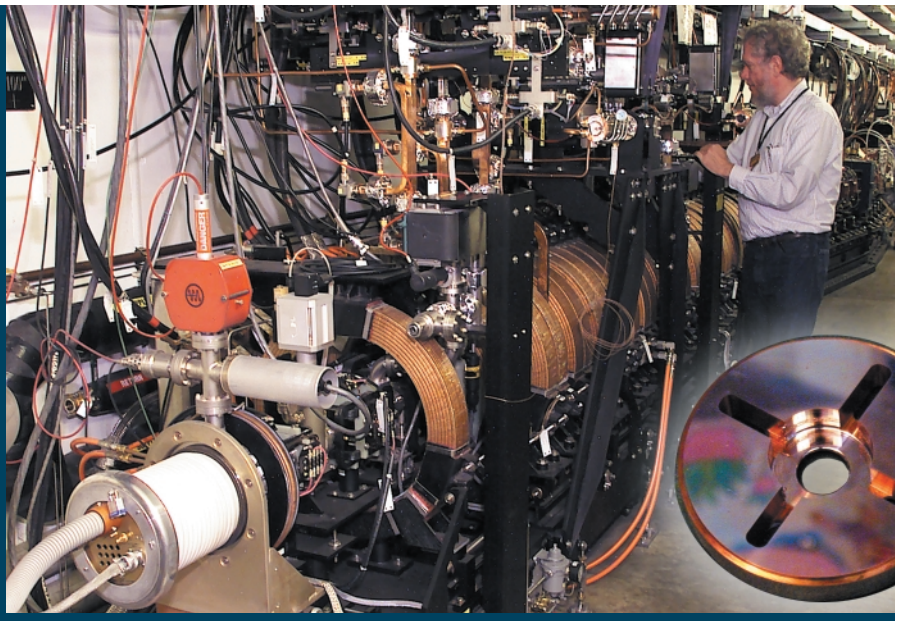
Heterocyclic amines, a potent class of both mutagens and animal carcinogens, are often formed during the cooking of muscle meats. Because human epidemiology studies suggest heterocyclic amines may be etiologic agents for breast, prostate, colon, and other cancers, reducing exposure to these chemicals is warranted. Cooking most meat at high temperatures with methods such as frying, broiling, and grilling produces higher amounts of carcinogens than boiling, roasting, or baking. Longer cooking time also produces higher amounts of these agents. After confirming that a 158°F (70°C) internal temperature is sufficient to kill most microorganisms, Livermore researchers determined that the fewest amounts of carcinogens were produced when the meat was flipped frequently while cooking. They recommend the following frying method: turn the meat frequently while cooking over medium heat to the recommended internal 158°F temperature.

Biology Research Blossoms at CAMS

With funding from the National Institutes of Heath, the National Resource for Biomedical Accelerator Mass Spectrometry was established at Livermore in 2000. Through this resource, Livermore's Center for Accelerator Mass Spectrometry (CAMS) is being made available to biomedical researchers who need this accurate tool to measure very low levels of carbon-14. The resource provides access to carbon-14 accelerator mass spectrometry (AMS), aids development of new methods and instrumentation for the use of AMS in biomedical research, and demonstrates new applications of AMS for biomedical research.

More than 19 academic and industrial collaborations were begun during 2000 in fields such as biochemical toxicology, nutrition, and structural biology. For example, one recent project allowed a researcher at the University of California at San Francisco to detect and characterize low doses of carbon-14–benzene adducted to proteins in the bone marrow of treated mice. These results will help researchers to understand the mechanism of induction of leukemia by benzene. Results from nearly half of these collaborative projects have already been presented at national and international conferences.

The pursuit of fundamental science and the advance of applied technology go hand in hand at Livermore. State-of-the-art technology is used to increase our understanding of science in areas pertinent to the Laboratory's major missions. Conversely, Livermore's scientific advances have important spin-off applications and help to achieve program goals.

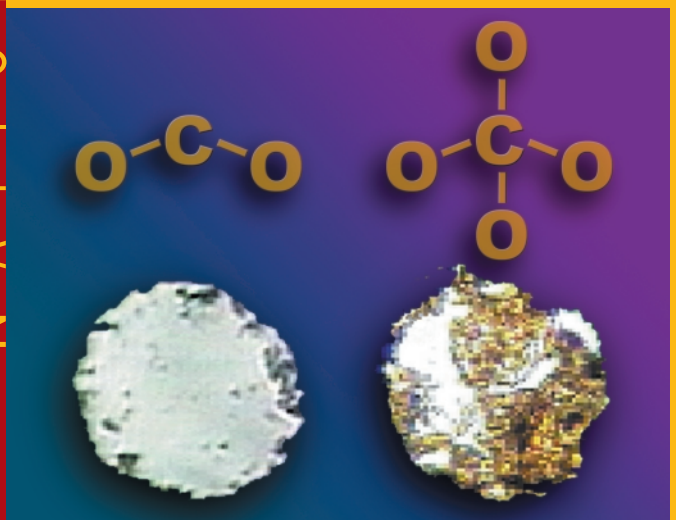


Pursuing Breakthroughs in Science and Technology

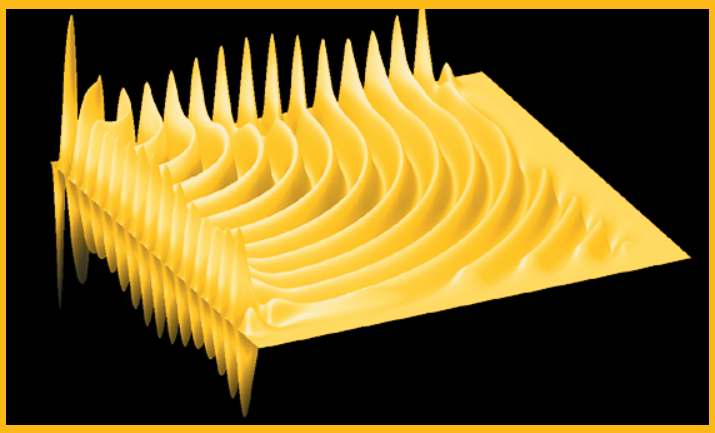
Understanding How Materials Age

Computer simulations combined with experiments are providing new insights about the aging of materials. Of particular interest to Laboratory researchers is the long-term effect of radiation on materials—for applications ranging from pressure vessels in nuclear reactors to radioactive waste containers to components of nuclear warheads. A team of Laboratory researchers reported in *Nature* new findings that connect radiation damage in crystalline metals, which occurs at ultrasmall scales (nanometers and picoseconds), to degradation over time of its mechanical properties. Because radiation damage to materials is a multiscale phenomena, the process must be modeled accordingly.

The team used atomistic and 3D microscale simulations of irradiated metals. The simulations showed that nanoscale defects accumulate and quickly grow into clusters. These clusters inhibit the movement of dislocations (misaligned planes of atoms) and make the material more brittle. Simulations also accurately predicted the formation of defect-free channels in irradiated metals through the



Researchers study the equation of state of materials at extreme conditions using Livermore's diamond anvil cell. They created two forms of solid carbon dioxide never before seen in the laboratory (CO_2-IV, left, and CO_2-V, right). CO_2-V has covalent bonds and shows nonlinear optical behavior, which may eventually lead to a new class of generating materials for high-power lasers.



Researchers from Livermore and Berkeley national laboratories and the University of California at Davis used supercomputers to obtain a complete solution to the ionization of a hydrogen atom by collision with an electron. The results were reported in *Science* and *Physics Today*. The computed radial wave function of the two electrons in the collision is shown above.

Livermore is contributing expertise in the design of the power modulators (left) and the precision engineering of copper cells for the accelerator structure (right) in the proposed Next Linear Collider.

annihilation of defects as dislocations move. These clear channels, which were observed in experiments, reduce material strength.

Next Linear Collider

The proposed Next Linear Collider (NLC) is designed to collide electrons and their antiparticles (positrons) after they have been accelerated to exceptionally high energy—about a trillion electron volts. The energy released will go into the creation of new particles. The experiments will help physicists answer some of the most fundamental questions about the nature of matter and the structure of space–time. The NLC is being developed through a collaboration of four DOE laboratories—Stanford Linear Accelerator Center (SLAC), Lawrence Livermore and Lawrence Berkeley national laboratories, and Fermi National Accelerator Laboratory.

Livermore's contributions include the development of power modulators for the NLC's linear accelerators. Based on solid-state technology, our new modulator for the NLC is designed to be affordable, efficient, reliable, and serviceable. Modulator cells were built and successfully tested, and in 2000, a complete modulator (consisting of 75 cells) was fabricated and delivered to SLAC. The NLC also will require between 5,000 and 10,000 structures to accelerate bunches of electrons and positrons. Each structure has about 200 precision copper cells, each slightly different. Livermore's role is to develop cost-efficient procedures for diamond-turning these cells to micrometer-level tolerances and to fabricate prototypes.

JanUSP to Explore New Plasma Regimes

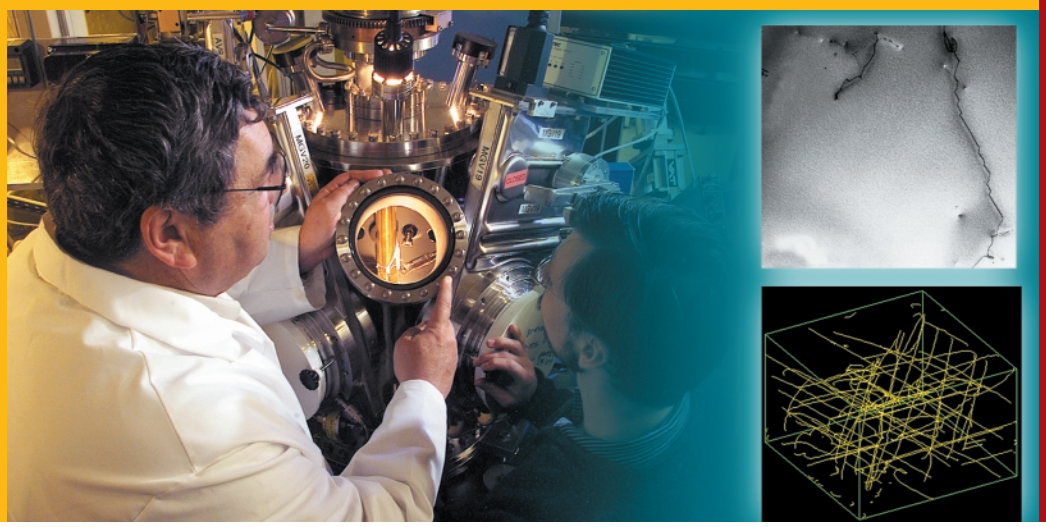
Livermore's JanUSP has set the record as the world's brightest laser. The laser produces ultrashort pulses (less than a tenth of a trillionth of a second long) and has achieved an irradiance of two sextillion (2×10^{21}) watts per square centimeter. This level of brightness allows scientists to explore plasma conditions similar to those inside stars and detonating nuclear weapons, with pressure one trillion times that of Earth's atmosphere at sea level.

Scientists plan to heat small samples of material by using the enormous pressure of the laser light to ionize surface material and accelerate the ions into the sample. In less than a billionth of a second, the sample will turn into a superhot plasma (about 10 million degrees). For the experiments to succeed, the rise time of the laser pulse must be extremely fast with no prepulse. In 2000, researchers achieved the goal of reducing the prepulse energy from JanUSP to less than one ten-billionth that of the main pulse.

ISO 9002

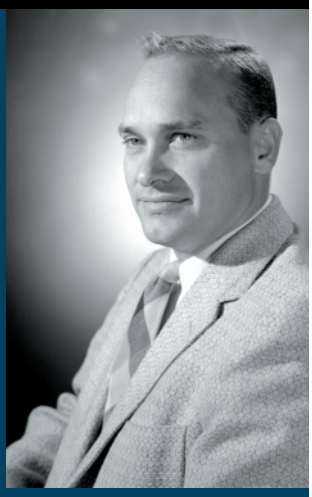
The Laboratory's Engineering Manufacturing and Services Group is officially registered as compliant with the International Standards Organization ISO 9002—a worldwide benchmark for assuring high quality and customer satisfaction in production, installation, and service. ISO certification was awarded following an audit by Bureau Veritas Quality International, an independent agency that checked for compliance with ISO quality standards at all levels, including management policies, operating procedures, and work process. The group is believed to be the first within the DOE complex to receive this quality certification.

Materials simulations are closely coupled to laboratory experiments, including measurements of the transport properties of radiation damage defects in metals (left). An electron micrograph of molybdenum (top right) is used to establish initial conditions in a simulation of dislocation dynamics, one step in multiscale modeling. After compression, many dislocations run through the crystalline lattice (bottom right).



Shaping the Future

Livermore's multidisciplinary approach to problem solving will be needed to address large-scale technical problems that the nation will face in the 21st century. Continuing success in the Laboratory's endeavors will be challenging. We must deliver on major programmatic commitments, ensure that we meet high standards in all operations, and provide a work environment that continues to attract a diverse, highly talented workforce. Our mission-directed research, exceptional science and technology, continuous improvement of operations, workforce and strategic planning, and significant partnerships position the Laboratory for the future.



Positioning the Laboratory for the Future

The Long-Range Strategy Project provided an opportunity for a diverse group of people, who will be making important decisions about the direction of Livermore's programs in the coming decades, to get to know each other and the many issues that the Laboratory faces. Their summary report, *2020 Foresight*, synthesizes and highlights the principal results of their studies.

A Quality Workforce

Livermore's principal asset is its quality workforce. Our achievements are the product of a highly talented, productive, motivated, flexible staff that is committed to the Laboratory's goals. We strive for a workforce that reflects the diversity of California and the nation. And we seek to provide a work environment in which all employees can contribute to the fullest and feel valued for their role. The Laboratory is pursuing initiatives to enhance the work environment.

Our association with the University of California (UC) enhances the Laboratory's intellectual vitality and our ability to recruit and retain a quality workforce. In January 2001, DOE and UC modified and extended to 2005 UC's contract to manage the Laboratory.

Program Direction and Planning

The future direction of the Laboratory is guided by evolving national needs. Livermore's priorities are spelled out in the strategy document, *Creating the Laboratory's Future*, and the Laboratory's *Institutional Plan FY 2001–2005*. In early 2000, the Long-Range Strategy Project, conducted by about 20 early- to mid-career scientists and engineers at Livermore, completed its final report, *2020 Foresight*. The project considered the potential advances in science and technology and prospects for Livermore over the next 10 to 20 years.

In addition, significant organizational changes have been made in response to newly arising programmatic and operational demands on the Laboratory. The selection process is being completed in 2001 for many new top-level managers.

Roger Batzel
1922–2000
The Laboratory's future builds on a foundation of technical excellence and important mission responsibilities. Roger Batzel served as Director for nearly one-third of Livermore's history (1971 to 1988), a time of technical diversification and remarkable growth for the Laboratory. We will sorely miss him.

In an example of our ties to the University of California, Merced Community College President Ben Duran, UC Merced Chancellor Carol Tomlinson-Keasey, and Laboratory Director Bruce Tarter (left to right) gather to sign a Memorandum of Understanding to create academic partnerships among the three institutions. Below, reporters cover the announcement of a formal collaboration between the Laboratory and the UC Davis Cancer Center to pursue research on cancer prevention and control and to develop new treatment techniques.

High Standards in Operations

Our efforts to continually improve Laboratory operations focused in 2000 on safety and security. Both are of prime importance at the DOE nuclear weapons laboratories.

We completed implementation of DOE's Integrated Safety Management System to improve safety performance and management at Livermore. Our policy is that safety of both workers and the public has the highest priority.

The Laboratory also continues to improve security by providing even greater protection of critical assets, implementing state-of-the-art computer security, and expanding our counterintelligence program.

Major Partnerships for Mission Success

Increasingly, Livermore's technical achievements are the result of major partnerships with industry, academia, and other laboratories. Partnerships and collaborations help us accomplish our programmatic goals more efficiently and cost effectively. They also provide a mechanism for commercializing and returning for broad public benefit the technological advances made at the Laboratory.

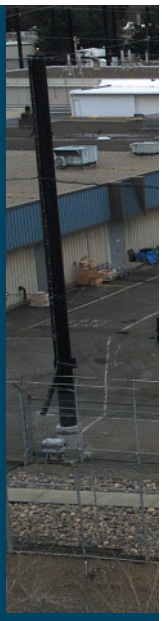
Award-Winning Science and Technology

Outstanding scientific and technical achievements define the Laboratory and chart its future. Breakthrough accomplishments, critical to Livermore's success, are the product of a quality staff—both individual and team efforts. Frequently, such achievements lead to outside recognition, such as the many awards garnered in 2000.

Safety has the highest priority in all Laboratory operations. In 2000, Livermore implemented DOE's Integrated Safety Management System.

Safety and security are the most important considerations in day-to-day operations. Protection of sensitive information, nuclear materials, and other valuable assets at the Laboratory is a critically important responsibility. So is safety. The Laboratory is committed to providing every employee and the community with a safe and healthy environment in which to work and live. We have taken steps to improve safety and ensure its top priority. Our environmental protection efforts continue to focus on pollution prevention, waste reduction, and cleanup of the Livermore site.

In addition, we broadly contribute to the high-tech, global-outlook atmosphere of the region. Technical expertise, science education efforts, and the many volunteer activities by Laboratory employees are important aspects of being a good neighbor.



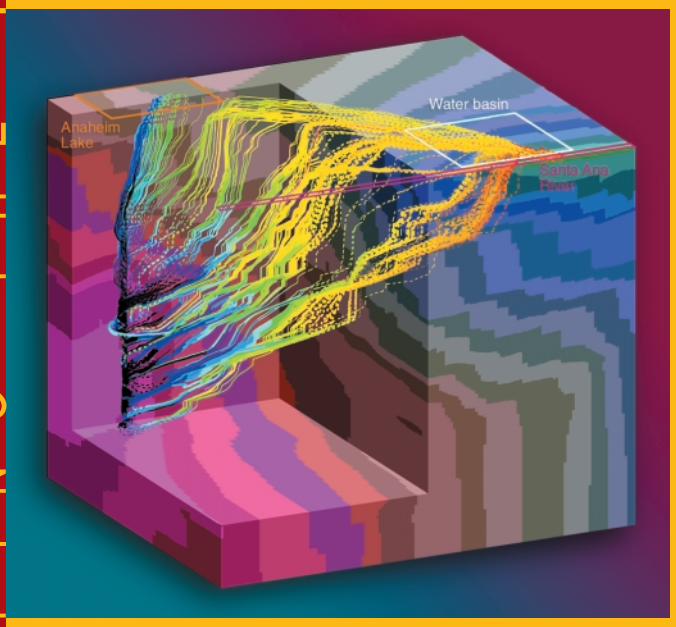
Secure, Safe Operations and a Good Neighbor

Implementing Integrated Safety Management

In 2000, DOE's operational concept, Integrated Safety Management (ISM), was implemented at Livermore. ISM strengthens Livermore's commitment to and performance of safe practices in the workplace.

ISM at Livermore is based on a set of work standards that were developed in partnership with DOE's Oakland Operations Office and the University of California.

A DOE Verification Team determined that the Laboratory effectively implemented ISM. Through the hard work of the ISM implementation team and Laboratory staff, we were well prepared for final verification in September, which entailed the inspection of safety procedures at 25 facilities across the Laboratory and the review of over 700 supporting documents.



The Laboratory aided the Orange County, California, Water District by calculating "backward travel" of water between a production well (at left) and three recharge basins at ground level (upper right). Yellow and orange portions of the color-coded water travel time indicate that the recharged water would stay underground long enough for the water district's needs.

Upgrades to Security

Livermore, Los Alamos, and Sandia national laboratories are expeditiously taking measures to tighten security. Protection of sensitive information and special nuclear materials is vitally important, and we are using increasingly sophisticated measures to provide it. For example, we implemented a tri-laboratory cybersecurity plan developed with DOE. To ensure improvement in identified areas, the plan included numerous specific milestones, such as the installation of an institution-wide firewall to protect all computer systems, which was completed in March 2000.

Our computer-security upgrades build upon our efforts over the past three years to develop an overall information architecture that integrates the Laboratory's needs for both functionality and security in computing. The strategy is to not only comply with DOE orders, but also to proactively determine the computer-security needs of our institution and build the necessary computer-security practices and technologies into our infrastructure.

Environmentally Responsible Operations

The *1999 Site Annual Environmental Report*, released in November 2000, concludes that

In addition to cybersecurity improvements, the Laboratory made important physical and technical upgrades to the security of the Superblock, which contains the plutonium facility, to provide even greater protection against attempted intrusions.

Portable treatment units contribute to the remediation of groundwater beneath the Laboratory, which was contaminated with volatile organic compounds during early operations. These units are just as effective yet cost only 40 percent of fixed treatment facilities and attendant pipelines.

Laboratory operations posed no threat to the environment for the year. We continually monitor the air and wastewater from the Laboratory and test soil samples for radioactive and hazardous materials. Through efforts in waste minimization and pollution prevention, we have increased the amount of recycling and diversion of wastes from disposal. Remediation activities continue to remove volatile organic compounds from offsite groundwater such that contaminated plumes have been pulled back to just beyond the Laboratory's western boundary.

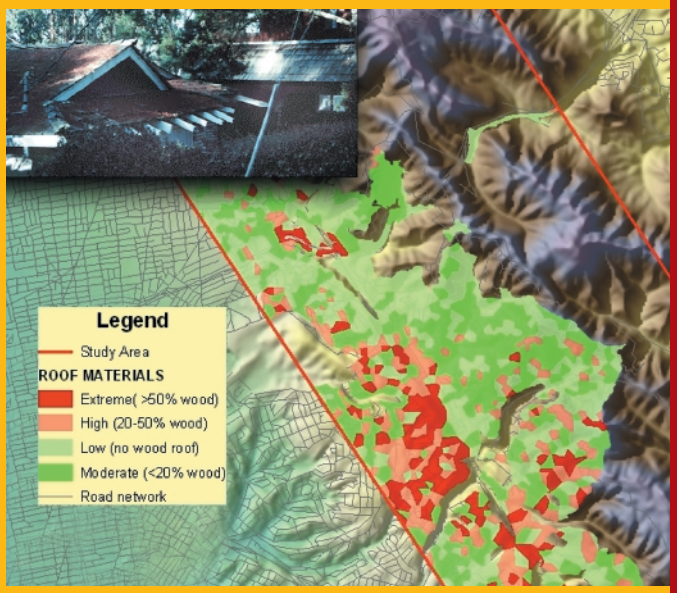
Meeting California's Needs

From analyzing the consequences of seismic activity to developing technologies to monitor movement and remediation of contaminated groundwater, Livermore pursues technological innovations that apply to important issues in California. For example, we are working with Los Alamos on a Wildfire Behavior Prediction Initiative. The effort combines Los Alamos' ongoing wildfire modeling effort with weather models at Livermore's National Atmospheric Release Advisory Center (NARAC). The goal is to develop a computer simulation capability that will support firefighters in real time by predicting the behavior of wildfires and weather. We are applying our current models to simulate the smoke behavior from prescribed burns in Los Angeles County (for the L.A. County Fire Department) and are preparing to support prescribed burns at Fort Ord, California (for the Army). In addition, we are working with the East Bay Regional Park District to study wildfire scenarios in the hills of Oakland, California, using a high-resolution database.

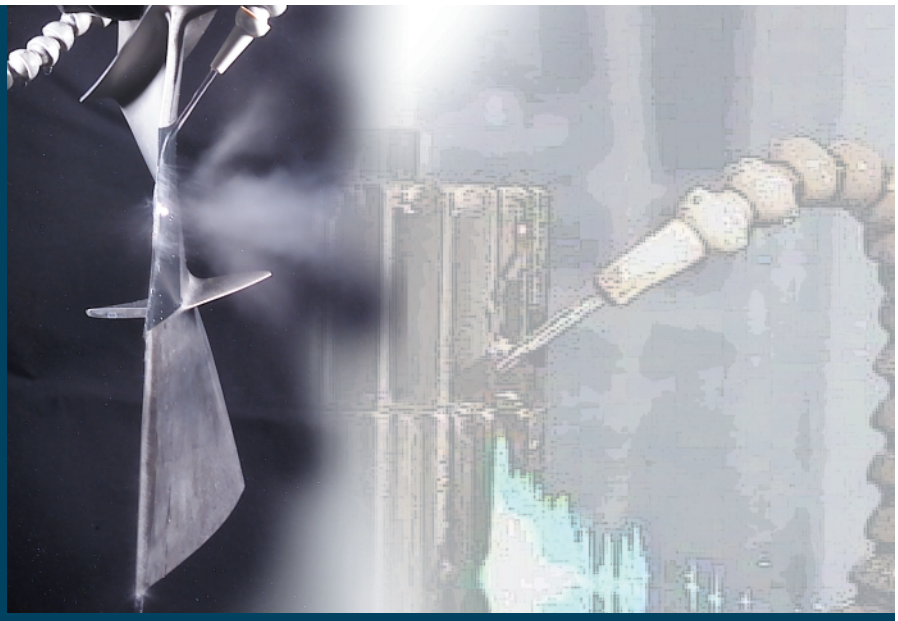
Laboratory Employees Donate $1.26 Million

The annual campaign to Help Others More Effectively (HOME) raised $1.26 million for Bay Area and Central Valley charity organizations in 2000, breaking the previous year's record. HOME is but one example of many outreach activities that include employee participation in community economic development organizations; environmental, health, and safety working groups; and educational activities such as science fairs and student and teacher programs.

The database for studies of wildfire scenarios in the hills of Oakland, California, includes detailed information about roads, terrain, and vegetative fuels as well as the roof and siding materials used in each of 51,452 houses in the area.



Through major partnerships with U.S. industry, the Laboratory is acquiring mission-critical capabilities such as the Accelerated Strategic Computing Initiative and constructing the National Ignition Facility. We obtain other critical capabilities needed at the Laboratory through partnerships, and we create new opportunities for U.S. industry by "spinning off" technologies.



New Capabilities through Partnerships

A melting operator performs a visual inspection of the continuous melting laser glass as it comes out of the Lehr oven at Hoya Corporation. Each laser glass slab is carefully fine annealed and extensively tested and inspected. The glass produced by a continuous melting system has successfully achieved the stringent specifications required for NIF.

Technology Development with Industry

Livermore's interactions with U.S. industry are exemplified by our 88 active licensing agreements, 47 cooperative research and development agreements, 175 reported inventions, 299 industrial work-for-others agreements, 112 patent applications, and 95 issued patents in FY 2000.

For example, we are partnering with BioLuminate Inc. to develop Smart Probe, a tool for detecting early breast cancer with accuracy levels comparable to biopsies but without removing tissue.

In a licensing agreement, MiniMed Inc. is using a novel Livermore technology to develop a noninvasive glucose measurement for continuously indicating the sugar level in diabetic patients. When used with an implanted insulin pump, the two devices would essentially become an artificial pancreas.

In another licensing agreement with two companies, FlexICs Inc. and Rolltronics, a Livermore laser-based technique is being developed for producing plastic flat-panel displays. Plastic displays are rugged, compact, and lightweight, and they are cheaper to produce than the glass displays that they would replace.

We are one of the founding partners (with Sandia National Laboratories, the City of Livermore, and private-sector sponsors) of the Tri-Valley Technology Enterprise Center (TTEC)—a regional business incubator under the aegis of the Tri-Valley Business Council. TTEC is providing support for start-up high-tech companies.

Laser Glass Production for NIF

The construction of the National Ignition Facility (NIF) at Livermore relies on hundreds of partnerships to develop the required technologies. For example, obtaining large quantities of quality glass was one of the project's top technological and manufacturing challenges. By the end of January 2001, our commercial vendors, Schott Glass Technologies and Hoya Corporation, had produced more than 1,000 laser glass slabs for NIF, roughly half of the total laser glass slabs needed.

Research and development spearheaded by Livermore and the two glass manufacturers made production possible. Both Schott and Hoya demonstrated a process to ensure economical production of high-optical-quality, neodymium-doped, phosphate laser glass at a rate

The LaserShot[SM] Peening system won a 2000 Federal Laboratory Consortium Award of Excellence in Technology Transfer for transferring technology to the commercial marketplace. Because laser peening is more effective than other strengthening methods, parts such as aircraft engine fan blades and gears can be made thinner and thus lighter. In addition, laser-peened products will probably need less energy to operate.

20 times faster than could be achieved using existing technology. They carried out cooperative research specifically aimed at reducing moisture contamination so that the glass would meet the stringent specifications required for NIF.

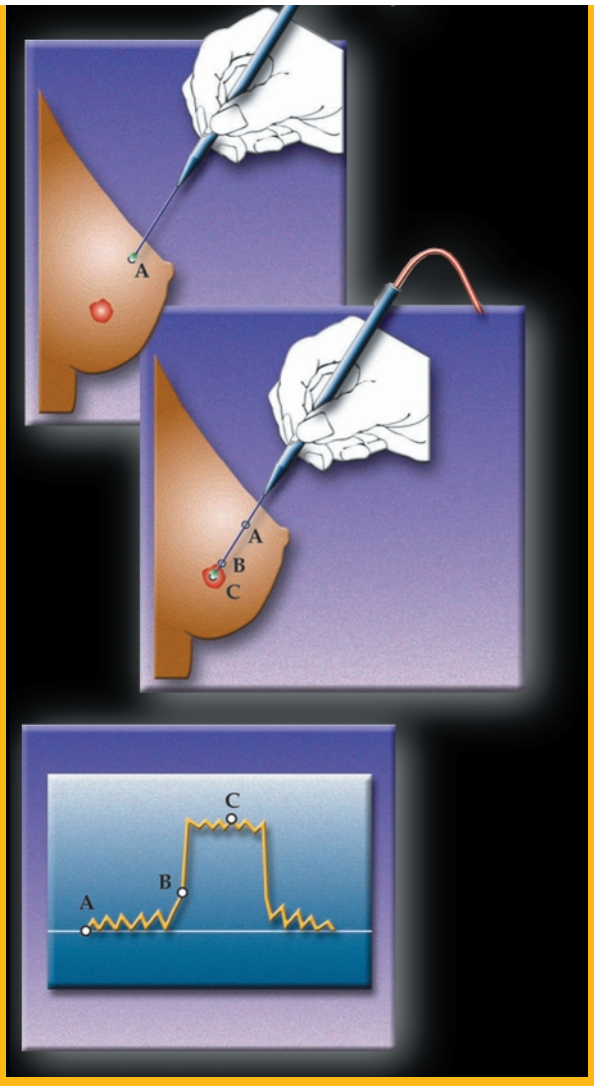
Preparing to Demonstrate EUV Lithography

Teamed together as a Virtual National Laboratory (VNL), researchers from Lawrence Livermore, Sandia, and Lawrence Berkeley national laboratories are working with an industrial consortium to develop next-generation technology for semiconductor manufacturing. The team is pursuing extreme-ultraviolet (EUV) lithography as a means for etching ultrathin patterns into silicon chips. The research and development effort by VNL is a $250-million, multiyear cooperative research and development agreement (CRADA) with the EUV LLC (Limited Liability Corporation) consortium consisting of Intel, AMD, Motorola, Micron, and Infineon.

Efforts by VNL have focused on integrating the necessary technologies into an engineering test stand that will function as a prototype EUV lithography system. Livermore leads the efforts in the test stand's optical systems and components, thin films, masks, and submicrometer metrology. A goal for early 2001 is to use the test stand to print patterns onto silicon chips with features as small as 0.10 micrometer, or about a thousandth the width of a human hair. Through further technological improvements, engineers expect to shrink features to less than 0.03 micrometer, making it possible to manufacture the much smaller, more powerful chips.

PEREGRINE Goes Commercial

Livermore's PEREGRINE technology is a revolutionary tool for analyzing and planning radiation treatment for cancer patients. The NOMOS Corporation has been licensed by Livermore to use the PEREGRINE technology and recently was granted clearance by the U.S. Food and Drug Administration to produce and market PEREGRINE systems to the medical community. Compared with other dose-calculation methods in current use, PEREGRINE more exactly estimates the radiation being delivered to a specific tumor and nearby tissue. Its modeling explicitly accounts for inhomogeneities in the body such as air, muscle, and bone that are identified on the patient's computed tomography (CT) scan.



We are partnering with BioLuminate Inc. to develop Smart Probe, a tool for detecting early breast cancer without biopsy. Sensors on the tip of the probe measure in real time the optical, electrical, and chemical properties that are known to differ between healthy and cancerous tissues. Physicians can then determine whether more tests are necessary.

Livermore researchers are developing technologies to carefully control the wavefront of 13.4-nanometer-wavelength light reflected by very precise mirrors. The shape of the wavefront must be accurate to 1 nanometer for EUV lithography to be able to produce next-generation silicon chips with features as small as 30 nanometers.

Each year, the scientific and technological accomplishments of our employees are recognized outside the Laboratory by prizes, awards, and front-page publicity. Some of these achievements are described here. In addition, a program of directorate-level awards was instituted to formally recognize within the Laboratory outstanding achievements by individuals and project teams. In all, more than 3,600 awards were presented in 2000.

Award-Winning Science and Technology

Edward Teller Fellows

The first group of Edward Teller fellows was named in 2000. They are Christine Hartmann-Siantar (for leadership in the PEREGRINE program), Bill Nellis (for discovery of metallized fluid hydrogen), Anne Happel (for the study of environmental contaminants in groundwater), and Mordy Rosen (for long-standing scientific excellence). The recipients are provided a year-long opportunity to do self-directed work for the benefit of the Laboratory.

Lawrence Livermore Fellowships are awarded to attract outstanding postdoctoral fellows and continue the Laboratory's tradition of breakthrough science and technology.

Many Significant Honors and Awards

Former Livermore director Herbert York received the Enrico Fermi Medal, given for a lifetime achievement in the field of nuclear energy.

The Laboratory shared the most prestigious award in high-performance computing—a Gordon Bell Prize—for a second consecutive year. Representing Livermore was Bruce Curtis of the team winning the special category for high-performance reactive fluid flow simulations using adaptive refinement on thousands of processors. Other team members were from the University of Chicago, Intel Corp., Drexel University, and NASA.

The American Physical Society named four Laboratory physicists as new fellows: Robert Cauble, James Hammer, Joseph Nilsen, and Ann Orel Woodin.

Livermore physicist John Lindl and retiree Garth Cummings were named fellows of the American Association for the Advancement of Science.

Stephen Payne and former Laboratory researcher Mike Perry were elected fellows of the Optical Society of America.

Roger Aines was named one of Top 25 Newsmakers in the construction industry by *Engineering News-Record* for work developing steam–oxygen injection technology for cleaning petroleum contaminants.

The DoD Defense Modeling and Simulation Office honored a Laboratory

The first Edward Teller fellowships were awarded in recognition of scientific excellence (recipients have the plaques): Christine Hartmann-Siantar, Bill Nellis, Anne Happel, and Mordy Rosen. The awards were presented by Edward Teller (front) and Deputy Director Jeff Wadsworth, Director Bruce Tarter, and Deputy Director Bob Kuckuck.

team that developed the Joint Conflict and Tactical Simulation (JCATS) computer code. Faith Shimamoto led the team, which included Mike Uzelac, Hal Brand, Greg Bowers, and Tom Kelleher.

David M. Cooper, associate director for computation and Livermore's chief information officer, was named by *Computerworld* as one of the "Premier 100 Information Technology Leaders for 2000."

The Industrial Partnerships and Commercialization Office's Christine Smith was named one of the top 100 young innovators for efforts "that paved the way for productive research collaborations among thousands of people."

The Federal Laboratory Consortium honored Livermore for success in transferring two new technologies to the commercial marketplace: PEREGRINE, which will improve cancer treatment, and LaserShot℠ Peening, which will extend the life of critical metal parts such as aircraft engine fan blades.

The American Astronomical Society awarded Charles Alcock, former head of Livermore's Institute for Geophysics and Planetary Physics, the Beatrice Tinsley Prize for "innovative and original work."

Don Correll, director of Science and Technology Education, was awarded Fusion Power Associates' Special Award for Education.

Mark Herrmann, a postdoctoral fellow, received the American Physical Society's Award for Outstanding Doctoral Dissertation in Plasma Physics.

Ted Saito was named chair of the American Association of Engineering Societies.

Senior staff member Jay Davis, former associate director at Livermore, was awarded the Department of Defense Medal for Distinguished Public Service for his work as director of the Defense Threat Reduction Agency.

A DOE Project Management Award was given to the Stanford Linear Accelerator Center's B Factory project, to which the Laboratory was a major contributor.

The Laboratory garnered an R&D 100 Award with its Waste Inspection Tomography for Non-Destructive Assay, which was developed by a team of engineers and physicists headed by Patrick Roberson and Harry Martz.

John Lindl was awarded a Fusion Power Associates Year 2000 Award for leadership and excellence in fusion engineering.

Doug Faux received a letter of commendation from the U.S. Army Space and Missile Defense Command, which cited many years of distinguished service for performing and managing analyses of theater missile defense and national missile defense interceptor lethality.

STARS

To recognize star performers and their achievements, the Laboratory created a Web site—Science and Technology Awards and Recognition System (STARS)—to track and publicize the many achievements of our scientists and engineers. For information about the Laboratory's STARS project and other awards, see its Web site at http://stars.llnl.gov/.

The Waste Inspection Tomography for Non-Destructive Assay won an R&D 100 Award in 2000 for providing accurate assay values of radioactive wastes inside sealed drums.

Lawrence Livermore National Laboratory's principal asset is its workforce. Through a long association with the University of California, the Laboratory has been able to recruit a world-class workforce and sustain a tradition of scientific and technical excellence. With approximately 8,000 employees, Livermore has an essential and compelling core mission in national security and the capabilities to solve difficult, important problems.

General John Gordon, administrator of NNSA, visited Livermore in August to meet with employees and learn more about the Laboratory's programs. In an address to the staff, he reiterated his message to the American people—that NNSA and its laboratories are partners in a vital mission in national security and that the nation should take great pride in the Laboratory and its employees.

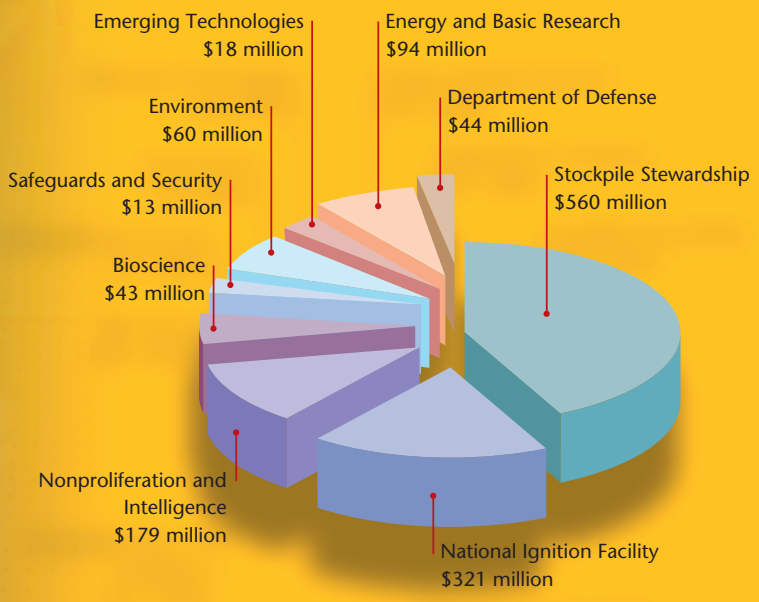
About the Laboratory's People and Programs

We Value Our Workforce

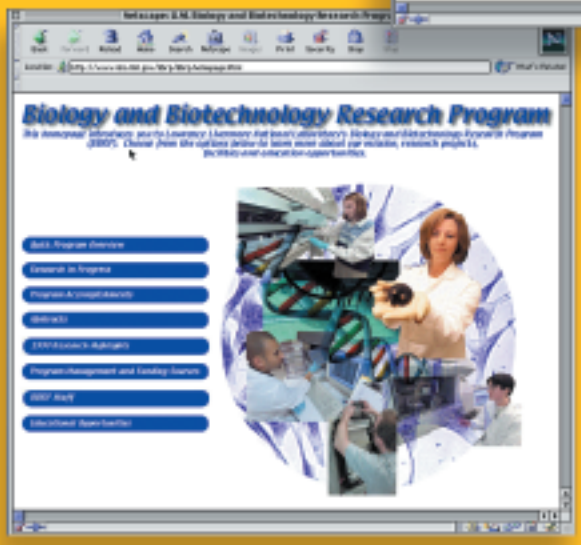
The Laboratory's achievements are the product of dedicated, high-quality efforts of all employees. We greatly value the outstanding scientific and technical achievements of the staff. Breakthrough accomplishments are critical to success and provide the foundation for future programs to meet national needs. The Laboratory's success also depends on those who provide essential services and help to make Livermore a safe, secure, healthy, and efficient place to work.

Laboratory Budget

Most of Livermore's $1.33-billion budget for FY 2000 was designated for research and development



FY 2000 Budget: $1.332 Billion



activities in program areas supporting the Department of Energy's missions.

As a national security laboratory, Livermore is part of DOE's National Nuclear Security Administration (NNSA). We receive most of our funding from the NNSA Office of Defense Programs for stockpile stewardship. We also receive funding from the NNSA Office of Defense Nuclear Nonproliferation, various Department of Defense sponsors, and other federal agencies for national security work.

As a multiprogram laboratory, we apply Livermore's special capabilities to meet important national needs. Activities are pursued for other DOE programs, principally Environmental Management, and the Offices of Science, Civilian Radioactive Waste Management, Nuclear Energy, and Security and Emergency Operations. Non-DOE sponsors include federal agencies (such as the National Aeronautics and Space Administration, Nuclear Regulatory Commission, National Institutes of Health, and Environmental Protection Agency), State of California agencies, and industry.

Find Out More about Us

Visit the Laboratory's frequently updated Web site at http://www.llnl.gov/ to learn more about our many scientific and technical programs. Discover the many opportunities for employment, academic research, and industrial partnerships. Read about our accomplishments each month in *Science & Technology Review* on the Web or in print. *S&TR*, annual reports, and other publications are consistent award winners in the Society of Technical Communication competitions.

University of California
Science & Technology Review
Lawrence Livermore National Laboratory
P.O. Box 808, L-664
Livermore, California 94551

Construction Pushes Forward at the National Ignition Facility
At Lawrence Livermore, NIF's target chamber is completed and installed in its final position in the target bay. In addition to the ports for the laser beams, the 10-meter-diameter aluminum spherical vacuum vessel provides nearly 200 ports available for diagnostic instrumentation on the world's largest laser.

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