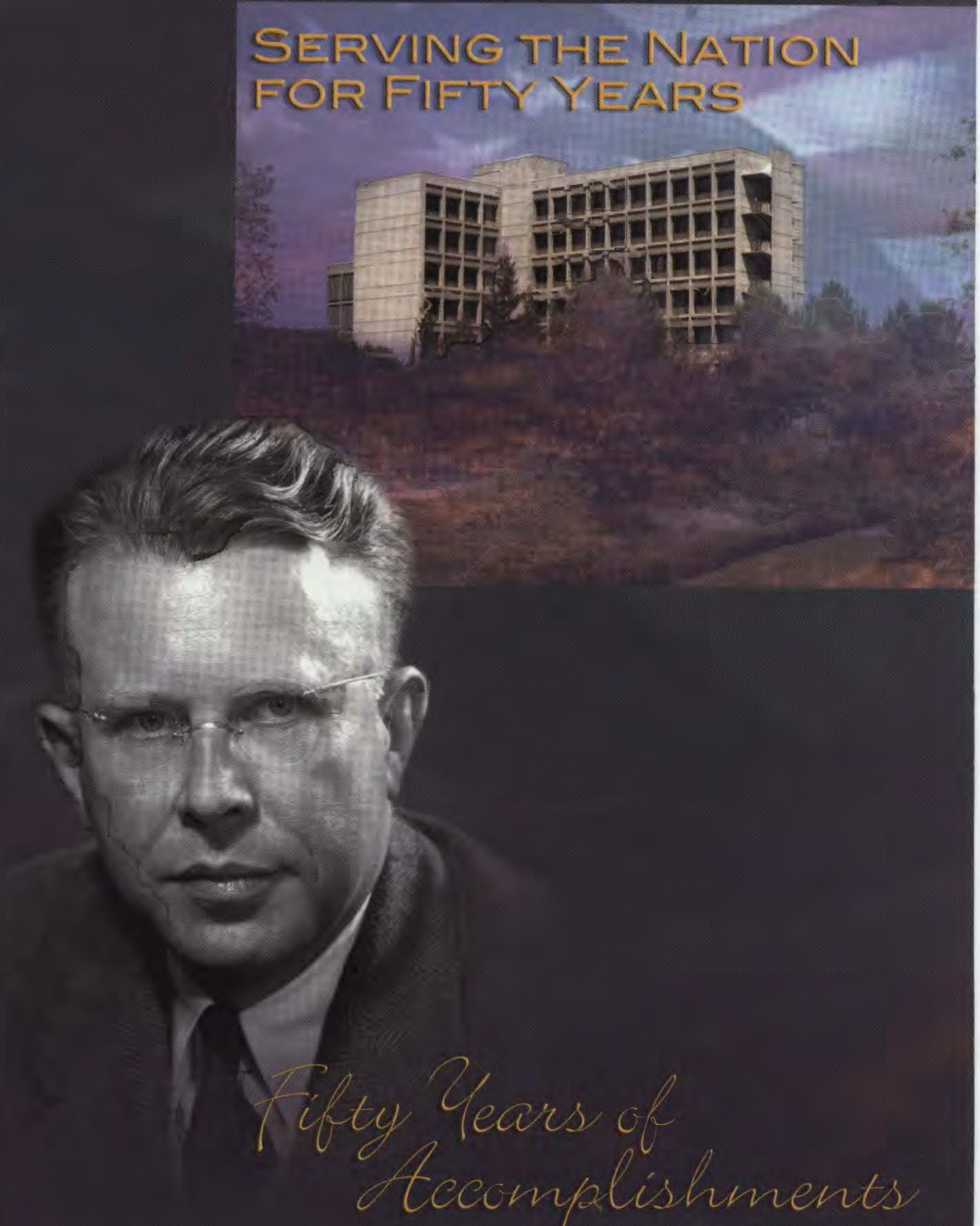
1952 • 2002 Lawrence Livermore National Laboratory



SERVING THE NATION FOR FIFTY YEARS

Fifty Years of Accomplishments

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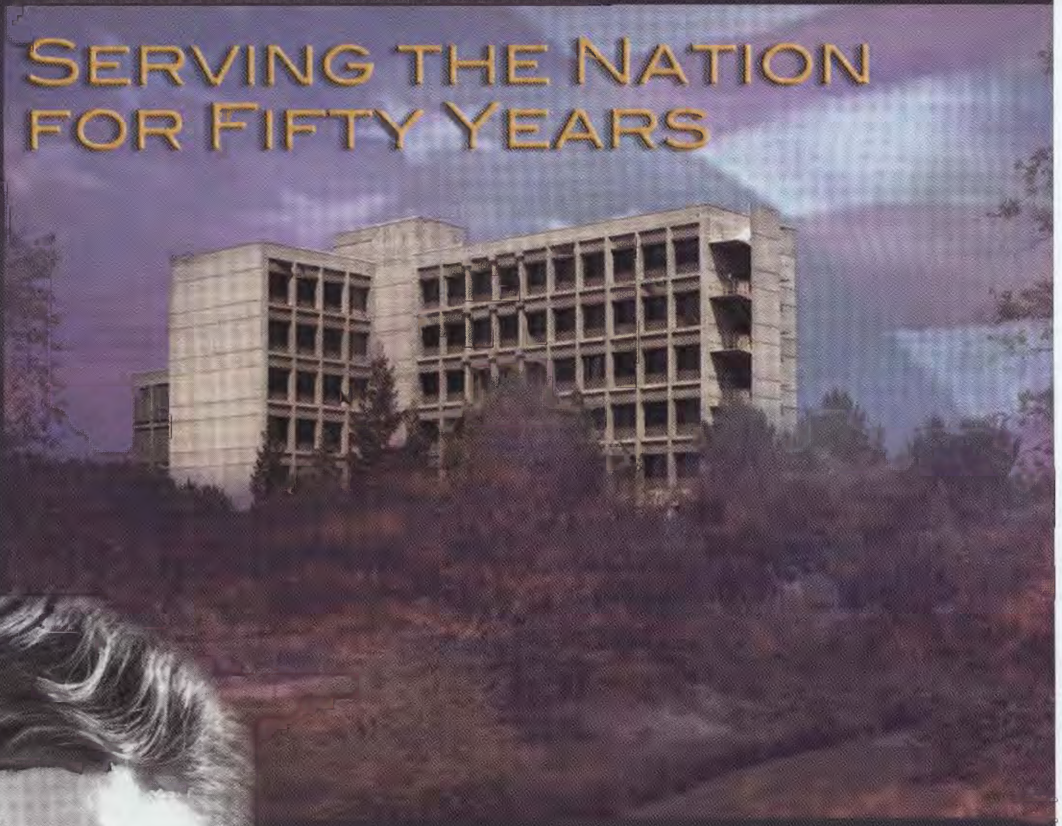

About the cover:
Lawrence Livermore National Laboratory is named after Ernest O. Lawrence (shown), who co-founded with Edward Teller a branch of the University of California Radiation Laboratory at the Livermore site in 1952.

Fifty Years of Accomplishments

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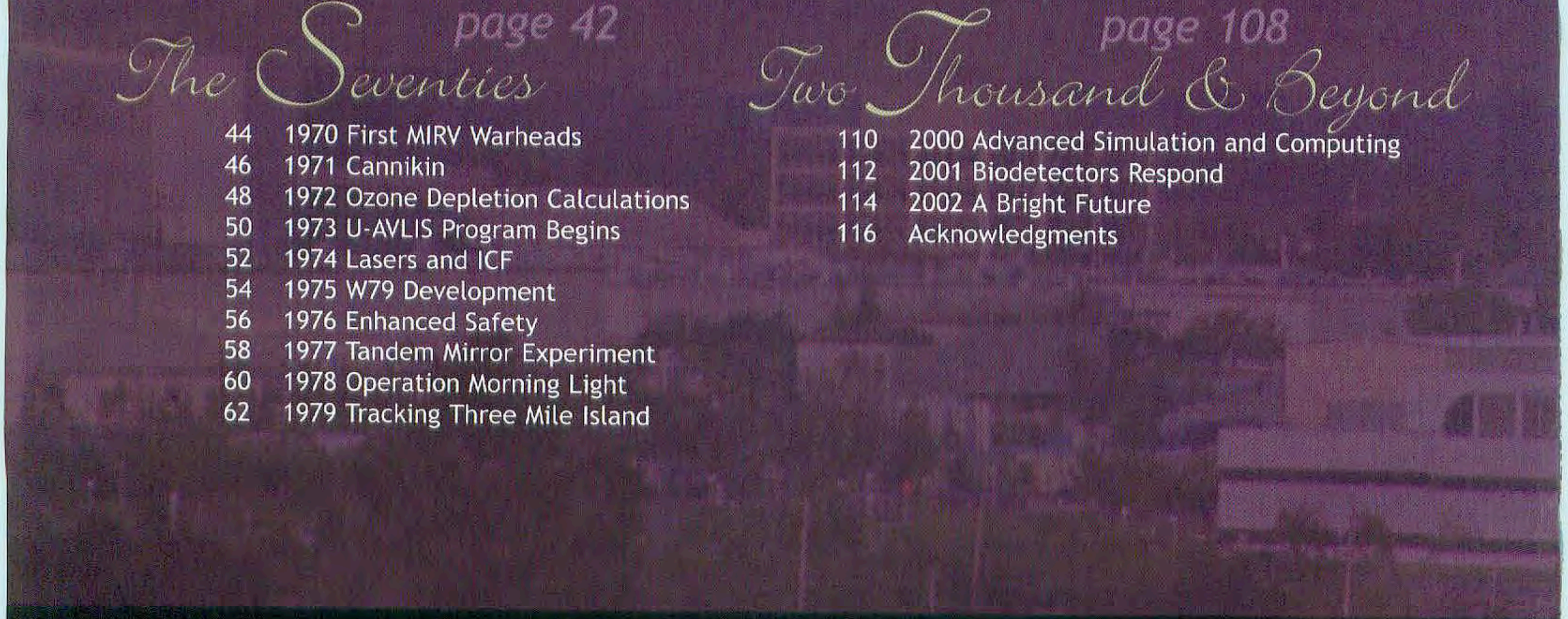
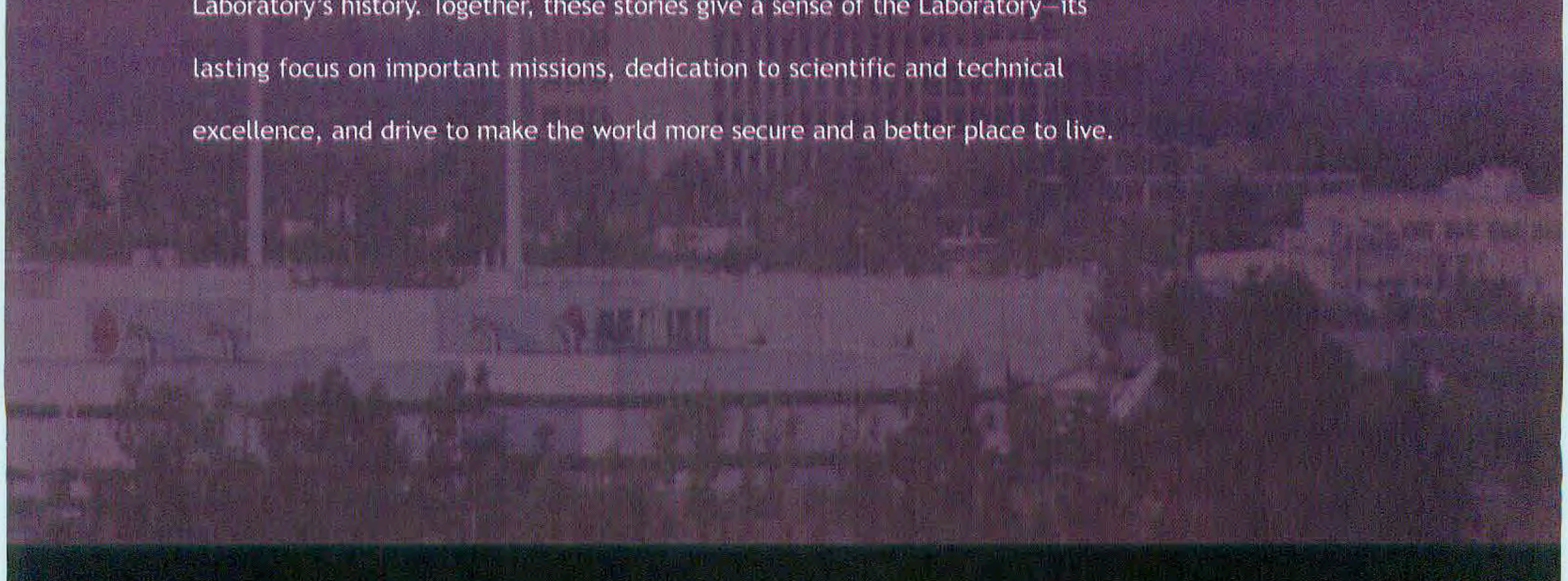


Preface

For 50 years, Lawrence Livermore National Laboratory has been making history and making a difference. The outstanding efforts by a dedicated work force have led to many remarkable accomplishments. Creative individuals and interdisciplinary teams at the Laboratory have sought breakthrough advances to strengthen national security and to help meet other enduring national needs.

The Laboratory's rich history includes many interwoven stories—from the first nuclear test failure to accomplishments meeting today's challenges. Many stories are tied to Livermore's national security mission, which has evolved to include ensuring the safety, security, and reliability of the nation's nuclear weapons without conducting nuclear tests and preventing the proliferation and use of weapons of mass destruction. Throughout its history and in its wide range of research activities, Livermore has achieved breakthroughs in applied and basic science, remarkable feats of engineering, and extraordinary advances in experimental and computational capabilities.

From the many stories to tell, one has been selected for each year of the Laboratory's history. Together, these stories give a sense of the Laboratory—its lasting focus on important missions, dedication to scientific and technical excellence, and drive to make the world more secure and a better place to live.



The Fifties

NEW Leadership


Herbert F. York
(1952•1958)


Edward Teller
(1958•1960)

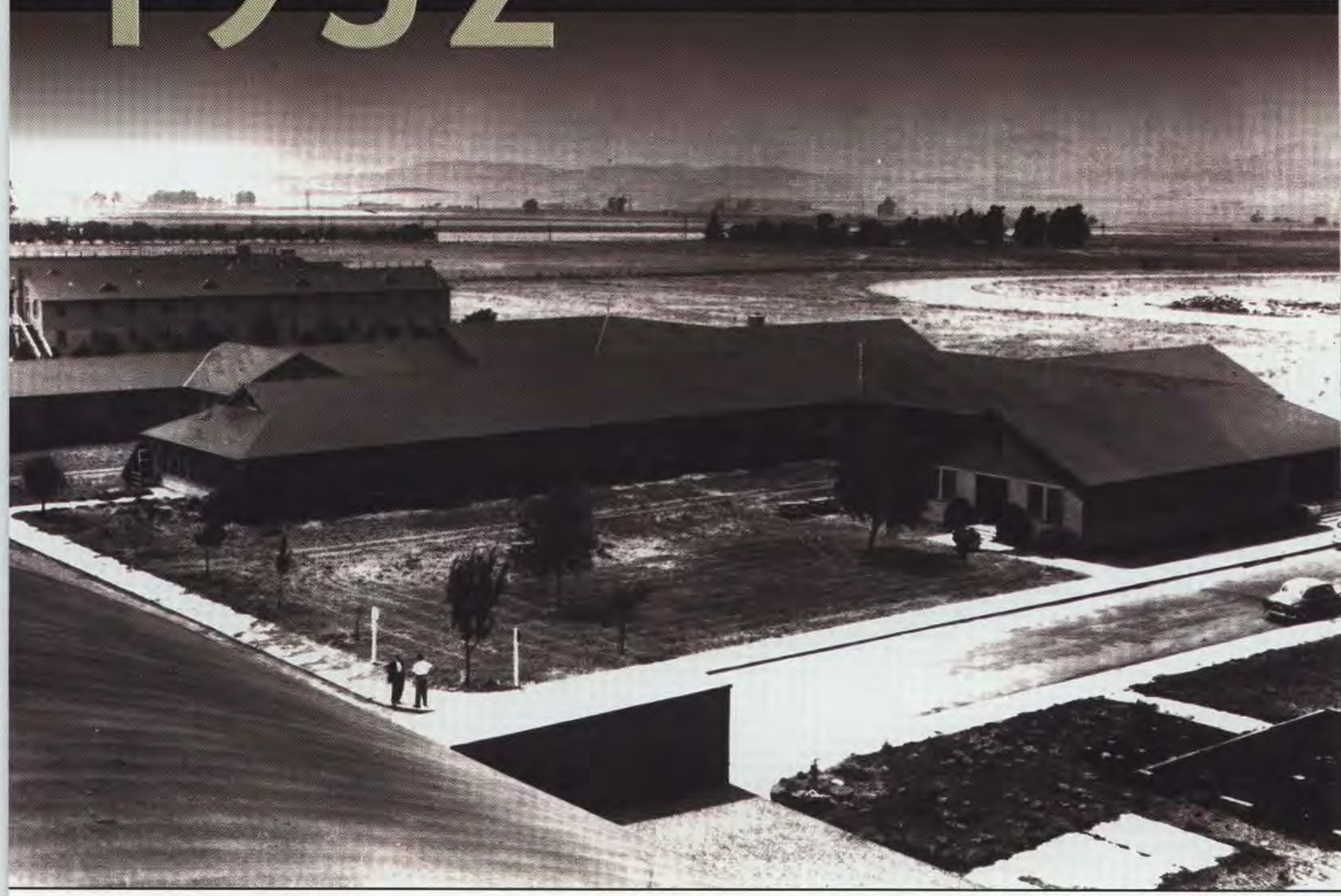
The Cold War was raging, and on August 29, 1949, the Soviet Union detonated its first atomic bomb—much sooner than expected by Western experts. Less than a year later, Communist North Korean forces crossed the 38th parallel to invade the Republic of Korea. National security was at stake. The urgent need to accelerate the nation's H-bomb program led

A "new ideas" laboratory

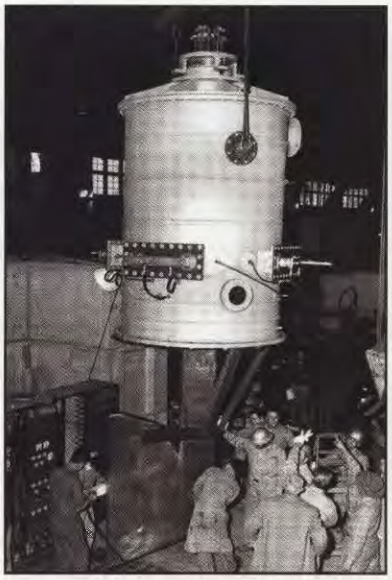
Ernest O. Lawrence and Edward Teller to argue for the creation of a second laboratory to augment the efforts of Los Alamos. On September 2, 1952, a branch of the University of California's Radiation Laboratory opened in Livermore, California.

Livermore's first director, Herbert F. York, and a remarkable group of young scientists set out to be a "new ideas" laboratory. They were committed to pursuing innovative solutions to the nation's pressing needs to advance nuclear weapons science and technology. The Laboratory's first nuclear experiments were failures. But later in the decade, Livermore scientists made a major breakthrough—the design of a megaton-class warhead for ballistic missiles that could be launched from submarines.

1952 THE LAB OPENS



When the Laboratory opened in 1952, the old Navy infirmary (above) served as the administration building, and it housed Livermore's first computer.



Two of the Laboratory's first major facilities for nuclear research were the 90-inch cyclotron (far left), which operated from 1954 to 1971, and the Livermore Pool-Type Reactor (left), which was used for experiments from 1957 to 1980.

Team Science in the National Interest

The Livermore branch of the University of California Radiation Laboratory (UCRL) at Berkeley opened for operation on September 2, 1952, at a deactivated Naval Air Station. The infirmary at the old air station had been used by a group of UCRL physicists to help Los Alamos with diagnostics for the George thermonuclear test fielded at Eniwetok Atoll (Central Pacific) in May 1951. The site also was being used by California Research and Development, a subsidiary of Standard Oil, to build the Materials Testing Accelerator (MTA), a pilot for a larger accelerator to produce tritium and plutonium for weapons. Conceived by Ernest O. Lawrence, founder of UCRL, the MTA project was abandoned in 1954 after the discovery of large domestic deposits of uranium ore, and the "Rad Lab" took sole possession of the square-mile site.

Working conditions at the Rad Lab were primitive, with the staff housed in old wooden buildings with poor heating and no air conditioning. Initially, there were fewer telephones than promised, no post office box for mail delivery, and, according to the minutes of an early administrative meeting, "The desk lamp situation is very bad." The infirmary building was in the best shape, so Herbert F. York, the first director, and an opening-day staff of 75 located there. York's office was in the x-ray room—it was lead shielded, and he could carry on classified discussions without being overheard.

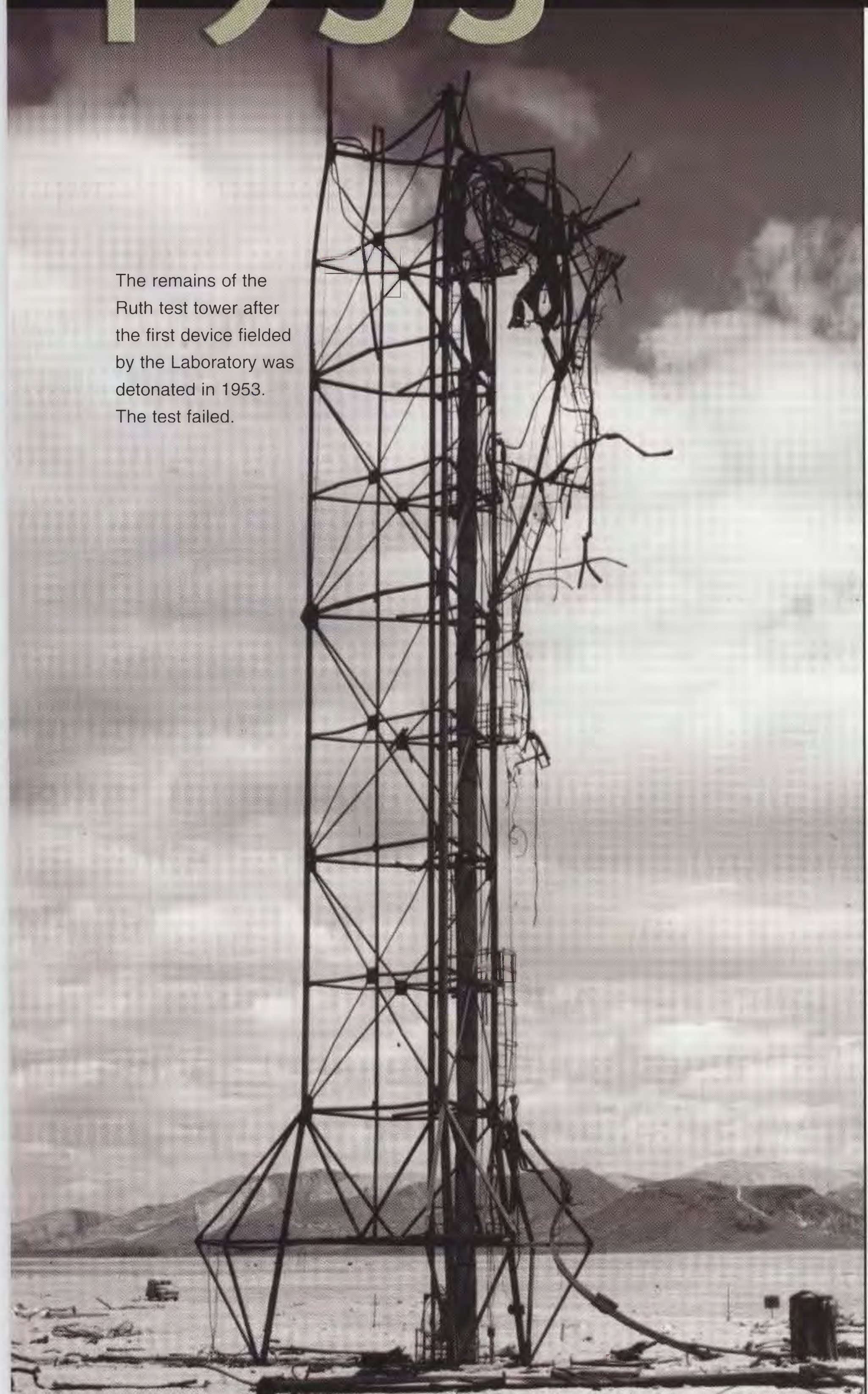
Establishment of the Laboratory was triggered by the detonation of the first Russian atom bomb in 1949, which alarmed some American scientists who feared a quick Soviet advance to the next step, the hydrogen bomb. Edward Teller and Lawrence, both very concerned, met on October 7, 1949, at Los Alamos to discuss the crisis. The ensuing actions taken by key figures in Washington led to the creation of the Livermore Laboratory to more rapidly advance nuclear weapons science and technology. Activities began with a sketchy mission statement and a commitment by York and his team to be a "new ideas" laboratory.

York, then 32 years old, was singled out by Lawrence to head the new laboratory. He had co-led the team that worked on diagnostics for the George event. York faced two principal challenges: planning the Laboratory's research program and recruiting the first employees. His plan had four main elements: development of diagnostics for weapons experiments (for both Los Alamos and Livermore), the design of thermonuclear weapons, Project Sherwood (a magnetic fusion energy program), and a basic physics program. Staff recruitment relied heavily on connections with Berkeley. By the end of 1952, the staff had grown to 300, by the end of the first year of operation to 1,000, and within just five years to 3,100.

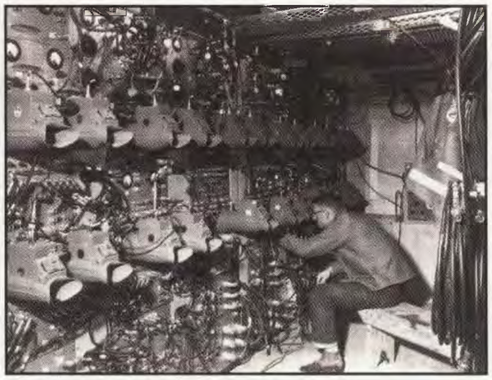
Following the lead of his mentor, York established a matrix organization for the Laboratory, a distinguishing feature of Livermore still in use today. In this approach, experts in various relevant disciplines assemble as a team and work together to understand and solve complex problems. This way of structuring and organizing research and development enables the Laboratory to better reach its mission-directed technological goals. And the rest is history.

Livermore's first director, Herbert F. York (right), confers with founders Ernest O. Lawrence (left) and Edward Teller (center).

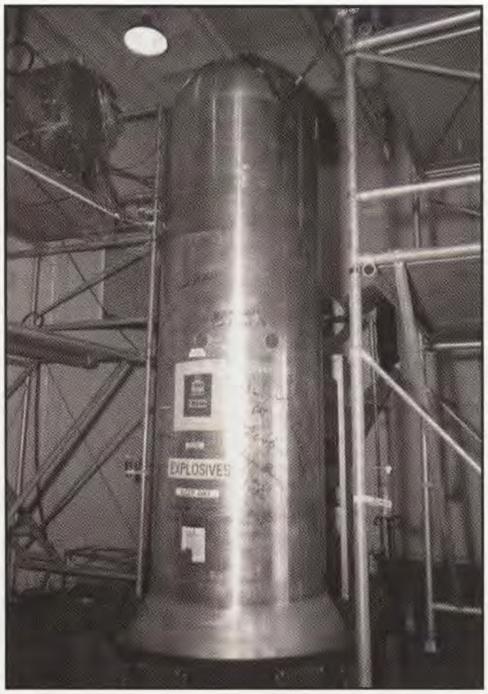
1953 RUTH



The remains of the Ruth test tower after the first device fielded by the Laboratory was detonated in 1953. The test failed.



Banks of oscilloscopes are used to capture data at the Nevada Test Site during Operation Teapot in 1955.



Shown in position inside a barge, one of the Laboratory's largest designs, the Tewa device, yielded five megatons when it was detonated near Bikini Atoll in 1956.

Pushing the Frontiers of Nuclear Weapon Design

Ruth, the Laboratory's first nuclear test, explored a new design for fission devices that offered hope for smaller, more efficient bombs and provided information about certain thermonuclear reactions. The experiment, and the test that followed (named Ray), exemplified Livermore's commitment to be a "new ideas" laboratory and, in the words of Edward Teller, to "plan and explore all kinds of new developments in the field of bomb physics."

The device was mounted on a 300-foot steel tower, and Ruth was fired on March 31, 1953—just six months after Livermore opened. The test was a fizzle. More than half of the tower remained standing afterward. Fired on April 11, 1953, Ray also was a fizzle, although legend has it that Ray was mounted on a shorter 100-foot tower to ensure its complete destruction. But the Laboratory pressed ahead in its quest for more compact weapon designs that were efficient in their use of nuclear materials.

Livermore's interest in novel small fission weapon designs would come to fruition in the 1950s, in part because of Los Alamos's attention to meeting the Air Force's needs for large H-bombs. The Army was interested in atomic projectiles between 8 and 11 inches in diameter, and the Air Force envisioned the need for nuclear-tipped antiaircraft missiles. Livermore's main thrust in this area was a new design concept that combined disparate elements from previous fission weapon designs. Ideas matured for fission weapons with a smaller diameter, requiring less nuclear materials and/or an increased yield to weight.

This research led to some of the Laboratory's first weapon-development assignments, including the W45 for the Little John and Terrier tactical missile systems and the W48 155-millimeter howitzer atomic projectile. A strong continuing interest in improved designs for tactical systems culminated in the Laboratory's work on the W79 enhanced-radiation artillery shell in the 1970s (see Year 1975).

The role of Livermore as the "new ideas" laboratory also guided the decision to focus thermonuclear work on the design of small H-bombs. As early as the Castle test series in 1954, Livermore investigated H-bomb designs smaller in size and yield than those designed by Los Alamos. The first thermonuclear test, Koon, also was a fizzle, yielding only 100 kilotons of an expected 1 megaton. Continuing efforts and future successes led to Livermore's development of much smaller diameter H-bomb missile warheads later in the 1950s, which made the Polaris submarine program possible (see Year 1956).

An Eyewitness Account of Ruth

Wally Decker, who later headed the Mechanical Engineering Department and finished his long career on the Director's Office staff, was a young engineer when he witnessed Ruth. According to Decker, "We got everything ready. We stood back with our dark glasses on, waiting for the device to go off. When it was fired, all we could see was a small speck of light on the horizon—no mushroom cloud, no nothing.

"But we didn't give up. We prepared for another event with a slightly different design. And when we fired the device, it was dismal, too.

"After those failures, our fortunes were at low ebb. We always said that we got a lot of good information from those failures—and we did—but you don't always get to stay around to play your best game. Fortunately, we did, and things got better for the Lab."

1954 THE IBM 701

The IBM 701 computer was delivered to the Lab in 1954—it was 12 times faster than its predecessor, the Univac-1.

The Origin of FORTRAN

The Univac-1 was a simple computer to program in machine language; however, the IBM 701 was more difficult to use—one reason was its reliance on punch cards for input and output. Programmers in companies and laboratories that owned 701s talked among themselves informally, and various "home-brewed" systems resulted. IBM soon began to develop a higher-level language, FORTRAN (formula translation), and the Laboratory sent Robert Hughes to IBM for an extended visit to contribute to the effort. The original FORTRAN manual lists four contributors, one of them Robert Hughes.

Speed Is the Game

With delivery of the IBM 701 in 1954, the Laboratory dramatically improved its capability to perform scientific calculations. With 72 cathode-ray tubes, 2,048 words of memory, and accompanying gadgetry, the machine was the first commercially successful "scientific" supercomputer because of its speed. It was 12 times faster than its predecessor, the Univac-1, which the Laboratory acquired during its first year of operation. The Univac-1 correctly predicted the Eisenhower landslide victory in the 1952 presidential election with only 7 percent of the vote tallied, but Livermore's needs quickly outgrew the machine's capabilities.

Even before the Laboratory was a reality, founders Ernest Lawrence, Edward Teller, and Herb York understood the need for mammoth amounts of computing power. Almost from the opening of the doors in 1952, a sizable team of Livermore people was learning to use the Univac-1 and troubleshoot its problems. At election time, the machine earmarked for Livermore was loaned to a TV network to predict the results. Acquisition of the Univac-1, and soon after the IBM 701, marked the beginning of the Lab's not-so-coincidental links to commercial supercomputing—their nearly identical birth dates, efforts to develop the fastest and most powerful machines, and use of machines to solve large, complex problems.

The IBM 701 and all of Livermore's supercomputers since have been developed in part at the Laboratory's encouragement. The IBM 701 was the last vacuum-tube model before magnetic core and transistor memory. With the change in technology to transistors, computer speed and storage capacity have rapidly advanced in accordance with a phenomenon dubbed "Moore's Law," formulated in 1965 by Gordon Moore, founder of Intel Corporation. The law has accurately predicted that every 18 months technology advances would allow a doubling of the number of transistors that could be put on a computer chip. Ongoing work at the Laboratory on extreme ultraviolet lithography (see Year 1999) aims to extend Moore's Law to approximately 2010.

Livermore is also part of the National Nuclear Security Administration's Advanced Simulation and Computing (ASCI) program, which was initiated in 1995 to increase supercomputer speed and capacity faster than afforded by Moore's Law. In the ASCI supercomputers, thousands of the most powerful microprocessors industry produces are configured to work in parallel. The IBM ASCI White machine at Livermore, the world's most powerful computer in 2002, consists of 8,192 processors and is able to perform 12 trillion operations per second (12 teraops)—30 billion times faster than the Univac-1 (see Year 2000).

Livermore's terascale computing capabilities keep the Laboratory at the forefront of scientific computing in the early 21st century. They promise to help experts maintain the nation's nuclear deterrent and open many new avenues of scientific discovery.

Delivered in May 1960, the building-size LARC (Livermore Advanced Research Computer) was built by Remington-Rand to specifications provided by the Laboratory.

1955 NUCLEAR PROPULSION

Construction is shown in progress to expand the “tank farm” that supplied high-pressure air to the ramjet reactor, which was tested inside a special facility (lower left in the photo). In one experiment, Tory II-C (far right photo) required hundreds of tons of heated air to operate for nearly five minutes.

Flying and Terrestrial Nuclear Reactors

In 1955, the Laboratory and Los Alamos began work on Rover, a project intended to supply nuclear propulsion for space travel. The nuclear rocket program continued for many years at Los Alamos with many technical successes, while Livermore's attention shifted in 1957 to a new flying reactor effort, Project Pluto, for the Atomic Energy Commission and the Air Force. An awesome undertaking, Project Pluto entailed the design and testing of a nuclear ramjet engine for low-flying, supersonic cruise missiles that could stay aloft for many hours.

For Project Pluto, Livermore designed and built two Tory II-A test reactors to demonstrate feasibility, and Tory II-C was designed as a flight-engine prototype. Laboratory experts in chemistry and materials science were challenged to devise ceramic fuel elements that had the required neutronics properties for the reactor yet were structurally strong and resistant to moisture and oxidation at high temperatures. Because the reactors needed hundreds of thousands of the elements, they also had to be mass producible. Testing the reactors required novel remote-handling technologies, as well as systems capable of ramming about a ton of heated air through the reactor each second.

For 45 seconds on May 14, 1961, Livermore tested the Tory II-A at the Nevada Test Site. After additional successful experiments in 1961, Tory II-C was designed and built. Generating 500 megawatts of power (about half the power capacity of Hoover Dam), it was successfully tested in the spring of 1964. All six tests of the two Tory reactors were conducted without failure. However, that summer, the project was halted for lack of a firm military commitment.

Laboratory expertise in reactors and the nuclear fuel cycle has continued to find many applications. The year Project Pluto ended, Super Kukla began operation in a shielded bunker at the Nevada Test Site. Super Kukla was a prompt-burst neutron-pulse reactor designed to serve as a neutron source for irradiating a variety of test specimens, including fissile material used in weapon components. Experiments using the reactor helped to assure that U.S. nuclear warheads would function in wartime environments. In addition, from 1957 to 1980, the Livermore Pool-Type Reactor (a megawatt-class reactor) was operated onsite for neutron radiography, fundamental research on radiation damage to materials, and the detection of trace quantities of materials through neutron activation.

Today, Laboratory expertise in fission energy serves the Department of Energy, the Nuclear Regulatory Commission, and other government agencies through more than 80 projects. These efforts apply Livermore's advanced science and engineering capabilities to the protection of public health and safety and to the advancement of technology in fission energy and the nuclear fuel cycle (for example, the Yucca Mountain Project, discussed in Year 1980). Projects include technical support and services in areas such as risk and hazard analysis; structural and thermal analysis; containment, shielding, and criticality analysis; accident analysis; environmental assessments; radiation protection; and quality assurance.

1956 POLARIS

The Laboratory's design for the W47 Polaris warhead made it practical for U.S. nuclear deterrent forces to be deployed from highly survivable submarines.

Teller Recalling Project Nobska

"The Navy asked if we could make a nuclear explosive of such and such dimensions and such and such a yield. What they wanted was a small, light, nuclear warhead in the 1-megaton range. Everyone at the meeting, including representatives from Los Alamos, said it could not be done—at least in the near future. But I stood up and said, 'We at Livermore can deliver it in five years and it will yield 1 megaton.' On the one hand, the Navy went away happy, and the program got approved. On the other hand, when I came back to Livermore and told them of the work that was in store for them, people's hair stood on end. They said, 'What have you done? We can't get a megaton out of such a small device, not in five years!'"

A Strategic Breakthrough

In the summer of 1956, a Navy-sponsored study on antisubmarine warfare was held at Nobska Point in Woods Hole, Massachusetts. Edward Teller attended the Project Nobska study. His bold input would profoundly affect the course of the Navy's Fleet Ballistic Missile Program and the future of the Laboratory. At the time, the approved program plans called for the deployment in 1965 of submarines that would carry horizontally four 80-ton Jupiter S ballistic missiles, which were large enough to carry existing thermonuclear warheads.

During Project Nobska, Frank E. Bothwell from the Naval Ordnance Test Station raised the possibility of designing ballistic missiles 5 to 10 times lighter than the Jupiter S missiles, with a range of 1,000 to 1,500 miles; however, they would be able to carry only a relatively low-yield nuclear weapon. Teller discussed the feasibility of a 1-megaton warhead compact enough to fit onto a torpedo—a radical concept. When asked whether his ideas could be applied to the Navy ballistic missile program, Teller replied with a question, "Why use a 1958 warhead in a 1965 weapon system?" He opened the door to a highly efficient deterrent system in which 16 compact missiles could be placed vertically on a submarine and launched on demand without repositioning—the Polaris program.

So began a crash, three-year effort. In early 1957, the Navy issued a requirement for an underwater-launched solid-fuel missile system by 1965. By the end of the year, following successful tests of Livermore designs at the Nevada Test Site, the Secretary of Defense authorized a step-up to deploy the system by 1960, which was accomplished.

The summer of 1958 brought genuine breakthroughs based on ingenious proposals by Carl Haussmann, Kenneth Bandtel, Jack Rosengren, Peter Moulthrop, and David Hall of A Division and by B Division's John Foster (Lab Director, 1961–1965), Chuck Godfrey, and Wally Birnbaum. The significance of the innovations was confirmed during tests in the Pacific only a few months before the 1958–1961 nuclear testing moratorium began. Work continued at the Livermore and Sandia laboratories, and through the efforts of weapons designers and engineers, computer specialists, and other experts, the W47 Polaris warhead was created.

The program's remarkable achievements were demonstrated in spectacular fashion on May 6, 1962. The USS *Ethan Allen,* the sixth-launched Polaris submarine, fired a complete operational test of the Polaris A-1 missile system, culminating with the successful detonation of the Livermore-designed megaton-class warhead (see Year 1962).

Conceived as a highly survivable system able to counterattack in the event of a Soviet first strike, Polaris has a unique place in American nuclear weapons history. The Laboratory's innovative design and development of the W47 as part of a crash program established Livermore's reputation as a major nuclear weapons design facility. The work spurred additional innovations and provided a model for future strategic weapon development.

The Polaris flag was presented by the Navy to Livermore scientists and engineers for the Laboratory's outstanding work in the development of the Polaris missile warhead.

1957 RAINIER

Radiation detection equipment in the foreground monitors the environment for a worker in a tunnel at the Nevada Test Site that was dug for the Rainier event in 1957.

Radiochemical analysis of the isotopes created by a nuclear explosion was an important diagnostic tool for determining the yield and studying the performance of tested devices. Major advances in radiochemistry were made by Peter Stevenson (second from the right), who was killed in a plane crash returning from the Nevada Test Site in 1979.

The First Underground Nuclear Test

On September 19, 1957, the Laboratory detonated the first contained underground nuclear explosion. Rainier was fired beneath a high mesa at the northwest corner of the Nevada Test Site, which later became known as Rainier Mesa.

Carrying out such an explosion had been proposed early in 1956 by Dave Griggs, a geophysicist who greatly contributed to Edward Teller's effort to establish a second nuclear laboratory while serving as Chief Scientist of the Air Force in the early 1950s, and by Teller. Their interest was in the coupling of the explosion energy to the surrounding geology and in the seismic effects. They also noted the environmental advantages of such a test at a time when there was growing concern about atmospheric nuclear testing. Rainier would prove to be a pivotal event by giving a boost to the nascent Plowshare Program and affecting the future of nuclear arms control and the conduct of nuclear tests.

The idea of using nuclear explosions for non-military uses—beating swords into plowshares—preceded the Rainier event. In the summer of 1956, Harold Brown (Lab Director 1960–1961) proposed a symposium on the subject to the Atomic Energy Commission (AEC), and it was eventually held at Livermore in February 1957. Some 24 papers were presented covering a broad array of ideas. Although the discussions were hampered by the lack of actual data on the effects of underground explosions, interest was high. In June, the AEC established the Plowshare Program to explore peaceful nuclear uses, such as the building of canals and dams, and the stimulation of natural gas reservoirs. Subsequently, the Rainier test and its data gave a tremendous boost in confidence that a variety of applications were possible and could be implemented safely.

The Rainier event was announced in advance so that seismic stations throughout the U.S. and Canada could attempt to record a signal. In addition, samples were collected for radiochemistry analysis by drilling a series of holes from the mesa above and in the original tunnel. More data was collected by mining a tunnel into the bottom of the explosion cavity about 15 months later when radioactivity had decayed to manageable levels. From these post-shot investigations, scientists were able to develop the understanding of underground explosion phenomenology that persists essentially unaltered today. That information provided a basis for subsequent decisions in 1963 to agree to the Limited Test Ban Treaty, which banned atmospheric nuclear weapons tests and led to systems being established for monitoring nuclear test activities worldwide, including an international array of seismic detectors.

The Legacies of Plowshare

The first Plowshare test, Gnome, created an underground cavity about 70 feet high and 165 feet in diameter in a dry salt bed near Carlsbad, New Mexico. Many potential applications were explored until the program ended in 1977, and they drove nuclear design to the two extremes—minimum fission or minimum fusion depending on the application. The most dramatic relic of Plowshare is a 350-foot-deep, 1,200-foot-diameter crater (right) at the Nevada Test Site created by the Sedan event in 1962. Important legacies of the effort include Livermore's biomedical research program to study the effects of fallout and other radioactive hazards on biological systems (see Year 1963) and the Laboratory's Atmospheric Release and Advisory Capability (ARAC) program, which grew out of the need to predict the potential for atmospheric release from cratering shots (see Year 1979).

1958 TEST MORATORIUM

Photo credit: Ernest Orlando Lawrence Berkeley National Laboratory

Premier Khrushchev delivers a speech during the reception in the Kremlin's Georgian Hall following the formal signing of the Limited Test Ban Treaty on August 5, 1963. Hoping he would not be caught taking this picture, University of California Professor Glenn T. Seaborg, who was then Chairman of the Atomic Energy Commission, captured an image of the event.

The Evolution of Nuclear Force Postures

Michael May's distinguished career included many contributions to the evolution of U.S. strategic forces. May, a Laboratory Director from 1965 to 1971, served as Technical Adviser to the Threshold Test Ban Treaty negotiations (1974) and as U.S. Delegate to the Strategic Arms Limitation Talks (SALT) with the Soviet Union (1974–1976). Although never ratified, the SALT II Treaty effectively capped the growth of strategic nuclear arsenals during the Cold War. In 1981, May participated in a panel chaired by Berkeley Professor Charles Townes that recommended to President Reagan how to base MX (Peacekeeper) missiles, and in 1988, he was lead author of "Strategic Arms Reductions" in *International Security*, a seminal paper that provided an intellectual basis for subsequent Strategic Arms Reduction Treaty force reductions. Serving as a member of the National Academy of Sciences Committee on International Security and Arms Control, May also directed a study that resulted in the 1991 report *The Future of the U.S.–Soviet Nuclear Relationship*, which paved the way for later decisions about post–Cold War nuclear policy and strategic force reductions.

Providing Technical Support for Arms Negotiations

In July and August 1958, Ernest O. Lawrence and Harold Brown (Lab Director, 1960–1961) attended the Conference of Experts held in Geneva, Switzerland, to examine how a comprehensive ban on nuclear testing could be verified. Their participation signaled the beginning of the Laboratory's long history of providing technical support for arms control negotiations and implementation. Lawrence served as one of the three U.S. representatives at the conference, and Brown was a member of the delegation's technical advisory group. At the conference, Lawrence performed his final service to the nation before suffering an acute attack of colitis that led to his death. Many Livermore scientists would follow in Lawrence's and Brown's footsteps by contributing their expertise to the negotiations of nuclear arms reduction and nuclear test ban treaties.

The Conference of Experts' report exposed the technical challenges involved in detecting and identifying nuclear explosions. The report was surprisingly accurate considering that the Rainier event had been the only underground nuclear test of significant yield (see Year 1957) and no nuclear explosions had occurred at high altitude or in space. The report also defined the technical equipment of the control system needed to detect and identify nuclear explosions.

At the conclusion of the Conference of Experts, President Eisenhower announced U.S. willingness to suspend nuclear weapons testing and begin negotiations on a comprehensive test ban. Concurrent with these negotiations, a feasible verification regime was to be developed. Research on monitoring nuclear explosions ensued at the Laboratory as part of the Vela program. The seismic detection of underground explosions (Vela Uniform) proved to be more of a challenge than anticipated by the report of the experts.

A worldwide network of seismic stations was built as a part of Vela Uniform, and for 40 years, this network has been the primary source of data for the seismic community. In 1961, the moratorium was broken when the Soviet Union resumed atmospheric testing. With the confidence gained through Vela in detecting and monitoring nuclear explosions, President Kennedy signed the Limited Test Ban Treaty in August 1963, which banned nuclear weapon testing in the atmosphere, underwater, and in space.

Nuclear explosion monitoring remains an important research activity at the Laboratory. Current efforts entail developing databases, methodologies, algorithms, software, and hardware to improve monitoring capabilities around the world. Technical support of arms control negotiations has also continued to be an integral part of Livermore's overall mission. Today, experts at the Laboratory provide technical assistance to the Department of Energy and National Nuclear Security Administration on treaty verification, and they analyze the effects of arms control measures on the weapons program and on the nation's nuclear deterrent.

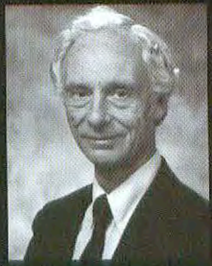
Michael May comments at one of a series of workshops held in 2001 on the future of deterrence. The meetings were sponsored by Livermore's Center for Global Security Research, which focuses its activities on the nexus between technology and national security policy.

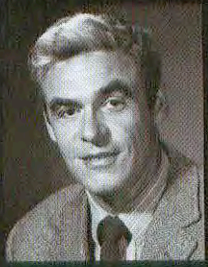
1959 E. O. LAWRENCE AWARDS CREATED


John S. Foster, Jr.
1960
Weapons


Herbert F. York
1962
Reactors


John H. Nuckolls
1969
Weapons


Michael M. May
1970
Weapons


Thomas E. Wainwright
1973
Weapons


Seymour Sack
1973
Weapons


Charles A. McDonald
1974
Weapons

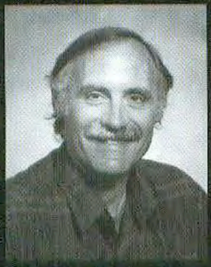

William Lokke
1975
Weapons


John L. Emmett
1977
National Security


B. Grant Logan
1980
Physics


Lowell L. Wood
1981
National Security


George F. Chapline
1982
National Security


George B. Zimmerman
1983
National Security

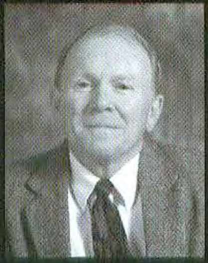

Robert B. Laughlin
1984
Physics


Peter L. Hagelstein
1984
National Security


Thomas A. Weaver
1985
National Security

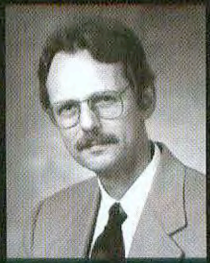

Joe W. Gray
1986
Life Sciences


Wayne J. Shotts
1990
National Security


Richard Fortner
1991
National Security


John D. Lindl
1994
National Security


E. Michael Campbell
1994
National Security


Charles R. Alcock
1996
Physics

Exceptional Contributions to Nuclear Energy

Established in November 1959, the Ernest Orlando Lawrence Memorial Award is presented each year to scientists and engineers for their exceptional contributions to the development, use, or control of nuclear energy. Nuclear energy is broadly defined to include the science and technology of nuclear, atomic, molecular, and particle interactions and their effects. Researchers at Livermore have won 22 of the over 200 awards presented to date. Today, the award consists of a medal and a $25,000 prize.

Lawrence was the father of "big science" and founder of the nuclear science laboratories (or "Rad Labs") at Berkeley and Livermore that were named for him. His invention of the cyclotron in the 1930s started nuclear science on a path that has led to inventions ranging from advanced accelerators for elementary particle physics and the atom bomb to cancer therapies.

After Lawrence's death in August 1958, John A. McCone, Chairman of the Atomic Energy Commission, wrote to President Eisenhower suggesting the establishment of a Memorial Award in Lawrence's name. President Eisenhower agreed, saying, "Such an award would seem to me to be most fitting, both as a recognition of what he has given to our country and to mankind and as a means of helping to carry forward his work through inspiring others to dedicate their lives and talents to scientific effort."

The Sixties

New Leadership


Harold Brown
(1960•1961)


John S. Foster, Jr.
(1961•1965)

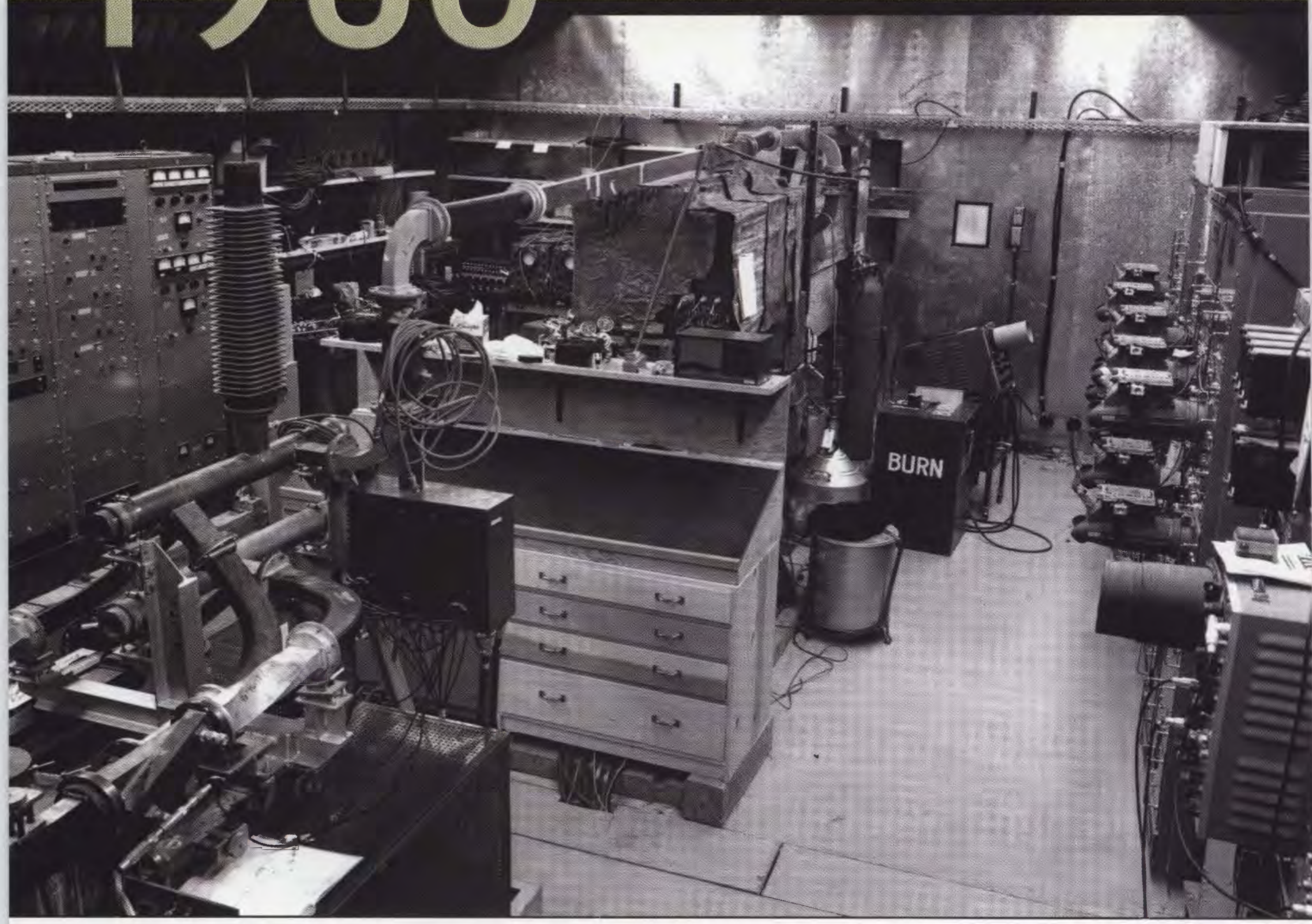

Michael M. May
(1965•1971)

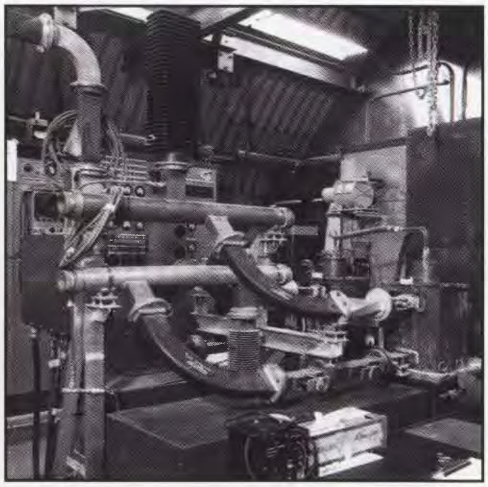
Multidisciplinary team science

Since its establishment, the Laboratory has followed E. O. Lawrence's approach of how large-scale science should be pursued—through multidisciplinary teams dedicated to solving challenging problems and responding to national needs. A rapid response was called for when the Soviet Union broke the international nuclear testing moratorium in August 1961. The following year, the United States mounted its most ambitious—and last—series of nuclear tests in the Central Pacific, Operation Dominic. The Laboratory proof-tested nuclear designs fielded during the moratorium and laid the groundwork for future Livermore designs of compact, high-yield ballistic missile warheads.

Multidisciplinary expertise gained by the Laboratory, along with the need to understand the consequences of atmospheric nuclear testing, spawned bioscience and environmental programs at Livermore. Subsequent biotechnology developments contributed to the Department of Energy's bold decision to launch its Human Genome Initiative. Environmental programs have led to novel groundwater remediation technologies and atmospheric modeling capabilities that range from local to global scales. A multidisciplinary approach is also the hallmark of Livermore's international assessments program, which has supported the U.S. Intelligence Community since 1965.

1960 LINACS FOR HYDROTESTING





The XR2 machine (above and left) was located in Sugar Bunker (far left) at the Nevada Test Site (NTS) until it was moved to Site 300 near Livermore. There, it provided the Laboratory's first primitive radiographic capability. A new linear accelerator was delivered to NTS in 1960.

Improved Nonnuclear Testing Capabilities

Site 300, the Laboratory's remote experimental test site, was a busy place in 1960. In the midst of a nuclear testing moratorium, Livermore was enhancing its nonnuclear testing capabilities. Two test complexes, a chemistry facility, a high-explosives preparation facility, a remote disassembly complex, and three other buildings were completed that year. In addition, a new linear accelerator (linac) was delivered to Site 300. That machine, which was installed in Bunker 351 (now 851), has undergone numerous upgrades and is still used for hydrodynamics experiments. The accelerator generates the powerful x-ray flashes needed for taking images of mock nuclear-weapon primaries as they implode.

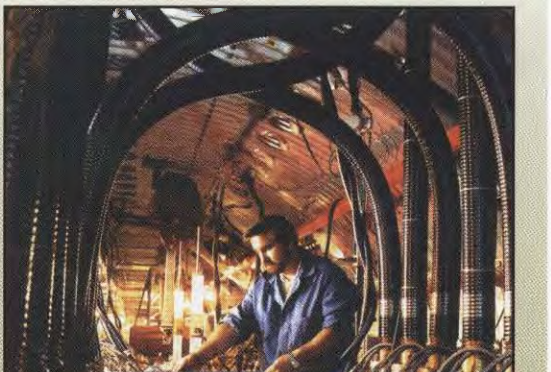
The linac for Bunker 351 superceded the capabilities of Bunker 312's XR2 machine, which had been moved from Sugar Bunker at the Nevada Test Site to Site 300 in the late 1950s. Charles McDonald, who later rose to senior management positions at the Laboratory, was one of the graduate students who helped build the XR2 in 1951 at the Radiation Laboratory in Berkeley. Starting at the Laboratory in fusion science research, McDonald became a weapon primary designer and then used the machine at Sugar Bunker.

Meanwhile, in another part of the Laboratory, Nicholas Christofilos, one of his generation's most original thinkers in physics, was pursuing a magnetic fusion concept, ASTRON. Born in Boston, Christofilos grew up in Greece, where he received a degree in engineering, privately studied physics, and first invented and patented the concept of alternate gradient (strong) focusing for particle accelerators. ASTRON required the invention of a new kind of electron accelerator, the induction linear accelerator (or induction linac), to produce an intense circulating electron beam to magnetically confine and heat a plasma to, it was hoped, thermonuclear ignition temperatures. The world's first induction linac was built for the ASTRON project in 1963.

Induction linacs are now the heart of the nation's two most modern hydrodynamic testing facilities—the Contained Firing Facility at Site 300 (with the Flash X Ray machine) and the Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos. Built in 1982 and subsequently upgraded, the Flash X Ray machine was used in the 1990s to perform the first experiments in which scientists recorded a detailed digital image of a highly compressed gas cavity inside a weapon (see Year 1985). Other successor induction linacs include the Electron Ring Accelerator at Berkeley and three accelerators built at Livermore for beam research: the Electron Test Accelerator (ETA), ETA-II, and the Advanced Test Accelerator at Site 300.

Accelerator Technology Development

The Laboratory has a long history of advancing the technology of electron linear accelerators for scientific and national security applications. After ASTRON, the Electron Test Accelerator (ETA) was built to study electron beam propagation in air as a possible directed-energy weapon. Completed in 1983, the 10-times more energetic Advanced Test Accelerator at Site 300 (right) furthered the study of beam propagation, and the beam was used as a pump for a free electron laser (FEL). ETA-II was designed to further FEL research and is contributing to the development of advanced radiographic capabilities for stockpile stewardship. In the 1990s, Livermore also collaborated with the Stanford Linear Accelerator Center (SLAC) and Lawrence Berkeley National Laboratory to design and build the B-Factory at SLAC.



1961 PROJECT SHERWOOD

The Table Top machine was used by researchers to confine a hot electron plasma between magnetic mirrors for about a millisecond.

Discovery of Element 114

Beginning in 1958, fusion researchers from the United States, Europe, the Soviet Union, and Japan shared their ideas and achievements—cooperation that persisted throughout the Cold War. Laboratory scientists now work collaboratively with Russian colleagues on a wide range of scientific projects. A notable example is the discovery of element 114. This long-sought experimental goal was achieved by researchers from Livermore and the Joint Institute for Nuclear Research in Dubna, Russia, in December 1998 (right). Element 114 lies in a predicted island of nuclear stability and lived for 30 seconds, which is 100,000 times longer than the previous new element found, element 112.

Magnetic Fusion and International Cooperation

In 1961, the International Atomic Energy Agency held its first conference on controlled nuclear fusion in Salzburg, Austria. It was the second international gathering of fusion researchers, following the 1958 Atoms for Peace Conference in Geneva, Switzerland. The Geneva conference had attracted 5,000 scientists, government officials, and observers, who witnessed the unveiling of fusion research by American, British, and Russian scientists. The weekend before the conference, the United States and Great Britain announced the end of secrecy in their controlled fusion research efforts. The Russians then announced that they had built the world's largest fusion research device, a doughnut-shaped machine called a tokamak, and declassified their research as well.

Livermore's Controlled Thermonuclear Reactions (CTR) Program, which was part of the Atomic Energy Commission's Project Sherwood, began when the Laboratory opened in 1952. Herbert York's original written prospectus for the Livermore site included the establishment of a small CTR group of about seven physicists and engineers. Richard Post, who wrote many of the CRT group's first monthly reports, was recruited by York to help launch the program. Early exploration of a number of concepts led the team to focus its efforts on the magnetic mirror concept, in which a hot fusion plasma (charged particles) would be confined in a cylindrical region by a uniform magnetic field with intensified fields at the ends. Researchers explored two experimental lines using two series of machines: one led by Post (Table Top, Felix, ALICE, and Baseball I and II) and the other led by Fred Coensgen (Toy Top, Toy Top II, 2X, 2XII, and 2XIIB).

At the 1958 Geneva conference, the Laboratory's significant achievements in magnetic fusion were reported: the creation of a hot, mirror-confined plasma in Toy Top; the confinement of a hot-electron plasma between mirrors for a millisecond using Table Top; successful measurement of plasma density; and the development of ultrahigh vacuum techniques for use in Felix. Laboratory researchers also formulated the idea of hydromagnetic instability of plasma confined in a simple mirror machine, developed the theory of adiabatic (i.e., slow) confinement of charged particles in mirror systems, and recognized the need to overcome impurity radiation losses from plasmas to achieve fusion temperatures.

After Geneva, fusion energy research hit roadblocks—plasma instabilities in Livermore's mirror machines allowed the hot plasma to escape. At the 1961 Salzburg conference, the Soviet Union's chief fusion experimentalist, L. A. Artsimovich, was sternly critical of Livermore's fusion research; however, the meeting did pave the way for future cooperation with Russian scientists while the Cold War raged. Artsimovich's colleagues shared how they suppressed plasma instabilities by reshaping the mirror field. Within months, Livermore researchers duplicated this result and went on to pioneer new and improved mirror field configurations (see Year 1977). However, overcoming other high-frequency plasma instabilities would prove to be a major obstacle.

An early fusion research device called Toy Top was used to create a hot, mirror-confined plasma by plasma injection and magnetic compression. Toy Top experiments succeeded in producing fusion neutrons, a significant early achievement in the controlled fusion program.

1962 OPERATION DOMINIC

The mushroom cloud from the Frigate Bird operational test of the Polaris missile and warhead was observed through the periscope of the USS *Carbonero*, which was stationed some 30 miles from ground zero.

The Largest U.S. Nuclear Testing Operation

On August 30, 1961, Premier Khrushchev announced that the Soviet Union would break the three-year moratorium and resume nuclear testing. Two days later, the Soviets started an unprecedented series of atmospheric tests, including the detonation of a 50-megaton device. Subsequently, President Kennedy decided that the nation must resume atmospheric nuclear testing, and he approved Operation Dominic—the largest U.S. nuclear testing operation ever conducted.

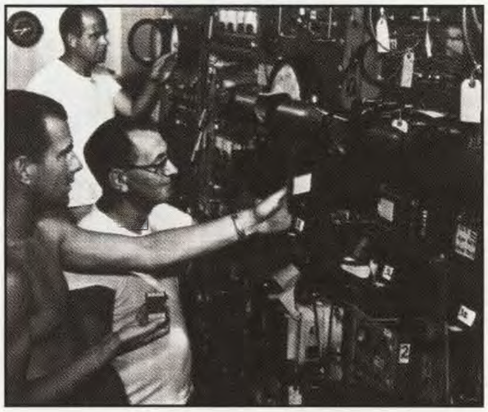
Thirty-six atmospheric tests were conducted at the Pacific Proving Grounds under Operation Dominic between April and November 1962. Approximately 28,000 military and civilian personnel participated in the test series, and more than 200,000 tons of supplies, construction materials, and diagnostics equipment were shipped or airlifted to the test areas. About 500 of the Laboratory's 4,700 employees participated in Operation Dominic. The Laboratory's Task Unit 8.1.2 was directed by Robert Goeckermann of Chemistry and Chuck Gilbert of Test Division.

Operation Dominic experiments proof-tested weapons introduced into the stockpile during the moratorium. The most dramatic experiment was Frigate Bird, in which the USS *Ethan Allen* launched a Polaris missile, and the Livermore-designed warhead successfully detonated over the open ocean. Most of the other tests were airbursts with the devices dropped by B-52 bombers. The data collected from these tests laid the groundwork for future Livermore designs of the Minuteman and Poseidon warheads, which were compact enough that numerous warheads could be carried by a single missile (see Year 1970).

Experiments were also carried out in 1962 to gather weapons effects data for the Department of Defense (DoD). For Operation Fishbowl (part of Operation Dominic), five Los Alamos–designed devices were lofted by Sandia-designed rockets and detonated at high altitude. Starfish Prime, for example, was a 1.4-megaton explosion at 400-kilometers altitude. Information was collected about the electromagnetic pulse phenomenon as well as other data related to ballistic missile defense systems (see Year 1966). Later in the year, additional tests for DoD were performed at the Nevada Test Site. In Johnnie Boy and Danny Boy, Livermore-designed devices were used to study cratering effects. The collected data also helped to validate later fallout models developed at the Laboratory.

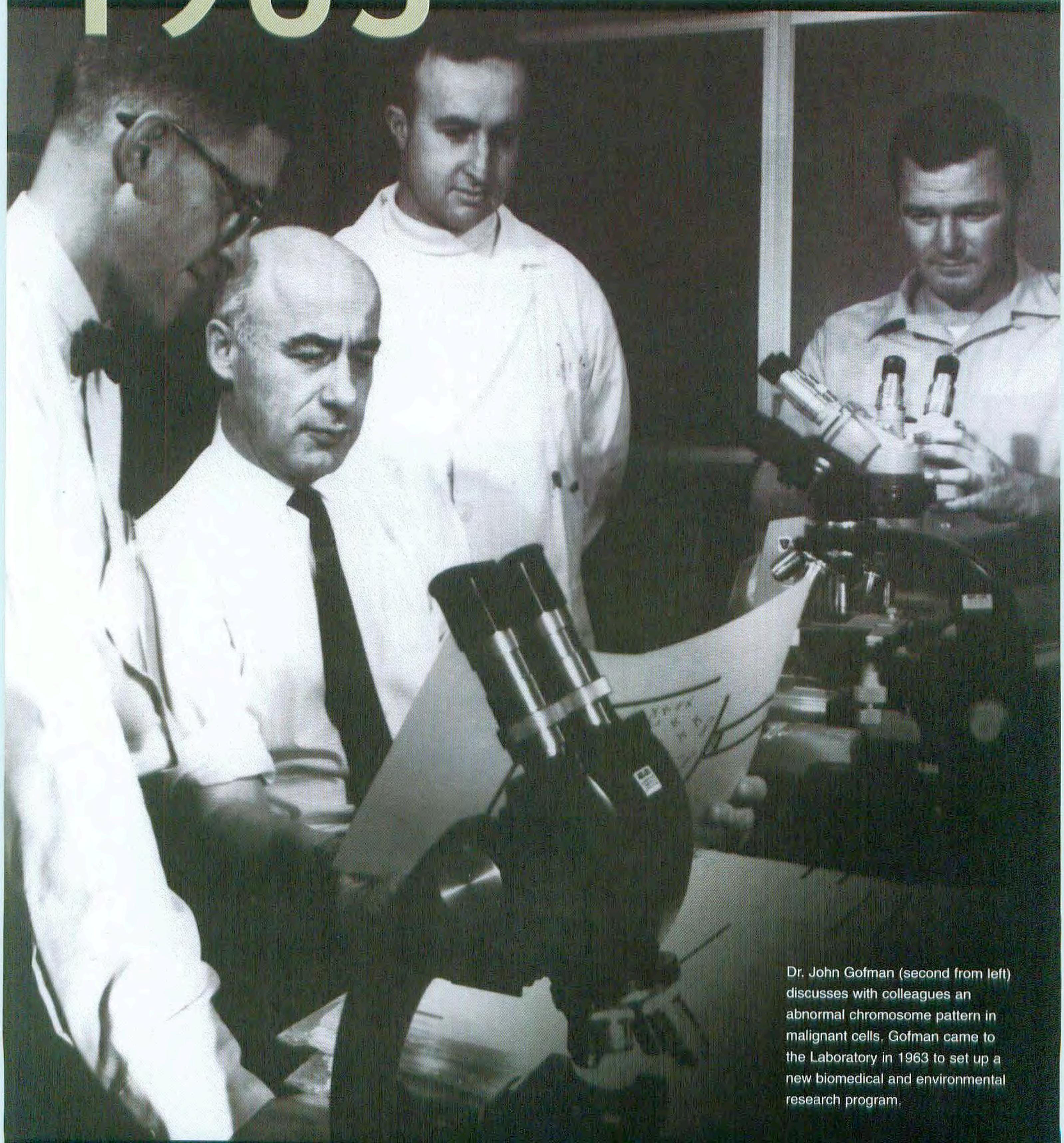
Operation Dominic was the last series of atmospheric nuclear weapon tests conducted by the United States. Signed in Moscow on August 5, 1963, the Limited Test Ban Treaty banned weapon tests in the atmosphere, in outer space, and underwater (see Year 1958).

In Livermore's Muskegon test in Operation Dominic, the nuclear device was air-dropped from a B-52 bomber near Christmas Island. The yield of the weapons-related experiment was in the range of 50 kilotons.



During Operation Dominic, diagnostic measurements were gathered aboard ships, and aircraft were used to collect debris samples.

1963 BIOMEDICAL RESEARCH



Dr. John Gofman (second from left) discusses with colleagues an abnormal chromosome pattern in malignant cells. Gofman came to the Laboratory in 1963 to set up a new biomedical and environmental research program.

To Understand the Effects of Radiation

The first biomedical and environmental research program began at Livermore in 1963. The Atomic Energy Commission had been conducting research into the biological consequences of fallout radiation since 1954. As the need grew for a bioenvironmental presence at the Nevada and Pacific test sites, the decision was made for this work to take place at Livermore. John Gofman, a distinguished professor at the University of California at Berkeley who was recruited to set up the program, was given the biomedical charge of studying the effects of radiation on humans.

In the early 1970s, the biomedical focus of the program shifted toward biological measurements that indicated the dose to subjects who had been exposed to radiation. That work led to an examination of the effects of radiation and other toxins on the building blocks of the human genetic apparatus. Increasingly, the focus was on DNA—how it is damaged, what damages it, how it repairs itself, and how these processes may vary with the genetic makeup of the individual. Technology development at Livermore and Los Alamos provided the basis for the Department of Energy's decision to launch its Human Genome Initiative in 1987 (see Year 1987). That initiative evolved into the international Human Genome Project, which took on the task of sequencing all of the 3 billion base pairs of our DNA. A major player, Livermore was one of the dozen or so laboratories in the world participating in the largest biological research project ever undertaken.

Biomedical scientists worked with engineers, physicists, laser experts, chemists, and materials scientists to develop Livermore's preeminence in flow cytometry, a technique for measuring and separating cells. Other innovations in analyzing and purifying biological samples, imaging chromosomes and DNA, early sequencing procedures, and associated database processes were a direct result of in-house, multidisciplinary expertise. The Laboratory's strength in computations has led to unique capabilities in computer simulation of biological processes, such as predicting the three-dimensional structure of proteins directly from DNA sequence data.

This same cooperative spirit has led Livermore's Center for Accelerator Mass Spectrometry (CAMS) to concentrate on biological measurements (see Year 1990). The extraordinary sensitivity of AMS means that it can detect, for the first time, the interaction of mutagens with DNA in the first step in carcinogenesis.

As Livermore moves into its second 50 years, the concern about terrorism has Laboratory scientists working together to improve detection systems for biological and chemical agents (see Year 2001). The Winter Olympics of 2002 was the first staging ground for Livermore methods to continuously monitor crowd venues for the presence of such agents. Given the growing concerns about bioterrorism, the Olympics was the first of many applications of our bioscience research to homeland defense.

Early groundbreaking work in flow cytometry, a technique for separating specific cells from other cells, has led to numerous medical research applications in genomics research and national security applications, such as biosensors that detect specific agents used in biological weapons.

1964 DEPARTMENT OF APPLIED SCIENCE

Former Vice President Nelson Rockefeller (shown above with Edward Teller, Director Roger Batzel, and a student) visited the Laboratory in 1977 to dedicate the new building (right) for the University of California at Davis Department of Applied Science.

Serving with the University of California

In the early 1960s, Edward Teller championed the need for a graduate program in applied science. He wanted to see a university-level educational facility established at Livermore. Teller held numerous meetings with University of California (UC) administrators at Berkeley and Davis before finally negotiating an agreement to create the UC Davis Department of Applied Science. That department, which was part of UC Davis's new College of Engineering, has often been referred to as "Teller Tech."

With a trailer for administrative offices and two rooms in an old barracks building for classrooms, the UC Davis Department of Applied Science was officially dedicated on January 16, 1964. In 1977, a permanent building for the department was dedicated just outside the Laboratory's gates, with no less than former Vice President Nelson Rockefeller on hand for the ceremonies.

Teller served as the department's first administrator, and his staff included one full-time employee as well as a half-time vice chairman. The Department of Applied Science opened with 81 students—12 full-time students and 69 Laboratory employees working to finish their advanced degrees. Since its inception, the department has awarded 370 Ph.D.s with about 50 percent of its graduates taking their first job at the Laboratory.

Today, the Department of Applied Science has 24 faculty members and 90 graduate students, all of whom are full-time students. Graduate students in the department specialize in virtually all combinations of traditional fields, with an emphasis on laser physics and technology, plasma diagnostics, fusion energy, accelerator technology, biotechnology, computational sciences, and graphics visualization. They are accepted into Laboratory research programs, offering the students unparalleled access to cutting-edge research equipment and facilities.

In tribute to Teller's unflagging commitment to science education and to the guidance he provided to generations of scientists, the Fanny and John Hertz Foundation gave $1 million to the University of California in 1999 to endow a chair in Teller's name in the Department of Applied Science. More recently, the Department of Applied Science and the Laboratory—in collaboration with the University of California Office of the President, UC Davis, and UC Merced—established the Edward Teller Education Center to foster excellence in teacher training in science and math.

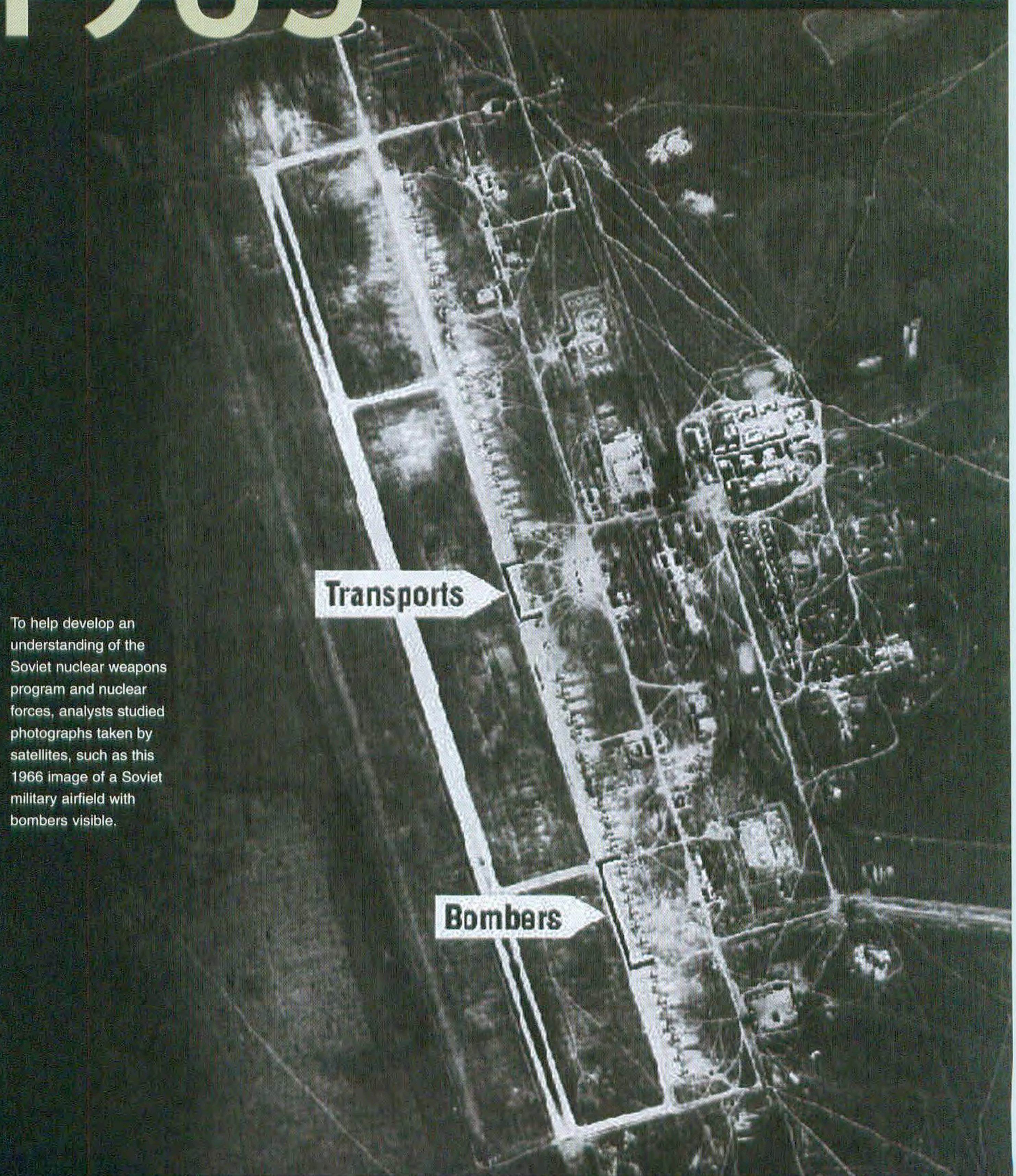
In addition to the Department of Applied Science, the Laboratory has many other academic ties to UC campuses. These ties, which are overseen by the University Relations Program, are important for recruiting and retaining an exceptional scientific staff. For example, the University Relations Program runs five Laboratory research institutes, which improve access to Livermore's unique facilities, contribute to science education, strengthen Laboratory programs, and enhance Laboratory researchers' ties to the academic community.

University of California at Merced

The University of California (UC) will soon break ground on its first new campus since 1965—and it will be in the Laboratory's backyard. UC Merced, which will be the nation's first research university to be built in the 21st century, is scheduled to open in 2004.

The Laboratory has worked closely with the University of California for well over a year to outline possible partnerships and collaborations, from access for faculty to Laboratory facilities to joint appointments and programs. Livermore representatives have helped recruit UC Merced's first two deans for its Division of Natural Sciences and Mathematics and its Division of Engineering, Computer Sciences, and Information Sciences.

1965 Z DIVISION



To help develop an understanding of the Soviet nuclear weapons program and nuclear forces, analysts studied photographs taken by satellites, such as this 1966 image of a Soviet military airfield with bombers visible.

Assessing the Weapons Capabilities of Others

Since the early days of Livermore, intelligence agencies have sought Laboratory expertise in nuclear weapons design to analyze atmospheric nuclear tests conducted by the Soviets and to develop an understanding of the Soviet nuclear program and weapon designs. The Soviet Union's first test of an atomic weapon in the late 1940s took the West by surprise, and monitoring the Soviet effort to rapidly develop nuclear weapons became a paramount concern of U.S. intelligence agencies. As the Cold War raged, the Laboratory's efforts expanded, and the Central Intelligence Agency (CIA) found itself needing a more formal mechanism for obtaining expert analysis of information about Soviet nuclear weapons tests.

In 1965, Laboratory scientists and engineers helping intelligence agencies understand the significance of Soviet nuclear weapons tests were consolidated into Z Division, today known as the International Assessments Program. ("Z" was chosen as the division title because it was one of the few remaining unused letters.) Under Laboratory Director John Foster, a formal relationship with the U.S. Intelligence Community was established in a memorandum of understanding signed between the CIA and the Atomic Energy Commission, a predecessor to the Department of Energy.

Z Division set up shop in Building 261. When more space was needed, a specially designed and secure addition was built to intelligence agency specifications. Scientists and engineers in Z Division analyzed radiological samples from Soviet, and later Chinese, nuclear tests. They also developed new technologies for monitoring tests and collecting data that allowed analysts to tell what kind of weapons were being tested—atomic or thermonuclear. In addition, the Laboratory's technical expertise was tapped by intelligence agencies to develop instruments, such as a "bug sniffer" for detecting minute electronic monitoring devices.

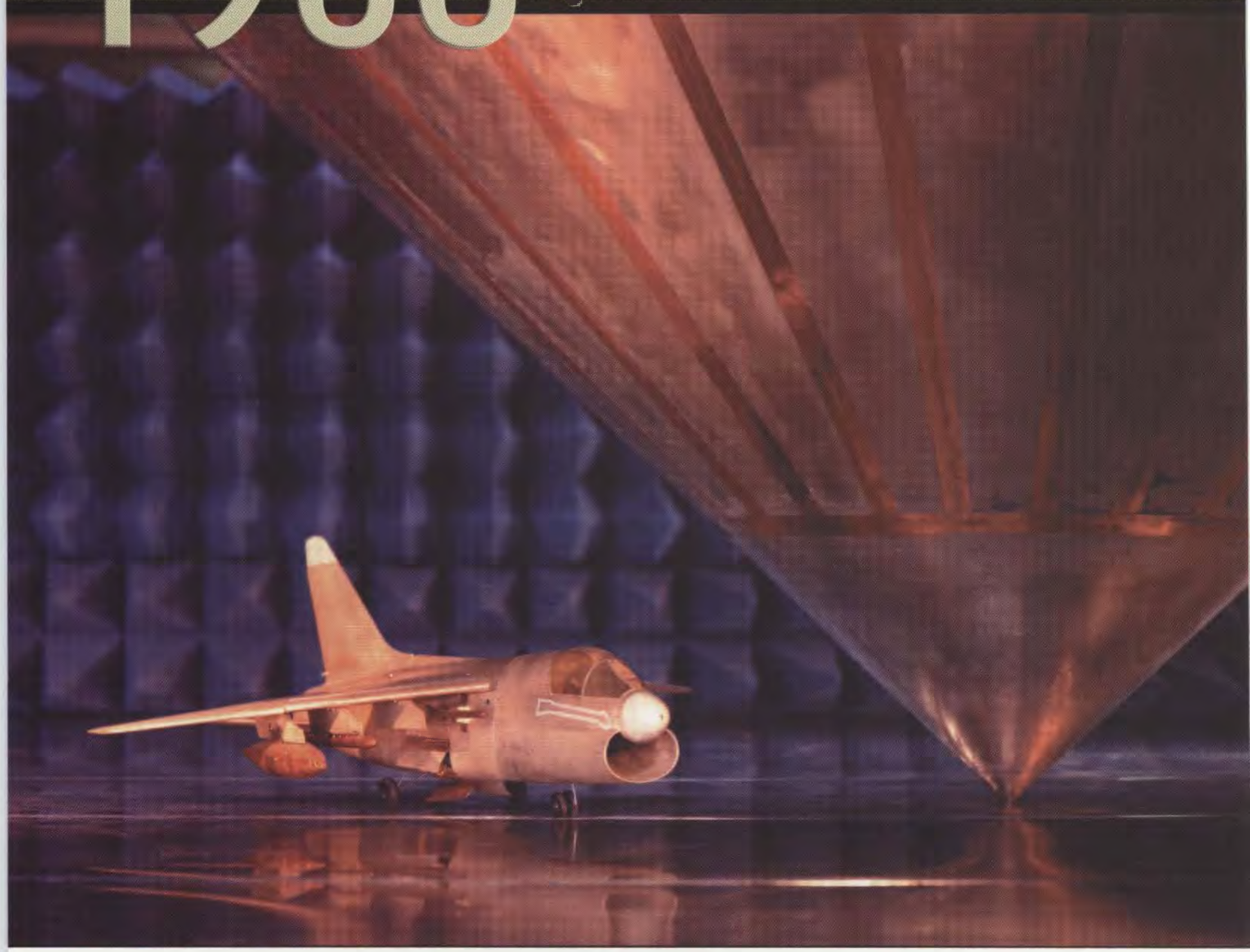
Anticipating that nuclear proliferation could become a major problem, Z Division started a proliferation monitoring program in the mid-1970s. That effort has continued to grow together with the Intelligence Community's need for all-source analyses of the nuclear programs of an expanding list of countries of concern. Involving both regional specialists and technical experts, these multidisciplinary analyses draw on general technical knowledge about nuclear testing, specifics about each country's nuclear capabilities, and evaluations of nontechnical issues that motivate nuclear programs. With the end of the Cold War, proliferation analysis activities are now a principal mission of Z Division, including examining activities related to other types of weapons of mass destruction (WMD) and their delivery systems.

Z Division was a primary building block of Livermore's Nonproliferation, Arms Control, and International Security (NAI) Directorate. Director John Nuckolls established NAI in 1992 in response to what was then an emerging threat—WMD proliferation and terrorism. The principal program elements of NAI are International Assessments (Z Division), Proliferation Prevention and Arms Control (PPAC), Proliferation Detection and Defense Systems (Q Division), and Counterterrorism and Incident Response (R Division).

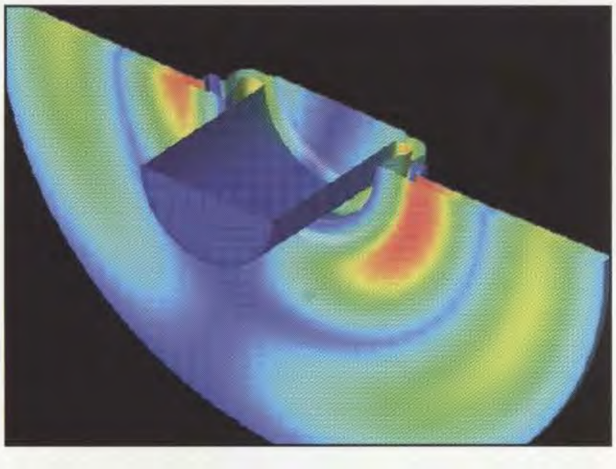
Models of early Soviet nuclear weapons are on display at the Nuclear Weapons Museum at Arzamas-16, the Soviet Los Alamos, shown in an early photograph.

Construction began in 2002 on the $25-million International Security Research Facility, which will consolidate Livermore's nonproliferation and intelligence-related operations into a single building with cutting-edge information technology tools.

1966 NUCLEAR EFFECTS



A scale model of a Grumman A-6 aircraft (above) is tested in the EMPEROR facility. The cone-shaped copper structure produces extremely high-bandwidth electromagnetic fields for EMP and high-power microwave vulnerability studies.



A recent Laboratory computational effort, EMSolve is a provably stable method for solving Maxwell's equations on three-dimensional unstructured grids (left). In a problem involving over 90,000 unknowns, EMSolve is used to study the electromagnetic characteristics of a prototype linear accelerator induction cell.

Dealing With Transient Electromagnetic Pulses

A consequence of the Starfish high-altitude nuclear test in 1962 was the failure of 30 strings of streetlights in Oahu, Hawaii, 1,300 kilometers away. Although only about 1 percent of Oahu's streetlights were affected, their failure raised concerns that the electromagnetic pulse (EMP) generated by a nuclear weapon burst could cause widespread damage to the nation's civilian and military infrastructures. The phenomena needed to be understood.

Modeling and experimentation to study transient electromagnetic pulses has been a research focus at the Laboratory ever since the Starfish Prime test (see Year 1962). Researchers have provided support to the Defense Nuclear Agency (DNA)—now the Defense Threat Reduction Agency—which is the Department of Defense agency responsible for assessing the hardness of military equipment to EMP. In addition, for the weapons program, the effects of fast electromagnetic pulses had to be understood to develop nuclear test diagnostics and to ensure the hardness of U.S. nuclear warheads to electromagnetic effects.

In 1966, the Institute of Electrical and Electronic Engineers published a paper by a Livermore researcher, K. S. Yee, that greatly advanced the art of modeling electromagnetic phenomena. "Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media" introduced the Finite Difference Time Domain algorithm—a stable, efficient computational means of solving Maxwell's equations that has been widely used ever since. Other electromagnetic simulation modeling capabilities also were developed at the Laboratory, in several cases building on, and significantly improving, codes originally written elsewhere.

An example is Livermore's Numerical Electromagnetic Code (NEC), an imported model that was greatly improved on by Laboratory researchers in the 1970s. NEC is still the world's most widely used code for analyzing the performance of wire-frame antennas; over 3,000 copies of it have been distributed. Also in the 1970s, with support from DNA, Livermore published the *Computer Code Newsletter* for the electromagnetics community. Laboratory researchers collected computer codes from various sources, tested them, documented them when necessary, and made them available to others.

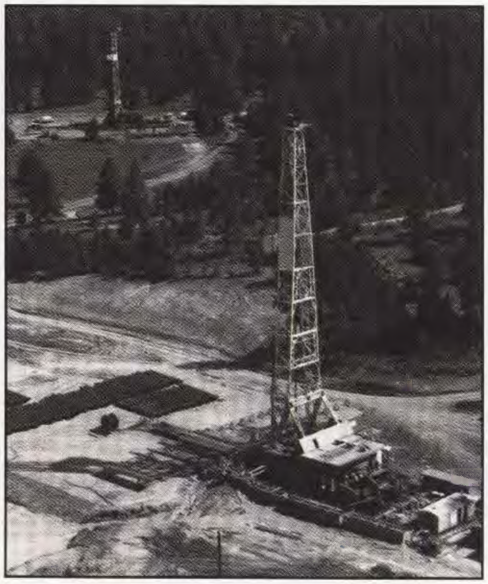
Theoretical work and the development of computer codes were complemented by experimental efforts to generate and measure fast transients for model validation. For example, to measure coupling of radio waves into structures, a large cone antenna (EMPEROR) was built at Livermore, and scale models of military hardware and other equipment were tested. Nonnuclear-generated, or high-power-microwave (HPM), weapons also were investigated in a program led by the U.S. Air Force.

Spin-offs of EMP research have taken Livermore to the forefront of many areas of technology: innovative use of solid-state and low-cost silicon electronics; pulsed-power systems that have been employed in laser and accelerator research; cross-borehole electromagnetic imaging and tomography to produce detailed underground maps; and photonics research that has had important ramifications in the telecommunications industry.

Hardening U.S. Nuclear Warheads

A transient electromagnetic pulse is only one of a variety of nuclear effects that a U.S. intercontinental ballistic missile or submarine-launched ballistic missile warhead might encounter—and have to survive—on the way to its target. Hardening warheads to nuclear effects has been an important issue since the Soviets began deploying antiballistic missile (ABM) defenses in the 1960s. Missile warheads have been designed with special hardening features to improve survivability when penetrating an ABM system (see Year 1970). These features were developed with the aid of experimental facilities, such as the Super Kukla burst reactor, and an extensive series of "exposure" nuclear tests conducted in conjunction with the Defense Nuclear Agency.

1967 GASBUGGY



In the Gasbuggy experiment, a part of Project Plowshare, a nuclear explosive was lowered down a 4,000-foot hole and detonated in a sandstone formation in New Mexico to increase natural gas production.

The Quest for Energy Resources

On December 10, 1967, under the technical direction of Livermore scientists, a 29-kiloton nuclear device exploded in a sandstone formation at a 4,000-foot depth in the San Juan basin of New Mexico. The experiment, Gasbuggy, was a joint venture of the Atomic Energy Commission, El Paso Natural Gas Company, and the Bureau of Mines of the U.S. Department of the Interior. It was the first of three Project Plowshare experiments, each partially funded by U.S. industry, to test the feasibility of using nuclear explosives to stimulate natural gas production in rock too impermeable for economical production by conventional means. Tight sandstone formations, like that in the San Juan basin, were projected to hold at least 300 trillion cubic feet of natural gas in the western United States.

The detonation produced an underground chimney 335 feet high with a diameter of almost 165 feet. Gas was extracted from the chimney in six subsequent major production tests (the last in 1973). Results were encouraging in that gas production was increased six to eight times over previous rates. However, the "clean" Plowshare device used in Gasbuggy, which was designed to minimize the post-detonation residual radiation, still resulted in undesirably high concentrations of tritium in the gas. Livermore's device design was acceptably clean for the subsequent Rio Blanco experiment; however, the economic viability of using nuclear explosives to stimulate gas production proved to be problematic.

Gasbuggy and two subsequent gas-stimulation nuclear tests brought to a close Project Plowshare field experimentation, but they marked the beginning of Livermore's work with U.S. industry to enhance conventional energy production. After the 1973 energy crisis, Laboratory researchers engaged in a variety of energy projects that culminated in large-scale demonstrations of technical feasibility and commercial viability. For example, processes for in situ coal gasification—converting coal beds to gas without mining—were developed. Activities ran from 1974 through 1988, with the first large-scale tests conducted at the Hoe Creek Site (Wyoming) in 1977. In addition, researchers pursued activities that led to technical demonstration of retorting oil shale to recover oil from large U.S. reserves. A 6-ton-capacity pilot oil-shale retort facility operated at the Laboratory in the early 1980s.

Currently, the Laboratory participates in the Department of Energy's Natural Gas and Oil Technology Partnership, a national laboratory–petroleum industry alliance to expedite development of advanced technologies for better diagnostics, more efficient drilling, and improved natural gas and oil recovery. In one project, Livermore researchers have been improving the capability of crosswell electromagnetic imaging, a technology for monitoring the movement of water injected into wells to enhance oil recovery. Successful field experiments have been conducted at two sites, including the Lost Hills oil field operated by Chevron USA in central California.

The feasibility of underground coal gasification was demonstrated by the Laboratory in large-scale field experiments at the Rocky Mountain Test Facility (left) near Hanna, Wyoming, and earlier at the Hoe Creek Site in Gillette, Wyoming.

1968 ROYSTON PLAN

The Royston Plan guided the Laboratory's transformation from a former military facility to a campuslike setting that is an attractive place to work and a vital part of the community.

An Attractive Place to Work

In 1968, the Laboratory went for a new look, away from the military aspect it inherited and toward more of a campus environment. At the initiative of Carl Haussmann, then Associate Director for Plans and in charge of Livermore's nascent laser program, the Laboratory hired landscape architectural firm Royston, Hanamoto, Beck & Abey to prepare a long-range development master plan for the site. The Royston Plan sought to bring order out of the chaos created by the haphazard, random construction of buildings and roadways that characterized the first 18 years of the Laboratory's existence.

At the time, employees worked in existing barracks and facilities crowded into a grid pattern in the southwest corner of the site. New facilities were built adjacent to existing buildings in what seemed the most expedient way to grow, but which, in fact, led to congestion and loss of the flexibility necessary for research. By contrast, the northeastern half of the Laboratory was underused.

The Royston study proposed a flexible development plan based on a curvilinear pattern of loop roads and utilities that would create a wider variety of land parcel shapes and large developable areas. The Laboratory adopted it as the framework for its first master development plan, which established basic planning principles to guide future growth. The Plan, as it has come to be called, was termed exemplary by the Atomic Energy Commission (the Department of Energy's predecessor) and sparked the initiation of comprehensive site plans at other facilities in the complex.

The Royston study introduced two loop-road systems—including northern California's first rotary—in the undeveloped area of the site, curving around a central hub that was zoned for general support functions such as the business offices, technical information facilities and libraries, and plant engineering. The loop system not only made for more efficient travel and utilities distribution around the site but also reduced traffic and saved money. Another major element of The Plan was making the site more attractive to employees by incorporating liberal landscaping and inviting bicycle and walking paths. An aesthetically pleasing work environment, it was judged, would help attract and retain valuable staff.

The Laser Program's facilities were the first developed in accordance with The Plan. Laser buildings 381 and 391 had offices and main entrances on Inner Loop Road, which was to be the "front door" to future facilities. Outer Loop Road was intended to act as the "service entrance" to the large laboratories behind the office buildings, with smaller laboratories forming a transition between the two areas.

Today, the Laboratory has little undeveloped acreage remaining, but The Plan continues to guide Lab growth while maintaining an attractive work environment. The Plan was so visionary that it still retains its integrity and flexibility even after more than 30 years.

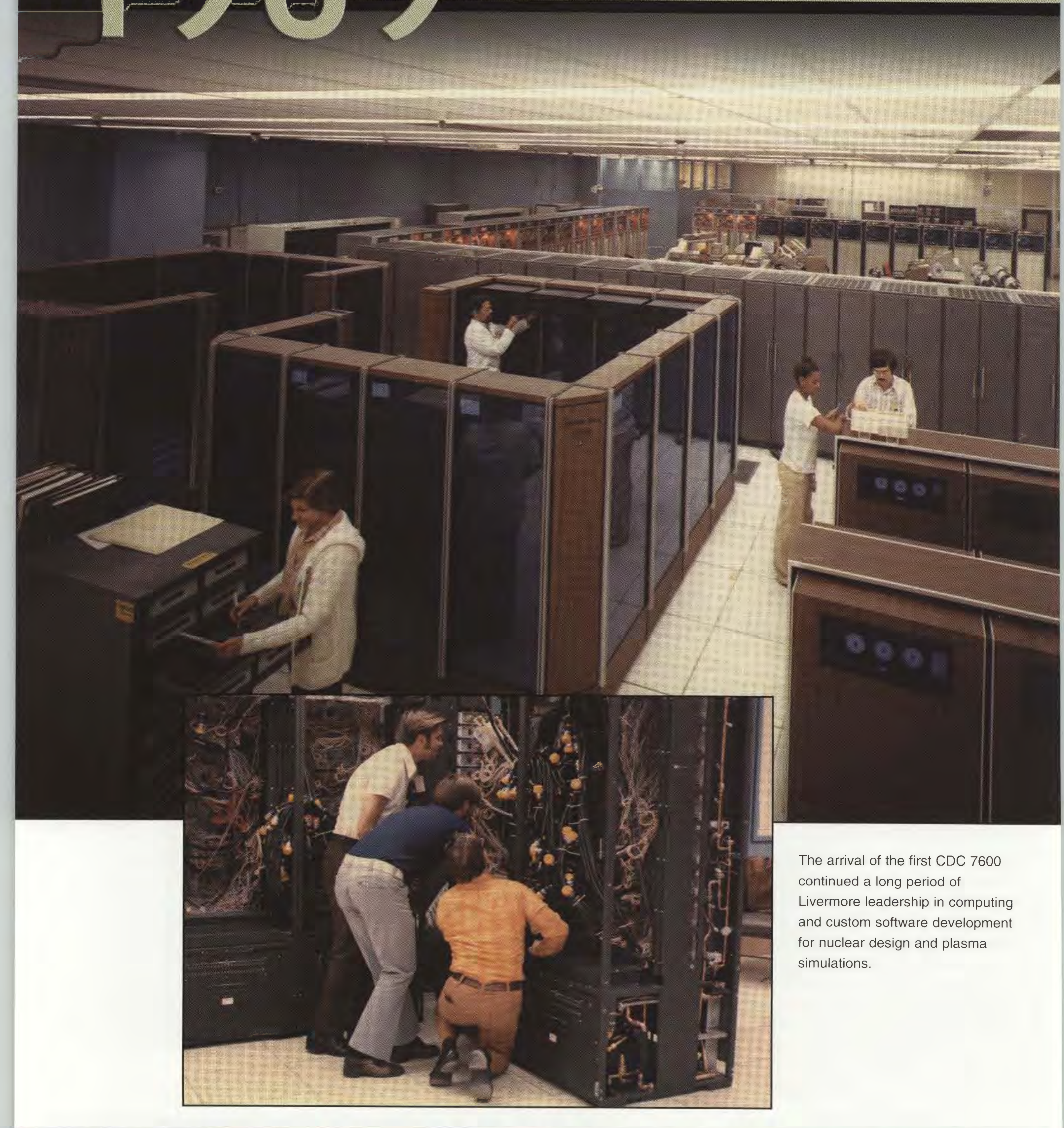
Carl Haussmann

In 45 years of service at the Laboratory, Carl Haussmann made major contributions in many technical areas, including weapons, high-end computing, and lasers. He also had a visionary interest in the strategic development of the site and was the driving force behind commissioning and implementing the Royston Plan. Known as the "Father of the Trees" because of his passion for landscaping, Haussmann arranged for the California Conservation Corps to plant some 300 trees throughout the site.

A plaque affixed near the entrance to Building 111 reads: "In gratitude for the beauty and function of the Livermore site, landscape, architecture, and trees, which Carl planned and patronized over 30 years."

Carl Haussmann with a disk laser, one of the technologies for the Cyclops laser.

1969 FIRST CDC 7600



The arrival of the first CDC 7600 continued a long period of Livermore leadership in computing and custom software development for nuclear design and plasma simulations.

Timesharing and Two-Dimensional Modeling

Always eager for better computer simulations, Laboratory weapons designers enthusiastically greeted the arrival of their first CDC 7600 supercomputer in 1969. Nineteen of the first 20 scientific computers purchased by the Laboratory had been from IBM. That string was broken in 1962 when the Lab bought a CDC 1604 mainframe from then-upstart Control Data Corporation of Minnesota.

A young CDC engineer named Seymour Cray was already at work on an innovative design for a machine 50 times faster than the CDC 1604, and Livermore happily acquired one of his CDC 6600 computers for $8 million in August 1964. Cray's design team then further refined this approach, yielding the even larger and faster CDC 7600 in 1969. In the hands of Laboratory users, these machines defined scientific supercomputing for a decade. Their small instruction sets, fast clock speeds, extremely dense custom-soldered circuit boards, and clever use of the machine frame itself for cooling were ideal for nuclear design and plasma simulations.

Laboratory computer scientists responded to the availability of the CDC 6600 and CDC 7600 with a long, fertile period of custom software development. The Livermore Time Sharing System (LTSS) enabled hundreds of users to run application codes simultaneously and tune them interactively. Large libraries of Fortran subroutines evolved, optimized for the Laboratory's mathematical and graphical needs. The local job-control language, online documentation system, and file-storage service set the standards in their fields, as did the whimsically named Octopus network that efficiently connected hundreds of remote terminals and printers to the central, shared computers.

This combination of leading-edge hardware and innovative support software yielded many benefits for the two-dimensional modeling projects then under way at Livermore. Better, higher-resolution simulations clarified important aspects of ongoing field tests. New experiments could be optimized at the desktop. And scientists gained increased understanding of the physics underlying many Laboratory projects.

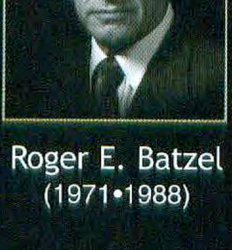
The Laboratory's collaboration with Seymour Cray continued for another 15 years as well. In 1972, he started his own company (Cray Research) and developed his first integrated-circuit (chip-based) scientific computer, the CRAY-1. As they became available, Livermore acquired early serial-number versions of every Cray Research machine, refining the Cray Time Sharing System (formerly LTSS) to make the most of each new generation of hardware.

In 1985, when the Laboratory received the world's first CRAY-2 supercomputer, it finally retired its last CDC 7600. In many ways, the hardware–software combination pioneered here was the model on which the National Science Foundation supercomputer centers later were created.

The innovative Livermore Television Monitor Display System, or TMDS (above), was a familiar sight in the 1970s, providing visual information to users. Data management and storage were improved with the first "chip" storage of the IBM Photostore system (left). It was designed to store online an astonishing (at the time) 1 trillion bits of data.

The Seventies

NEW Leadership



Roger E. Batzel
(1971•1988)

On the frontiers of science and technology

In the early 1970s, the Laboratory completed development of new warheads for the nation's strategic missile forces and for the Spartan antiballistic missile interceptor. Livermore pushed the frontiers of what was possible in nuclear weapon design and engineering. Designers then turned their attention to modernizing NATO's nuclear forces with novel weapon designs and to exploring the use of insensitive high explosives for improved nuclear weapons safety.

Capitalizing on an emerging technology, Livermore also began a laser program and has been at the forefront of laser science and technology ever since. In 1974, Janus was built, the first of a sequence of ever-larger lasers to explore inertial confinement fusion (ICF) for national security and civilian applications. Design, engineering development, and use of the Laboratory's ICF lasers have contributed to thermonuclear weapons science, enabled new scientific discoveries, and stimulated the development of new products and processes in U.S. industry. The 1970s energy crisis helped to invigorate long-term research efforts in both ICF and magnetic fusion as well as other energy research programs at the Laboratory.

1970 FIRST MIRV WARHEADS

In the 1970s, Minuteman III missiles with Livermore-designed W62 warheads were deployed in 550 silos at Air Force bases in three states.

Multiple Warheads Increase Missile Effectiveness

In 1970, the United States introduced a new capability that dramatically increased the effectiveness of its land- and sea-based strategic missile forces. Both the Minuteman III intercontinental ballistic missile and the Poseidon C-3 submarine-launched ballistic missile were deployed with multiple independently targeted reentry vehicles (MIRVs), a technology that allowed each missile to attack multiple targets within a large "footprint." This provided considerable flexibility in targeting. MIRVs also were more cost-effective because they leveraged the large costs of missile silos and submarines. The warheads for each of these missile systems were designed by Livermore. The W62 warhead for Minuteman III (deployed in April 1970) and the W68 warhead for C-3 (deployed in June 1970) pushed the envelope of yield-to-weight ratio, a key to the MIRV concept. They were also the first designs to include a comprehensive set of hardening features for protection against antiballistic missile (ABM) defenses. The warheads were the product of an extremely fruitful period in weapon development at the Laboratory during the 1960s.

The MIRV concept resulted from the convergence of missile technology improvements, concerns about Soviet work on ABM systems, and the desire for improved accuracy. Early in the development of Minuteman III, it became clear that a liquid-fueled fourth stage was needed for higher delivery accuracy. Further consideration led to the concept of using additional fuel in the fourth stage to independently target multiple RVs and penetration aids. Meanwhile, the ability of missile systems to deploy individual satellites through use of a post-boost control system had been demonstrated in the U.S. space program in October 1963. In December 1964, Secretary of Defense Robert McNamara approved development of a MIRV system for Minuteman III. By early 1965, the Navy's Strategic Systems Project Office had developed baseline design requirements for the C-3 missile that would include MIRV capability.

Livermore received the assignment for both systems, and each program faced significant design challenges. The requirement to put 14 vehicles on the relatively small C-3 platform was very stressing. The W68 (in the Mk3 reentry body) was the smallest strategic warhead ever deployed by the U.S. The accuracy requirement for the Mk12, which carried the W62, led to a vehicle design that placed stringent volume limitations on the warhead, and the yield had to be sufficient for attacking hardened missile silos. In addition, both warheads included special hardening features intended to improve survivability when penetrating a threat antiballistic missile system. These features were developed with the aid of an extensive series of "exposure" nuclear tests conducted in conjunction with the Defense Nuclear Agency.

When the first MIRV systems were deployed more than 30 years ago, they marked the end to a chapter in which Livermore and the military redefined the strategic missile posture of the United States. The W62 and W68 represented such a dramatic advance in the state of nuclear design that all subsequent missile system warheads have incorporated many of their key elements. Their extensive development programs, conducted in close coordination with the Air Force and Navy and their contractors, were a model for all subsequent generations of delivery-system design teams.

The Poseidon C-3 missile launched from a submerged submarine.

1971 CANNIKIN

A Spartan missile body with the nuclear device is lowered downhole for the Cannikin event. The test was successfully conducted on November 6, 1971, on Amchitka Island, Alaska.

At the Frontier of Missile Defense Technology

The morning before the Cannikin event at Amchitka Island, Alaska, the test site was subjected to rain and wind gusts up to 124 miles per hour. The test crew and visiting dignitaries, including Atomic Energy Commission Chairman James Schlesinger and his family, anxiously waited. Meanwhile, the Supreme Court ruled by a 4–3 margin that the test could take place. On November 6, 1971, at 6:30 a.m. in Amchitka, the go-ahead came from the White House on a telephone hotline. Cannikin was successfully detonated at 11 a.m., and the nearly 5-megaton blast generated the ground motion of a 7.0 Richter-scale-magnitude earthquake.

Cannikin was a massive undertaking involving hundreds of Laboratory employees and nearly five years of effort. Test operations overcame a myriad logistics hurdles, and experimenters achieved many technical firsts. Two years of drilling produced a record-breaking emplacement hole that was 6,150 feet deep and 90 inches in diameter with a 52-foot-wide cavity mined at its bottom. The diagnostics canister was 264 feet long, and altogether 400 tons of cables and equipment were lowered downhole. Cannikin was the first test in which a laser successfully aligned diagnostics downhole and a computer system assisted field operations. A record-setting number of recording trailers, 2,000 feet from ground zero and shock mounted to withstand a ground upheaval of 15 feet at shot time, were instrumented with 250 oscilloscopes. One hundred percent of the test data was successfully retrieved.

The experiment tested the design of the warhead for Spartan, the interceptor used in the upper tier of the U.S. Safeguard Anti-Ballistic Missile (ABM) system. Spartan missiles were to engage clouds of reentry vehicles and decoys above the atmosphere and destroy incoming warheads with a burst of high-energy x rays. The Laboratory stepped up to the difficult challenge of designing the appropriate warhead. The Spartan warhead had high yield, produced copious amounts of x rays, and minimized fission output and debris to prevent blackout of ABM radar systems. Livermore also developed and first tested the warhead technology for the second-tier interceptor, the Sprint missile. Subsequently, Los Alamos was assigned responsibility to develop the nuclear warhead for Sprint.

The Safeguard ABM system was a scaled-down version of the Sentinel system for defense of U.S. cities. Rapid evolution of offensive missile technologies (see Year 1970) made national defense impractical, and in 1972, the United States and the Soviet Union signed the ABM Treaty. However, protection against ballistic missile attack remained a noble goal and technological challenge for Laboratory researchers and was pursued with renewed vigor after President Reagan launched the Strategic Defense Initiative. Nuclear directed-energy weapons were pursued at Livermore, including experimental demonstration of x-ray lasing at the Nevada Test Site. Laboratory researchers also devised the concept of Brilliant Pebbles for nonnuclear defense against missiles in boost phase, which led to the Clementine experiment to map the Moon (see Year 1994).

During preparation for the Cannikin event, workers—including Test Director Phil Coyle (right)—ate their meals near the rigging.

1972 OZONE DEPLETION CALCULATIONS

Photo credit: The Boeing Company

Depletion of stratospheric ozone was one of the concerns raised when development began of commercial supersonic transport aircraft. Later, use of chlorofluorocarbons was prohibited because of similar concerns about ozone depletion.

Less Bay Area Ozone

In the late 1960s, the Laboratory responded to a growing interest in the quality of our environment by applying its capabilities to help understand human-induced affects on the atmosphere. The rising number of excess ozone days in the Livermore Valley prompted Mike MacCracken and colleagues to adapt a new modeling technique developed at the University of Illinois for use as the core of a Bay Area air-quality model. Results from this model and later versions served as the basis for preparing the Bay Area's Air Quality Maintenance Plan, which, with later revisions, has lowered the number of days of excess ozone from about 50 per year to just 1 or 2 per year.

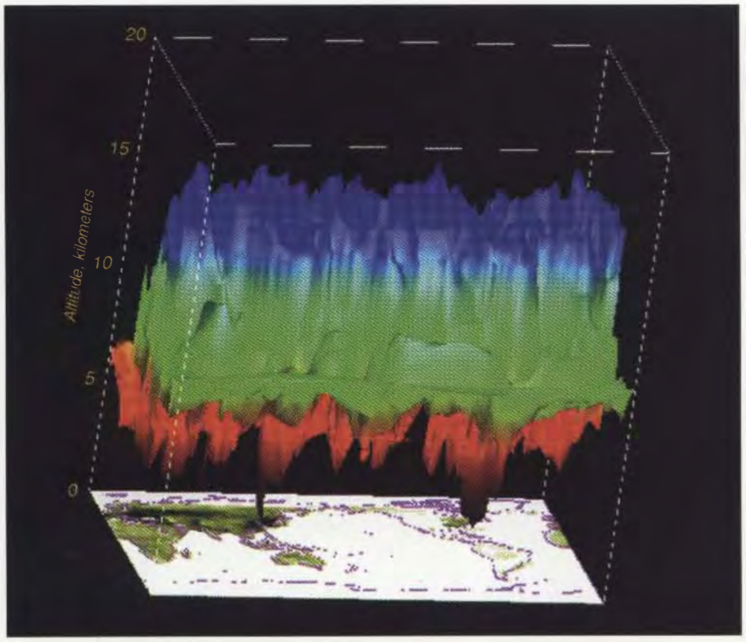
Preventing Planetary Sunburn

In 1972, the Laboratory applied newly developed modeling capabilities to investigate whether human activities might degrade the stratospheric ozone layer, which screens out most of the radiation that causes sunburns and skin cancer. U.S. decision-makers needed information on the potential effects of a proposed fleet of supersonic transports (SSTs)—faster-than-sound commercial jet aircraft—that would fly in the stratosphere. Concerns were raised that exhaust emissions might chemically react in ways that would thin the stratospheric ozone layer. Livermore's one-dimensional (altitude) model of stratospheric ozone, developed under Julius Chang, was one of the first simulation tools in the world used to examine ozone interactions with the SST's nitrogen oxide emissions.

An important early test of the model was its ability to explain the observed decrease in stratospheric ozone concentrations following atmospheric nuclear testing by the United States and the Soviet Union in the early 1960s (see Year 1962). These simulations clearly indicated that use of a large number of megaton-size nuclear weapons in a nuclear war would seriously deplete stratospheric ozone—in addition to the extensive destruction caused at the surface. This finding later played a central role in a 1974 National Academy of Sciences study on the potential long-term worldwide effects of multiple nuclear weapons detonations, adding impetus for the two superpowers to reduce weapon yield and the size of their nuclear arsenals.

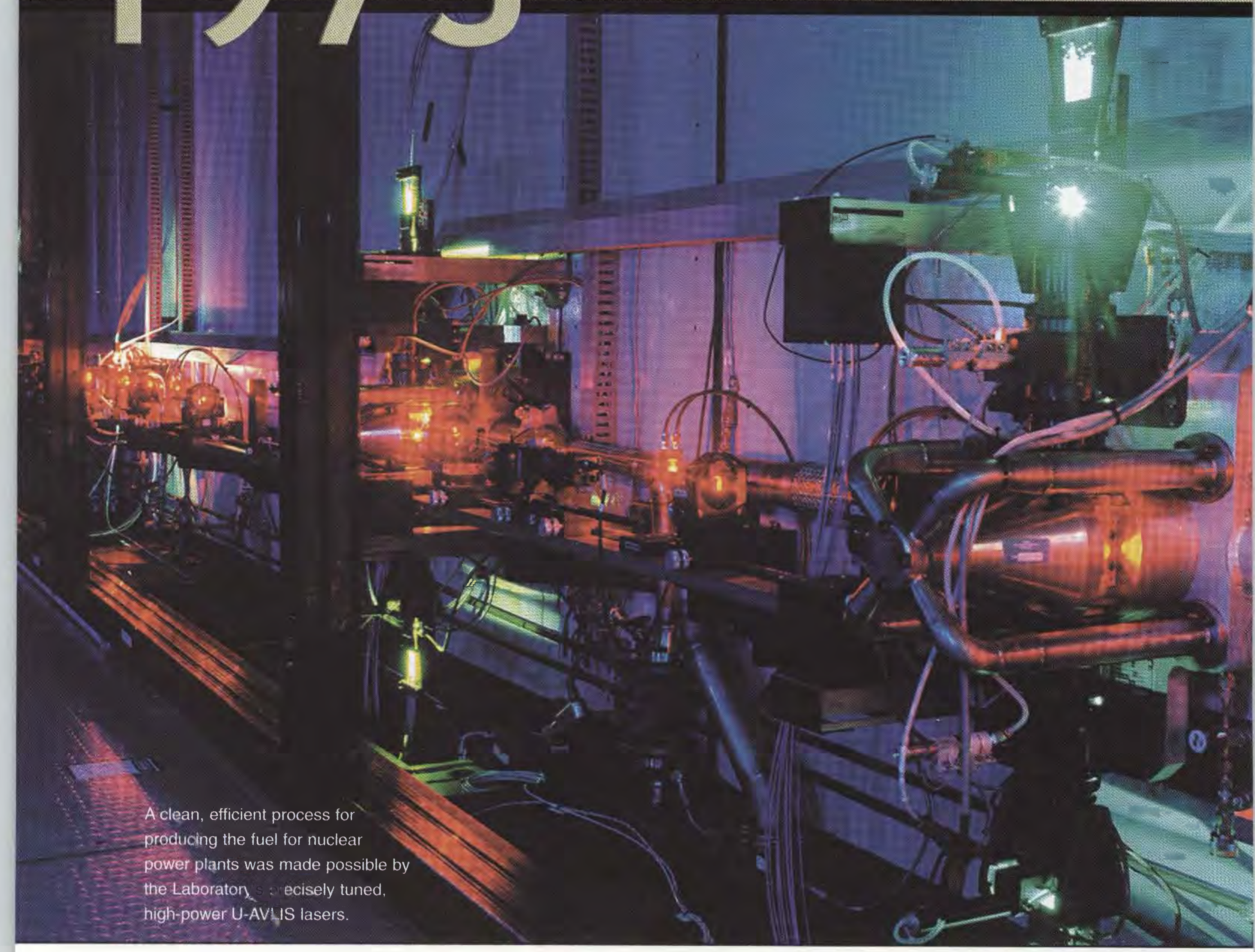
In 1974, the effect of chlorofluorocarbon (CFC) emissions on stratospheric ozone also became an issue. In response, Don Wuebbles and colleagues at the Laboratory developed a two-dimensional (latitude and altitude) model that predicted increasingly severe ozone depletion from continued use of CFCs in aerosol spray cans, refrigerators, and air conditioners. These results provided important input to the first international assessment of stratospheric ozone. International negotiations to limit CFCs ensued, and the U.S. prohibited their use as propellants in spray cans. Later, the research team developed a technique for calculating the Ozone Depletion Potential (ODP) of other compounds, a formulation that was included in the Montreal Protocol. Adopted in 1987, the protocol set goals for globally phasing out the use of halocarbons that have high ODP.

As computers became more powerful, Laboratory researchers developed three-dimensional global simulation capabilities and began analyzing the details of chemical reactions involving airborne aerosols (particles). Because of the Laboratory's scientific expertise and large-scale computing capabilities, Livermore now serves as the Core Modeling Team for the NASA Global Modeling Initiative.



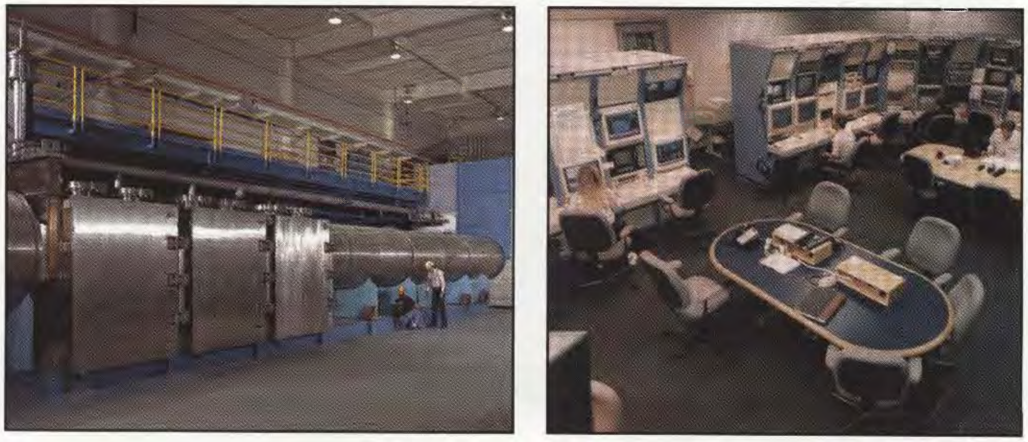
Livermore researchers continue to improve the air chemistry models in simulations of atmospheric circulation. The transport of ozone from the lower stratosphere to near-surface altitudes is studied using models that require the Laboratory's supercomputers.

1973 U-AVLIS PROGRAM BEGINS



A clean, efficient process for producing the fuel for nuclear power plants was made possible by the Laboratory's precisely tuned, high-power U-AVLIS lasers.

Livermore's plant-scale uranium separator system was one of the largest technology transfer projects in the Laboratory's 50-year history.



Industrial-Scale Applications for Lasers

In the early 1970s, many analysts were projecting a shortage of electricity starting in the next decade. One option was expanded use of fission energy, for which an inexpensive source of enriched uranium fuel was needed. At the same time, the inherent properties of lasers were recognized as having the potential of leading to a low-cost method to produce such fuel by selectively ionizing uranium 235 and electrostatically separating it from uranium 238. The Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) program began at Livermore in 1973 to help maintain the U.S. market share of enriched uranium fuel for the host of nuclear power plants that would be constructed to meet the world's energy needs.

The U-AVLIS process for separating isotopes of uranium presents numerous advantages. It achieves separation in one or two passes through the laser beam, rather than the hundreds of passes required in other processes. It needs only 1/20th the electrical power required by diffusion plants, producing significant cost savings. Because U-AVLIS uses uranium metal as the source material rather than uranium hexafluoride, the process is less expensive and less hazardous and produces less low-level nuclear waste.

In the early years of the program, the U-AVLIS process used copper vapor lasers to pump liquid dye lasers to effect the separation process, while in later years, more efficient solid-state lasers were developed as the pump lasers. Dye lasers were used because they can produce a broad and almost continuous range of colors. An optical system in the laser is able to "tune," or select, the laser to the precise color needed to separate the desired isotope.

Through its 25-year history, the U-AVLIS Program progressed from the Morehouse experiment that produced the first milligram quantities of enriched uranium in 1974 through the REGULIS separator in 1980, the MARS Facility in 1984, and the Uranium Demonstration System and the Laser Demonstration Facility in the 1990s. In the process, tunable laser technology was dramatically advanced, and significant scientific progress was made in the physics of laser–atomic interactions. In addition, the Laboratory staff gained valuable experience in laser-based industrial production, which contributed not only to the U-AVLIS program but also to other projects such as the Laser Guide Star (see Year 1996), the Laser and Materials Processing program, and the National Ignition Facility (see Year 1997).

Congress created the United States Enrichment Corporation (USEC) in 1992, which was a government corporation until privatized in 1998, to move the U-AVLIS program into the private sector. By the late 1990s, however, the energy economies of the world and the supply versus demand for enriched uranium had changed. USEC suspended the U-AVLIS program in 1999, retaining the rights to U-AVLIS technology for commercial applications.

A technician works with the diode-pumped solid-state green laser developed for U-AVLIS. The technology is being used for precision machining and many other applications, such as pumping ultrashort-pulse lasers, creating laser displays, and treating disfiguring skin conditions.

1974 LASERS AND ICF

The first Livermore laser for ICF research, Janus, had two beams and produced 10 joules of energy.

With the 20-beam Shiva laser in 1977, the Laboratory established its preeminence in laser science and technology.

Lasers Join the Quest for Fusion Energy

With the goal of achieving energy gain through inertial confinement fusion (ICF) as its mission, the Laser program constructed its first laser for ICF experiments in 1974. Named Janus, the two-beam laser was built with about 100 pounds of laser glass.

Under the leadership of John Emmett, who headed the Laser program from 1972 to 1988, researchers used Janus to gain a better understanding of laser plasma physics and thermonuclear physics and to demonstrate laser-induced compression and thermonuclear burn of deuterium–tritium. It was also used to improve the LASNEX computer code developed for laser fusion predictions. Janus was just the beginning of the development, in quick succession, of a series of lasers, each building on the knowledge gained from the last, moving toward the National Ignition Facility (NIF) under construction today. The pace of laser construction matched the growth in ICF diagnostics capabilities, computer simulation tools, and theoretic understanding.

In 1975, the one-beam Cyclops laser began operation, performing important target experiments and testing optical designs for future lasers. The next year, the two-beam Argus was built. Use of Argus increased knowledge about laser–target interactions and laser propagation limits, and it helped the ICF program develop technologies needed for the next generation of laser fusion systems.

The $25-million 20-beam Shiva became the world's most powerful laser in 1977. Almost the size of a football field, it delivered 10.2 kilojoules of energy in less than a billionth of a second in its first full-power firing. Two years later, Shiva compressed fusion fuel to a density 50 to 100 times greater than its liquid density. Shiva provided more power, better control over conditions, higher temperatures, and greater fuel compression than any previous laser.

The Novette laser came on line in 1983 as a test bed for the Nova laser design and an interim target experiment facility. It was used to demonstrate the efficient coupling of higher-harmonic laser light to fusion targets and to create the first soft-x-ray laser. The Nova laser (see Year 1984), 10 times more powerful than Shiva, was built the following year.

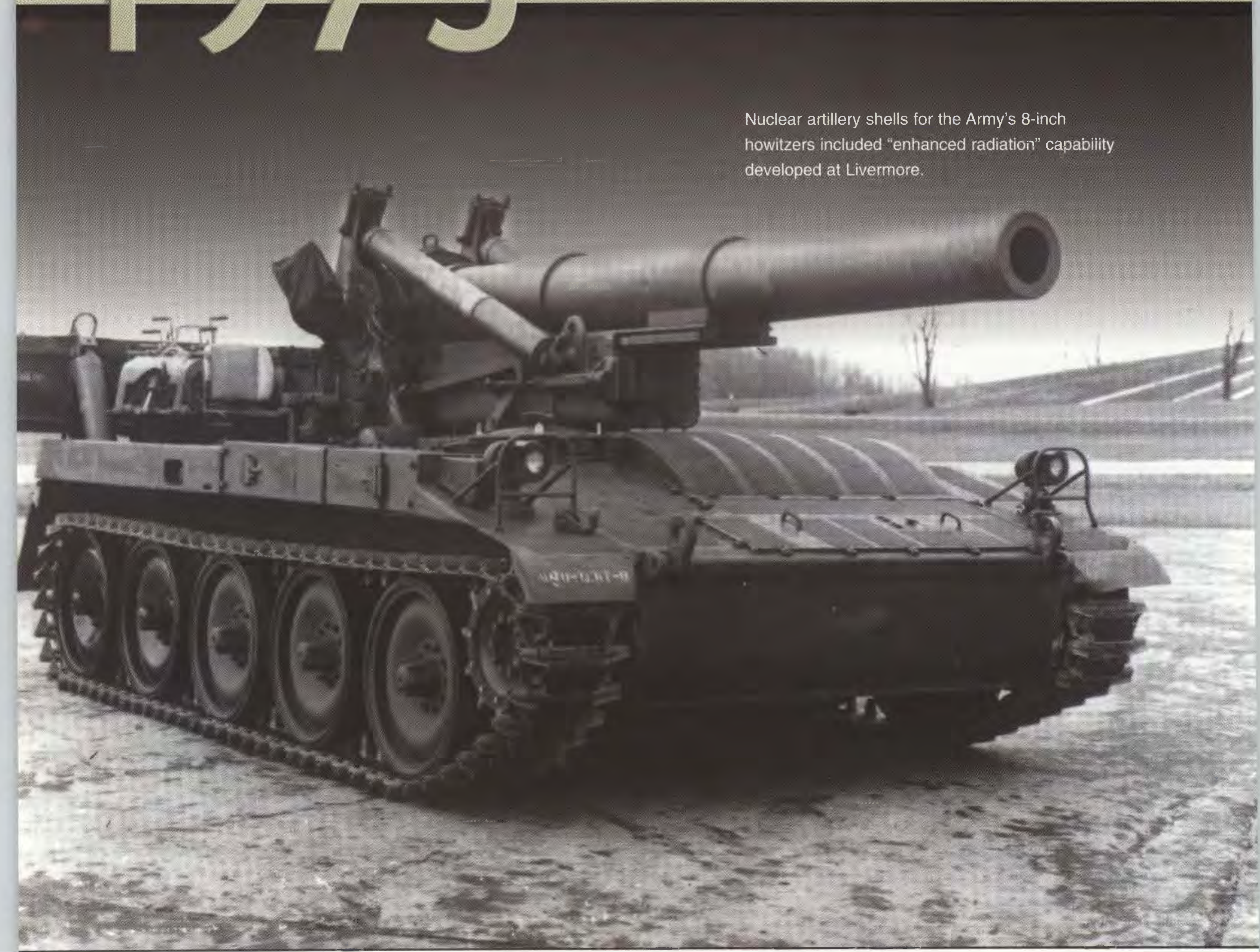
Altogether, six large fusion laser systems were engineered and built in 10 years. The next decade of ICF research was devoted to studying and demonstrating the physics required for fusion ignition and gain (fusion output greater than energy input). The work prepared the Laboratory to take the next major step, construction of the 192-beam National Ignition Facility (see Year 1997), where scientists expect to achieve fusion ignition and energy gain.

Inertial Confinement Fusion

In a fusion reaction, two nuclei—deuterium and tritium—collide and fuse together, forming a heavier atom and releasing about a million times more energy than in a chemical reaction such as fossil fuel burning. The nuclei must travel toward each other fast enough to overcome electrostatic forces. Thus, the fuel's temperature must be over 10 million kelvins, and the fuel must be compressed to a density 20 times greater than that of lead. Laser beam light heats the surface of the fuel pellet and rapidly vaporizes its outer shell, which implodes the inner part of the fuel pellet and reduces it in size by a factor of 30 or more—equivalent to compressing a basketball to the size of a pea.

Side view of a typical hohlraum for the Nova laser shown next to a human hair. Hohlraums for the National Ignition Facility will have linear dimensions about five times greater than those for Nova.

1975 W79 DEVELOPMENT



Nuclear artillery shells for the Army's 8-inch howitzers included "enhanced radiation" capability developed at Livermore.

Conflict Simulation Laboratory

To understand the role of tactical nuclear weapons, analysts have had to take into account many factors that are not amenable to analytical models—the so-called "fog of war." In the mid-1970s, under the leadership of Don Blumenthal, the Laboratory began building high-resolution combat simulation models. A major advance occurred in 1978, when George Smith developed Mini-J, the first two-sided, player-interactive combat simulation model. The players observed their own units in real time, interactively acquired enemy units on a computer screen, and gave orders. Mini-J evolved into Janus, and successively improved models developed by Livermore's Conflict Simulation Laboratory followed. The culmination of this work is the Joint Conflict and Tactical Simulation (JCATS) model, which is widely used by the Department of Defense, Secret Service, and other agencies for training and planning.

Special-Effect Weapons for the Tactical Battlefield

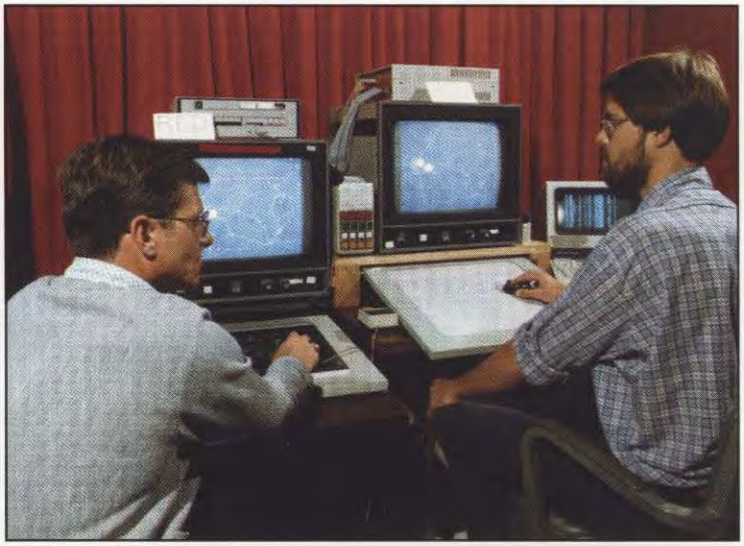
In January 1975, Livermore was assigned the task of developing a new nuclear artillery shell warhead, the W79, for the Army's 8-inch howitzers. Nuclear artillery shells were part of the U.S. arsenal from the mid-1950s until 1992. They were deployed for both Army and Navy systems and provided a highly accurate, short-range (typically about 10 miles), all-weather capability using delivery systems already deployed with conventional shells.

The W79 and the W70-3 were to be the first battlefield nuclear weapons to include an "enhanced radiation" (ER) capability. ER provided a relatively high fraction of the prompt weapon output in the form of neutrons (hence the nickname "neutron bomb"). ER technology began to be developed at Livermore in the early 1960s and entered the stockpile in 1974 with the deployment of the W66 warhead for the Sprint antiballistic missile interceptor (see Year 1971).

ER weapons were also developed for NATO forces. They were far more effective than previously deployed battlefield nuclear weapons for blunting a Soviet armored invasion of Western Europe and hence strengthened deterrence. A lethal radiation dose to enemy troops—likely protected in armored vehicles—could be achieved with the much smaller yield of an ER weapon than with a standard nuclear weapon. ER weapons could be employed to strike enemy units much closer to urban areas while avoiding collateral damage to towns and civilians.

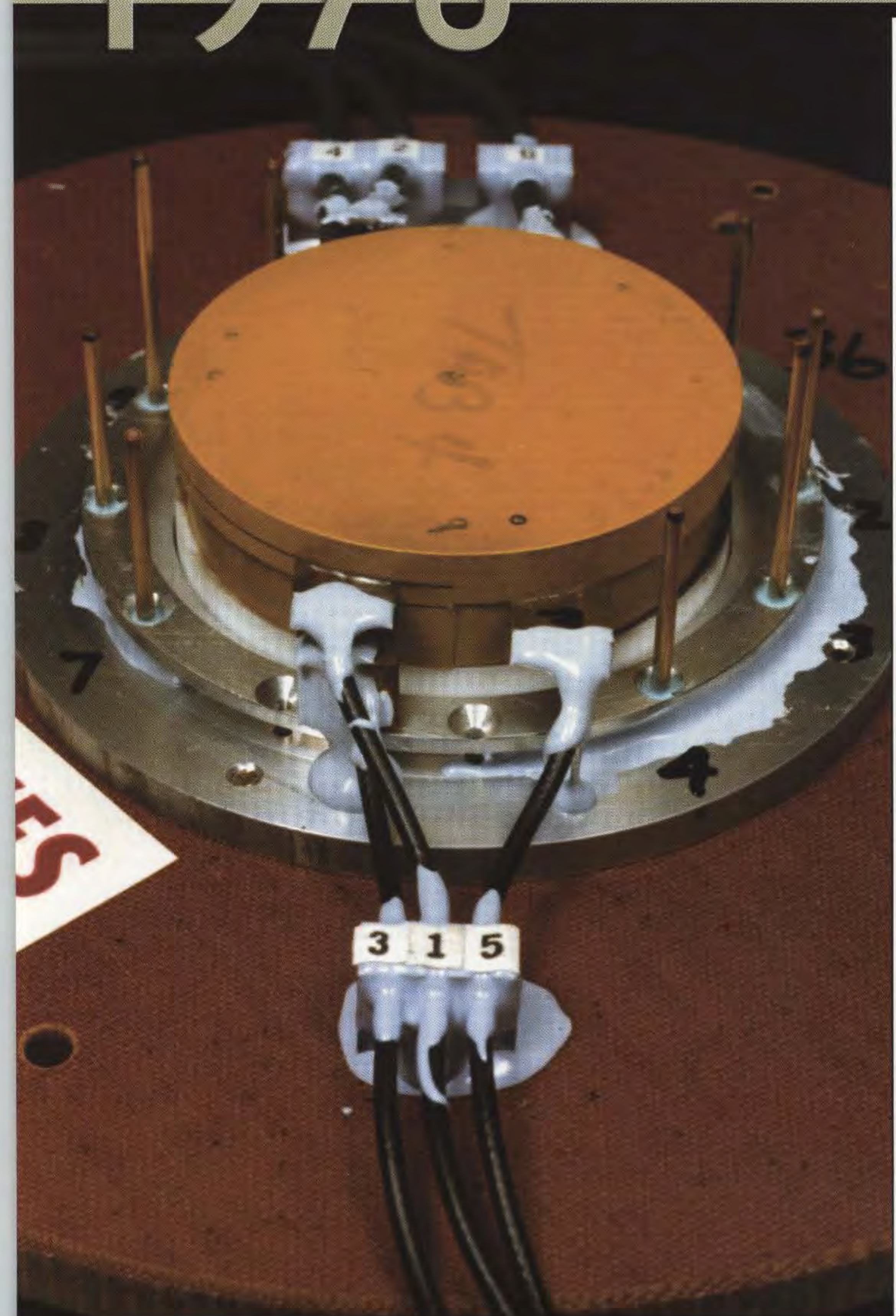
The W79 development program led to deployment in 1981. In 1976, the Laboratory received a second related assignment—to provide an enhanced radiation modification to the Livermore-designed W70 warhead for the Army's short-range Lance missile system. This warhead, the W70-3, was also deployed in 1981. The W82, a weapon program for the 155-millimeter howitzer, was also assigned to Livermore, but that program was canceled in the mid-1980s prior to deployment.

By the time the W70-3 and the W79 were part of NATO forces, they had become the center of an international controversy. A principal concern expressed by opponents was that by virtue of the lower yield and greater utility of ER weapons, their deployment would serve to lower the threshold for nuclear war. This controversy led to a 1985 Congressional order that future W79s be built without the ER capability, and existing units were modified to remove this capability. Eventually, all U.S. battlefield nuclear weapons were retired in accordance with President Bush's September 1991 address to the nation.

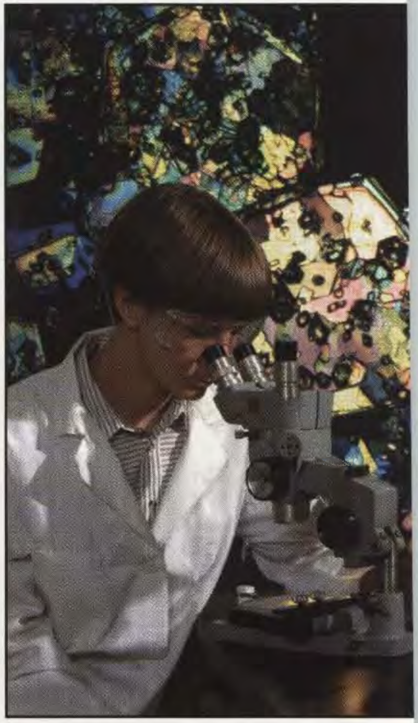


Models that could accommodate an increasingly larger number of units and were applicable to a wider range of scenarios, such as urban combat, were developed at the Conflict Simulation Laboratory (left) in the 1980s. Player-interactive simulations are used by the U.S. military for training, analysis of tactics, and mission planning.

1976 ENHANCED SAFETY



Research on energetic materials at the Laboratory has led to the formulation, detailed characterization, and development for weapons use (left) of extremely safe high-explosive materials for weapons.



Crystals of TATB (triamino-trinitrobenzene), which are shown magnified in the background, are examined under a microscope.

TATB Makes Nuclear Weapons Safer

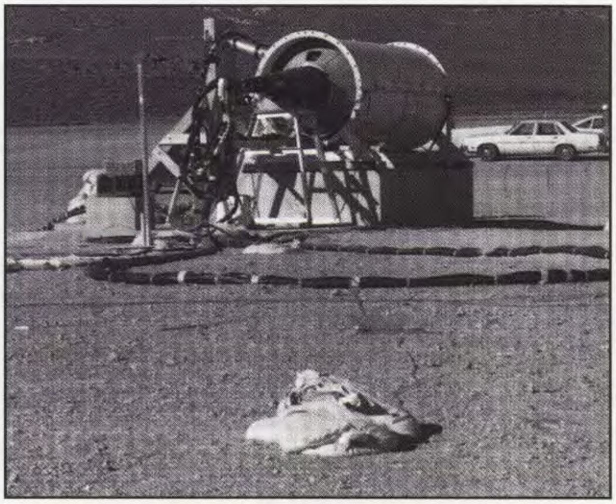
In 1975, Laboratory researchers published their first report on investigations of an insensitive high explosive, TATB (triamino-trinitrobenzene). Further work to characterize the material and find improved ways of producing it has led to widespread use of insensitive high explosives (IHE) in nuclear weapons. Use of IHE is one of the many important advances made over the past five decades to improve the safety and security of nuclear weapons. Its development is a demonstration of the expertise in energetic materials that resides at the nation's nuclear weapons laboratories.

First synthesized in the 19th century, TATB is referred to as an insensitive high explosive because of its inherent insensitivity to shock. The material is virtually invulnerable to significant energy release in plane crashes, fires, or explosions or from deliberate attack with small arms fire. In fact, TATB is so stable that researchers had to discover how to reliably initiate an explosion of the material. They also had to find a ready and affordable way to produce the material. Building on advances made at both nuclear design laboratories, Los Alamos researchers made a key improvement in 1967 by finding a way to prepare TATB as a molded, plastic-bonded explosive at close to theoretically maximum density.

Subsequent experiments at Livermore by Richard Weingart and his colleagues included shock-initiation, heat, and fracture tests to define the safety characteristics of plastic-bonded TATB. Other experiments helped researchers to understand how to initiate TATB reliably even in the extreme conditions that a nuclear weapon might face. A team led by physicist Seymour Sack made design advances that enabled TATB's reliable use in nuclear weapons. The first nuclear weapon systems to include TATB were a variant of the B61 bomb and B83 strategic bomb. The W87 ICBM warhead was the first design to use TATB for the explosive detonators as well as for the main explosive charge, further enhancing safety.

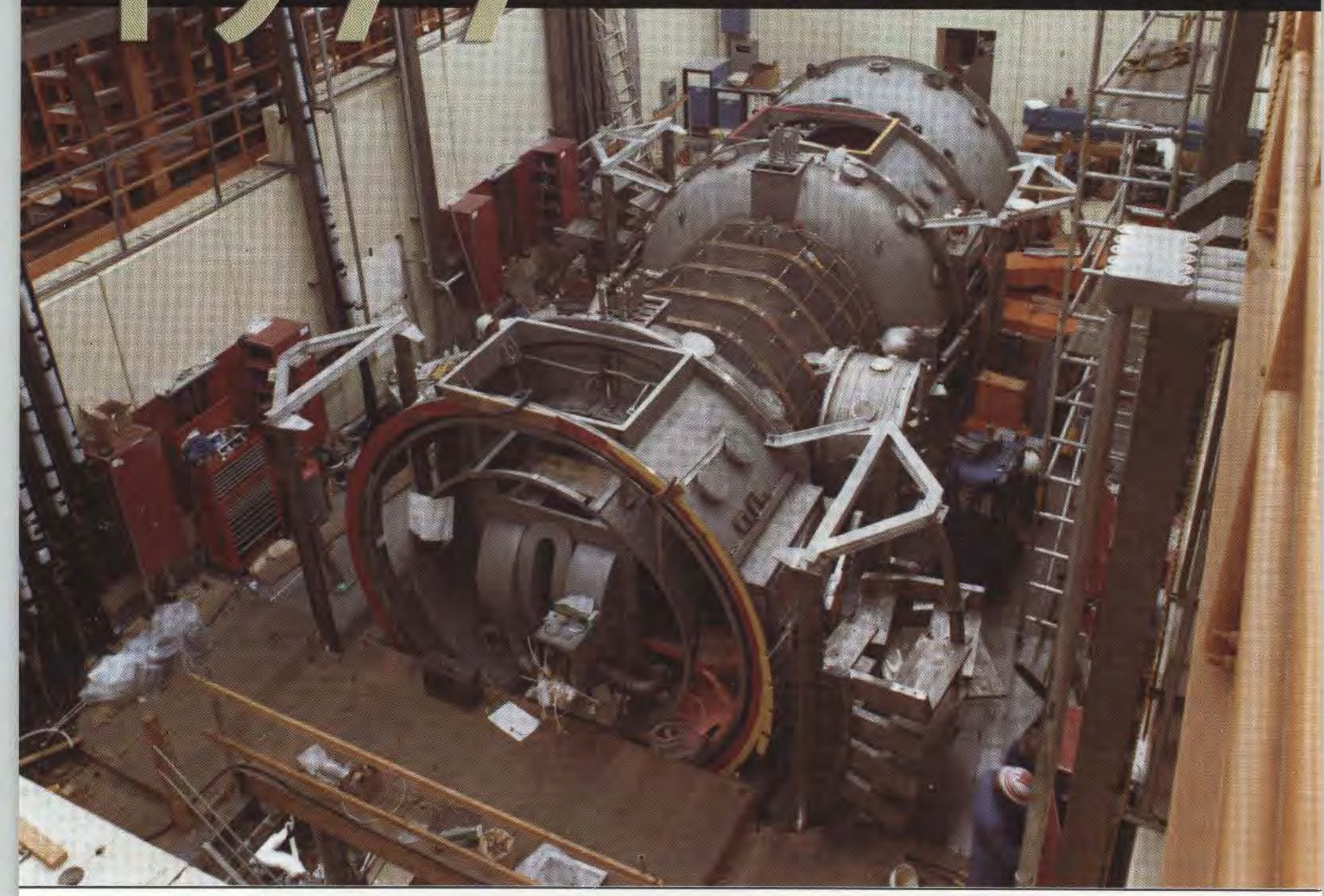
Despite its broad potential for military as well as civilian applications, use of TATB is largely limited to nuclear weapons because it is costly to manufacture. Even for nuclear weapon applications, a more environmentally benign method for producing TATB was needed. In response, Livermore developed in the 1990s a new manufacturing process called vicarious nucleophilic substitution (VNS). The process uses industrial materials that are environmentally less hazardous and avoids the need for chlorinated starters. VNS also saves 60 percent in manufacturing time and cost. The Laboratory's goal is to transfer the new process to private industry.

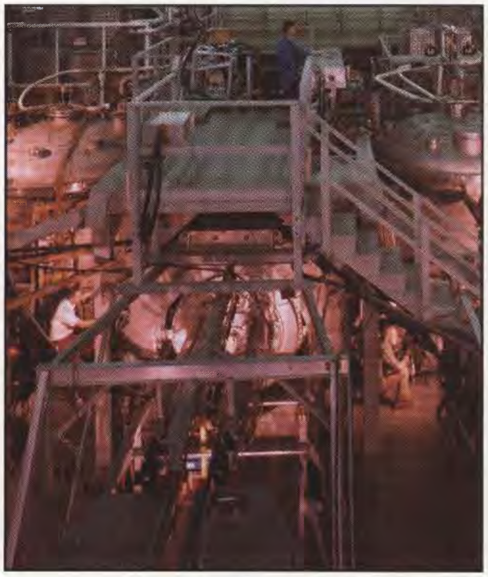
Energetic materials research at Livermore includes experimental activities at the High Explosives Applications Facility (HEAF) and Site 300, theoretical studies, and modeling efforts. One major challenge is to improve the models of the chemistry of detonation that are used in simulations of weapon performance. The detonation process involves many rapid chemical changes, with materials reaching extremely high pressure (up to 500,000 atmospheres) and high temperature (many thousands of kelvins).



A mock W87 warhead with IHE in a Mk21 reentry vehicle is mounted on simulated upper stages of the Peacekeeper missile (in the canister) in preparation for an explosive test to determine accident environments and warhead response.

1977 TANDEM MIRROR EXPERIMENT





Great success in the Tandem Mirror Experiment (above) led to TMX-Upgrade (far left and left). The vacuum vessel was enlarged, and new end coils were installed in an attempt to demonstrate the thermal barrier concept and improve performance over TMX.

Enormous Strides in Magnetic Fusion

In 1977, Laboratory researchers were making enormous strides both in the quality of their insights into plasma physics and in the size of their experimental equipment. In the spring, the Energy Research and Development Administration approved $11 million for the Tandem Mirror Experiment (TMX), which promised major performance improvements. That summer, researchers used an intense beam of energetic neutral atoms to generate and sustain a high-density (10^{14} particles/cm^3), high-temperature (160 million kelvins) plasma in the 2XIIB machine, which was the single-cell mirror experiment that set the stage for TMX. And in autumn, construction began on the Mirror Fusion Test Facility (MFTF), an advanced experimental fusion device designed to be an intermediate step between the existing mirror machines and an experimental fusion reactor. The goal was to increase plasma confinement to nearly 100 times that of 2XIIB and to increase plasma temperature to more than 500 million kelvins.

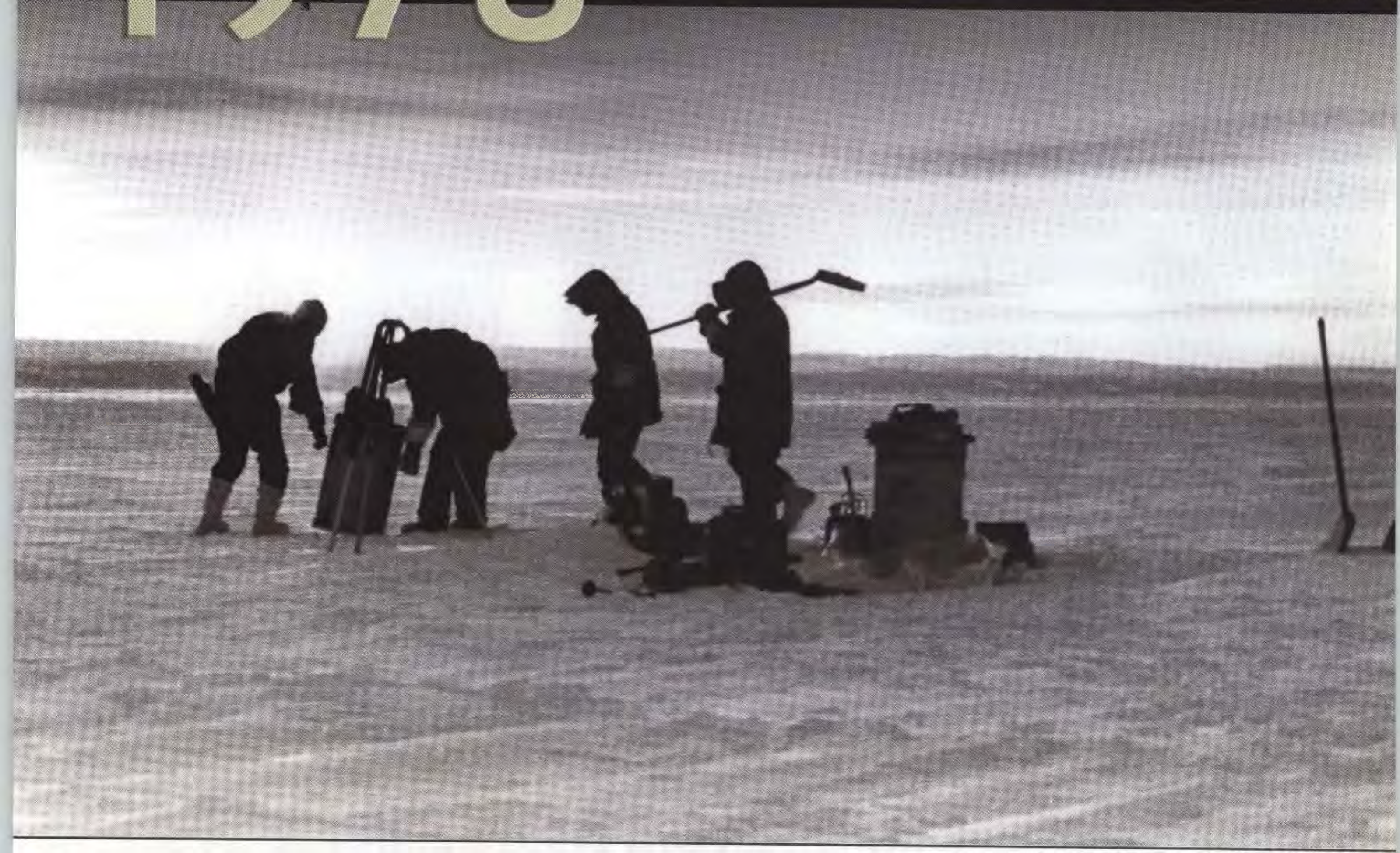
Success with TMX experiments over the next several years led the Laboratory to attempt to improve plasma confinement by heating the electrons at the ends of the machine to create a thermal barrier—a change that turned out to add to instabilities. At the same time, the MFTF design was substantially modified into a large tandem mirror configuration called MFTF-B. With a 58-meter-long vacuum vessel and the largest set of superconducting magnets in the world, MFTF-B was the Laboratory's largest construction project ($372 million) when completed in 1986. However, what could have been learned with MFTF-B will never be known because it was officially mothballed later that year. A scientific tool that had pushed the limits of engineering was turned off before it was ever turned on.

The decision was a major setback for fusion energy research at Livermore, but scientists continued work on other approaches to magnetic fusion. Laboratory researchers are collaborating in experimental studies of tokamak performance using the DIII-D tokamak at General Atomics, and they are providing leadership in the development and use of large-scale simulation of plasmas to carry out fusion research. In addition, Livermore is focusing its attention on advanced and alternative plasma confinement concepts. The Sustained Spheromak Physics Experiment (SSPX) was dedicated in January 1999. Its attractive features are simplicity of design and economy of size and cost when compared to the warehouse-size, technologically complex tokamak.

As one of its significant legacies, the large magnetic mirror fusion effort at the Laboratory led to the establishment of the nation's first unclassified national supercomputing center to provide magnetic fusion researchers nationwide with the computing horsepower that was then available only to nuclear weapons designers. When it opened at Livermore in 1974, the computer center pioneered many practices: remote access by thousands of users; high-performance data storage and retrieval; online documentation; and, around-the-clock support for users. In the 1980s, the center became the National Energy Research Scientific Computing Center (NERSC). It is now located at Lawrence Berkeley National Laboratory.

One of the yin-yang magnets for MFTF-B being moved into Building 431. The magnet system for MFTF-B was the largest superconducting system ever built.

1978 OPERATION MORNING LIGHT



NEST members from Livermore join the search for Cosmos 954, a fallen Soviet satellite. They found small pieces of the satellite and its nuclear reactor on frozen Baker Lake in the Northwest Territories of Canada.

When Satellites Go Bad

Cosmos 954 started losing orbital altitude in December 1977. The North American Aerospace Defense Command (NORAD) thought it would burn up in the Earth's atmosphere on reentry, but not much was known about the Soviet satellite—its size, its weight, and most important, the amount of nuclear material in its reactor. A month later, the Laboratory was quietly notified to get ready. NEST—the Nuclear Emergency Search Team—was prepared to find the satellite, wherever it landed.

After the first meeting at the Laboratory on January 18, 1978, two Livermore computer scientists were provided the exclusive use of a CDC-7600 computer, and they spent the next few sleepless days refining calculations of the trajectory and figuring out how wide an area—called the footprint—would result from the impact of variously sized pieces of Cosmos, including perhaps 100 pounds of nuclear fuel. The exact time and place of reentry would not be known until the final orbit.

Meanwhile, the Laboratory's NEST contingent—a group of health physicists, chemists, nuclear physicists, and engineers—left for the Las Vegas NEST office to wait. They had packed every type of clothing because they had no idea where they would ultimately end up. Radiation detectors, liquid nitrogen, sample containers, power generators, what passed for portable computers then, and even a helicopter were loaded into a C-141 aircraft—all to look for anything that survived reentry.

The final orbit happened on January 24. Cosmos fragments scattered across a 30-mile-wide, 500-mile-long swath of the Northwest Territories of Canada, a desolate area populated by caribou and a few Inuit hunters. Within 6 hours, the official request for help came from Canada, and Operation Morning Light began. The Canadians were depending on the Laboratory team to help find Cosmos pieces, identify the reactor fuel, and estimate the fission product inventory.

Soon, planes with radiation detectors were surveying the frozen landscape. The first radioactive pieces were found on January 26. Radioactivity ranged from a few milliroentgen to 100 roentgens per hour. No single piece was much larger than a small trash can, and tiny bits of radioactive fuel dotted the landscape. Hotspots were concentrated in a few places in the snow-packed forest and in the middle of frozen lakes. Because of the intense cold, team members could work only for short periods.

Operation Morning Light officially ended on April 18. At the peak of its operation—the first two weeks—120 U.S. personnel worked alongside the Canadians. Of that number, 39 were Laboratory people, with an additional 80 people back at Livermore supporting the team. Today, Laboratory personnel are still part of the Department of Energy's NEST team, ready to deploy at a moment's notice anywhere in the world.

Not Exactly California Weather

During Operation Morning Light, Livermore's Tom Crites was at the Baker Lake site, where the temperature hovered around –40°F, or around –120°F with the wind-chill factor. The Canadians had outfitted every team member with the latest survival gear. Tom needed it all. The hydraulically powered helicopter failed one day, requiring the team to build snow igloos and keep fires going. They endured a subzero night before a plane rescued them. A few people lost fingers and toes to frostbite. Tom has put his experience to good use leading Boy Scout camping trips in the Sierras. "Besides," he says, "where else can you look south to see the Northern Lights?"

1979 TRACKING THREE MILE ISLAND

ARAC scientist Marv Dickerson keeps members of the media informed about the status of radioactive releases from the Chernobyl nuclear power plant meltdown in 1986.

Responding to Nuclear Emergencies Worldwide

On March 29, 1979, Marv Dickerson and Tom Sullivan were at a meeting to secure an agreement with the Air Force Global Weather Center to supply information to the Atmospheric Release Advisory Capability (ARAC) at Livermore. ARAC had recently begun pilot operations under the sponsorship of the Department of Energy. They received a call: "There's been an accident at the Three Mile Island nuclear power plant. Could ARAC help, and how soon?"

Over the course of the next 10 days, ARAC scientists worked 24 hours a day, 7 days a week to predict possible levels and areas of radioactive fallout. Working with a private contractor that was taking aerial radioactivity measurements during flyovers of the area, Livermore scientists were able to use meteorological and topographical information to determine where the plume of radioactive materials was located and where it would travel.

From 1973 to the Three Mile Island incident in 1979, ARAC was a research and development project with a goal to track any radioactive accident that happened at a Department of Energy facility and assess its effect on the surrounding community. With the meltdown at Three Mile Island, ARAC became a household name within the group of federal agencies responsible for responding to nuclear accidents. The group included the Environmental Protection Agency, DOE, the Department of Defense, the Nuclear Regulatory Commission, and even the Federal Emergency Management Agency.

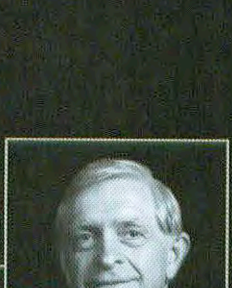
ARAC has since changed its name to the National Atmospheric Release Advisory Center (NARAC) partly because it has expanded its role to respond to nuclear, chemical, biological, or natural hazardous material releases. The center has responded to more than 160 alerts and incidents in over two decades of operations. Key events include the 1980 Titan II missile explosion in Damascus, Arkansas; the Chernobyl nuclear power plant meltdown in 1986; the Kuwaiti oil fires during and after the Persian Gulf War in 1991; the 1991 Mount Pinatubo eruption; an industrial cesium-137 release in Algeciras, Spain, in 1998; and local toxic incidents such as a large tire fire in Tracy, California, in 1999.

NARAC's Emergency Response Modeling System has been continually improved and now uses third-generation codes. The system realistically models actual terrain, uses observed and forecasted weather data, and simulates the release, transport, diffusion, and deposition of particles. Recently, NARAC scientists improved capabilities to simulate how a biological or chemical release would spread in and around complex urban environments, studying in detail Salt Lake City, Utah, the site of the 2002 Winter Olympics. In support of homeland defense, NARAC is an important tool in analyzing how a dangerous airborne substance could travel in a heavily populated area.

ARAC scientists track various airborne releases (left). They helped California state agencies and emergency workers during the June 1999 tire fire in Tracy, California, providing three-dimensional forecasts of the smoke dispersion of particulate concentrations (below).

The Eighties

New Leadership



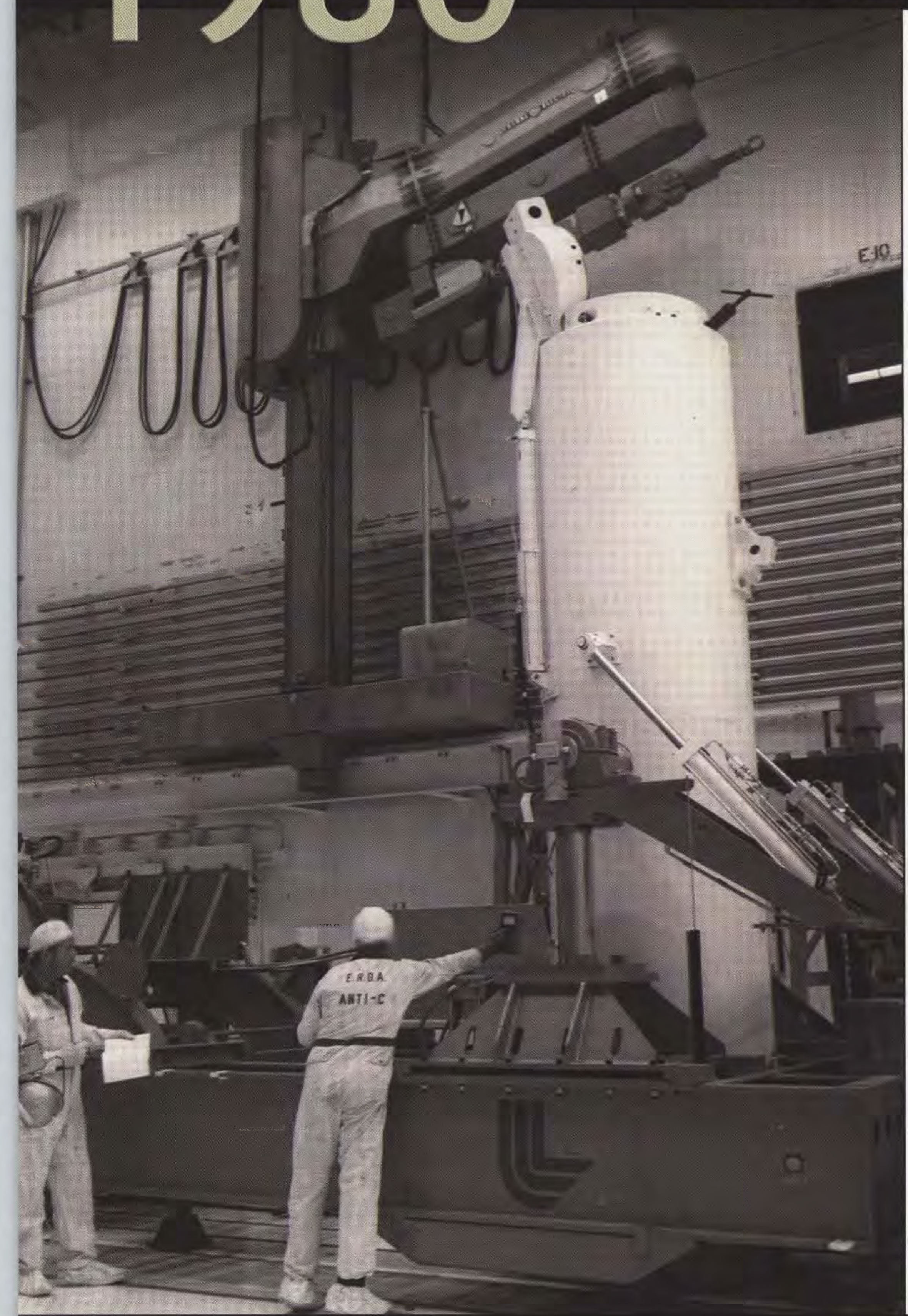
John H. Nuckolls
(1988•1994)

Simulations and experiments

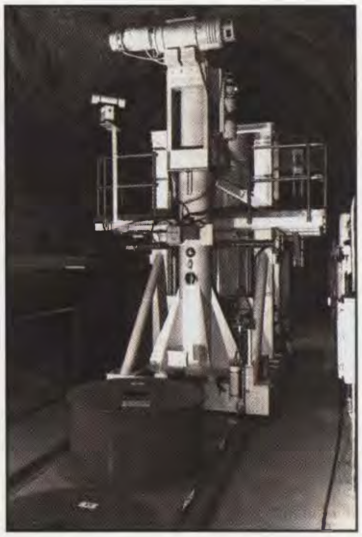
All major programs at the Laboratory have relied on the interplay between computer simulations and experiments to increase scientific understanding and make dramatic engineering improvements. In the 1980s, the combination of testing and simulations greatly contributed to the development of new strategic weapons, such as a nuclear bomb that could be delivered at low altitude, to help win the Cold War. The combination was also critically important to scientific exploration of x-ray lasers and the complexities of intense laser light interacting with matter. Major new experimental facilities were constructed such as the Bunker 801 complex at Site 300 for hydrodynamic testing, the Nova laser, and the High Explosives Applications Facility; and the first three-dimensional simulation codes were developed.

In the late 1980s, Laboratory researchers began to explore the feasibility of using multiple parallel processors for scientific computing—now a key component of efforts to maintain the nation's nuclear weapons stockpile. Since Livermore opened, the need for ever more powerful simulations for nuclear weapons design has guided industry's development of supercomputers, and the Laboratory has helped industry make prototype machines ready for a wider range of users.

1980 SPENT FUEL TEST–CLIMAX



Each spent-fuel canister was moved over paved Nevada Test Site roads from the hot-cell facility to the mined test facility in a specially designed surface cask mounted on a low-boy trailer. The cask was upright for loading and almost horizontal for travel.



Canisters of spent nuclear fuel were entombed 1,400 feet below the Nevada Test Site as part of the DOE National Waste Terminal Storage Program. They were placed in holes drilled in the Climax granite formation and retrieved three years later.

Meeting Challenges of Nuclear Waste

In 1980, the Laboratory placed spent nuclear fuel 420 meters underground at the Nevada Test Site beneath the floor of a tunnel in Climax granite. In this experiment, Spent Fuel Test–Climax (SFT–C), researchers measured thermal loads from 11 canisters of spent fuel, 6 electrical heaters designed to mimic fuel canisters, and 20 electrical heaters in adjacent tunnels. The combined measurements of the three-year-long test simulated the thermal behavior of part of a large geologic repository for nuclear fuel.

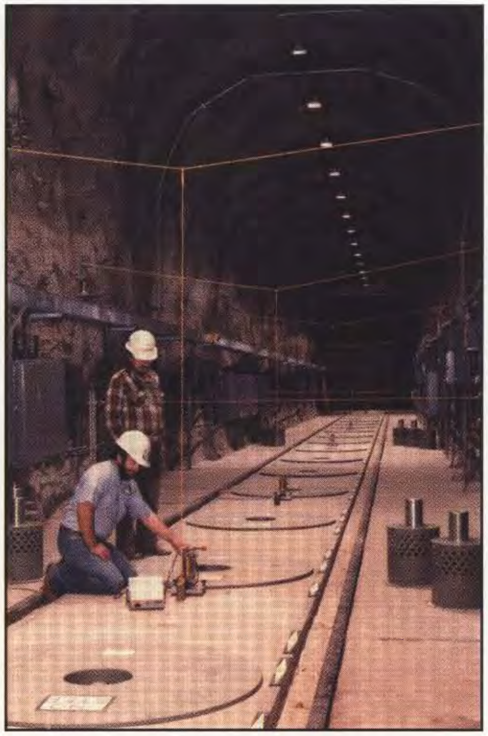
The Climax test was a significant large-scale field test for demonstrating essential technologies and revealing unexpected effects of high-level nuclear waste disposal in geologic repositories. Nuclear waste issues were looming on the horizon long before 1980, but Congress did not pass the Nuclear Waste Policy Act to deal with the problem until 1982.

Opportunities for testing at full scale were very limited this early in the U.S. nuclear waste management program. Livermore undertook SFT–C to demonstrate the feasibility of spent-fuel handling and retrieval from an underground repository and to address technical concerns about geologic repository operations and performance. The test was part of the Nevada Nuclear Waste Storage Investigations (NNWSI) project for the Department of Energy.

Operational objectives included packaging, transporting, storing, and retrieving highly radioactive fuel assemblies in a safe and reliable manner. In addition to emplacement and retrieval operations, three exchanges of spent-fuel assemblies between the SFT–C tunnel and a surface storage facility were part of this demonstration.

SFT–C technical objectives required a measurements program with nearly 1,000 field instruments and a computer-based data acquisition system. The system had to be robust enough to withstand the vagaries of the Nevada Test Site's power grid, shaking from nuclear weapons tests, and high temperatures caused by the thermal load. This was a major challenge for 1980s technology. When the Laboratory requested bids for a computer for logging the test data, only one company (Hewlett-Packard) answered the call. Undaunted, Livermore scientists and engineers designed most of the instruments, installed the system, and recorded geotechnical, seismological, and test status data on a continuing basis for the three-year storage phase and six months of monitored cool-down.

The SFT–C demonstrated the feasibility of deep geologic storage of spent nuclear fuel from commercial nuclear power reactors. The SFT–C showed the Laboratory's strong capabilities in materials science, nuclear science, earth sciences, advanced simulations, and engineered systems. The test's success provided a foundation for subsequent collaborations with nuclear waste disposal programs in other countries. More directly, as NNWSI evolved into the Yucca Mountain Project (YMP), the SFT–C helped prepare Livermore researchers for their role as experts in addressing YMP waste form, waste package, near-field environment, and repository performance issues.



Scientists perform an instrumentation checkout in the tunnel at the Nevada Test Site. The purpose of Spent Fuel Test–Climax was to determine the issues involved with storing and retrieving nuclear wastes underground.

1981 LODTM GROUNDBREAKING

The Large Optics Diamond Turning Machine and an aspherical mirror that the machine was first able to produce.

The Art of Precision Machining

It has been called the world's most accurate lathe, the world's most precise large machine tool. With the groundbreaking for the Large Optical Diamond Turning Machine (LODTM) in 1981, the Laboratory solidified its place at the top of state-of-the-art precision machining.

More than 20 years later, the machine's precision is such that LODTM (pronounced "load-em") still outperforms the measurers—the National Institute of Standards and Technology cannot corroborate the accuracy of its work. LODTM can machine metal to a mirror-smooth accuracy within one-millionth of an inch—1,000 times more accurate than conventional machine tools. It can handle a workpiece with a diameter up to 1.65 meters, a height up to 0.5 meters, and a weight up to as much as 1,360 kilograms.

Like a lathe, LODTM spins a workpiece as a tool cuts the revolving surface. But the similarity ends there, because LODTM leaves behind a gleaming reflective surface that often needs no further polishing. Since its construction, LODTM has been the tool of choice for contractors making lenses for heat-seeking missiles and other weaponry, exotically shaped optics for lasers, and mirrors for powerful telescopes such as Keck in Hawaii and NASA's space-based lidar-system, SPARCLE. When the Shoemaker–Levy comet collided into Jupiter in 1994, it was witnessed in real time, thanks to mirrors turned on LODTM and then installed at Keck.

Almost since its inception, the Laboratory has been among the leaders in the development of advanced techniques for precision measurement and manufacture to meet the demands of programmatic work. Livermore's first diamond turning machine was built in the late 1960s, and by the early 1970s, one-millionth of an inch precision was achieved. The idea of the LODTM arose later in the decade when researchers began considering the development of powerful lasers as an element of missile defense. The laser system's optics had to be extremely large, exotically shaped, and fabricated with a precision that corresponded to a small fraction of the wavelength of light. No machine had the needed capabilities.

Livermore's Precision Engineering Program, under the guidance of Jim Bryan, Jim Hamilton, Jeff Klingmann, Dennis Atkinson, and others, designed LODTM. The culmination of previous Laboratory research in machine tool accuracy, LODTM incorporated exhaustive analysis and elimination of factors that caused errors in machine tools—from the heat of the human body to the vibration from a heavy truck passing by.

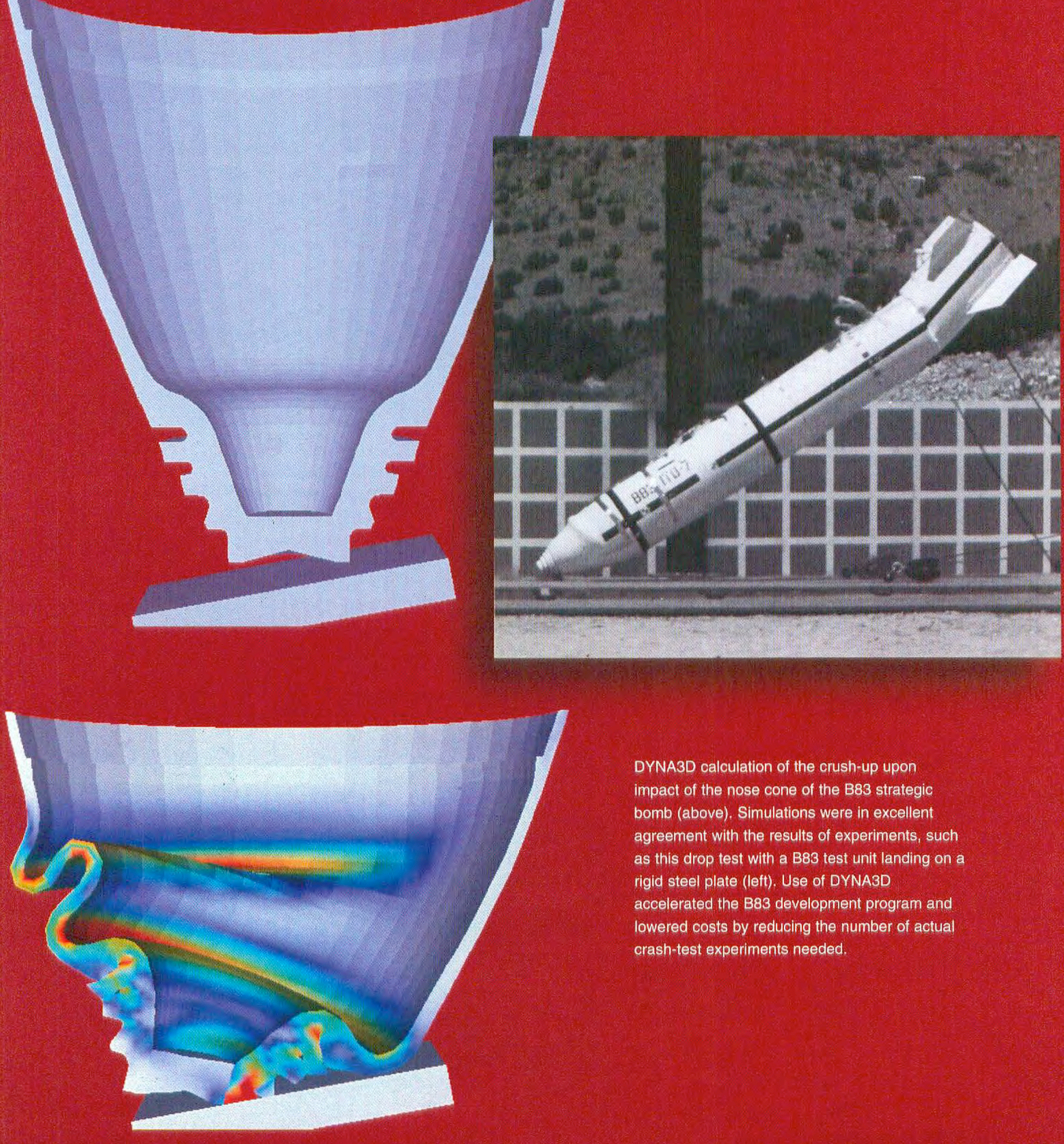
LODTM opened in 1983, two years after its groundbreaking. It continues to produce one-of-a-kind prototype optical devices. LODTM's next big project may be producing optics for NASA's next generation of telescopes.

A Hero of U.S. Manufacturing

Literally billions of dollars worth of machine tools have been tested with a small measuring device invented by Jim Bryan, who made wide-ranging contributions to metrology and precision machining in 32 years of service at the Laboratory. In the 1980s, Bryan reworked an old British invention called a fixed ball bar by adding a telescoping arm to the instrument. Today, versions of Bryan's ball bar are used around the world to test machine tool performance quickly. For this invention and other achievements, which include leading the design and construction of record-breaking diamond turning machines in the 1970s, Bryan was recognized in 2000 by *Fortune* magazine as one of six "Heroes of U.S. Manufacturing."

Machining metal up to 1.65 meters in diameter and at a precision of 2 micrometers is possible with LODTM.

1982 DYNA3D



DYNA3D calculation of the crush-up upon impact of the nose cone of the B83 strategic bomb (above). Simulations were in excellent agreement with the results of experiments, such as this drop test with a B83 test unit landing on a rigid steel plate (left). Use of DYNA3D accelerated the B83 development program and lowered costs by reducing the number of actual crash-test experiments needed.

From Swords to Plowshares with DYNA3D

In 1982, a growing list of users benefited from the publication of the first *User's Manual for DYNA3D*. This three-dimensional computer code was developed by Laboratory mechanical engineers to meet the needs of the nuclear weapons program, and it grew to become a remarkable "swords to plowshares" story. Interest in DYNA3D rapidly expanded from a manual to an international conference on the code's applicability to a wide range of structural analysis problems. The computer code has been used by industry for making everything from safer planes, trains, and automobiles to better beer cans.

Much of the early incentive to develop DYNA3D, short for dynamics in three dimensions, arose from challenges presented by the B83 program. The B83 nuclear bomb was to be released from a low-flying aircraft, and even though it was to be retarded by a parachute, the bomb would have to survive an impact with the ground or whatever irregular structure it hit at up to 75 miles per hour. Lawrence Livermore and Sandia national laboratories needed an affordable program of tests and simulations to design the B83 and certify its crashworthiness. DYNA3D was used to model the structural performance of the B83, a complex design using a wide variety of materials, and it saved millions of dollars and years of time.

The code DYNA3D soon began spreading to private industry in one of the Laboratory's best examples of technology transfer of software. An unclassified code, DYNA3D's list of current or one-time industrial users reads like a "Who's Who" of major firms—General Motors, Daimler-Chrysler, Alcoa, General Electric, Lockheed Missiles and Space, General Dynamics, Boeing Commercial Airplane Group, Adolph Coors Co., Rockwell International, and FMC Corp. For example, General Motors and Daimler-Chrysler have run DYNA3D to help design safer cars; GE Aircraft Engines has operated the code to design jet engine fan blades; and, in 1991, a British engineering firm used the code to study a London train mishap that killed two people and injured 512 others.

At times, upwards of 300 companies have used the code to model their systems before they were built. A 1993 study found that DYNA3D and DYNA-like programs conservatively save U.S. industry $350 million annually. As one aerospace engineer stated, "DYNA is what Hershey is to chocolate bars and Kleenex is to tissue. People don't ask for a (dynamic) finite element code; they ask for a DYNA-like code."

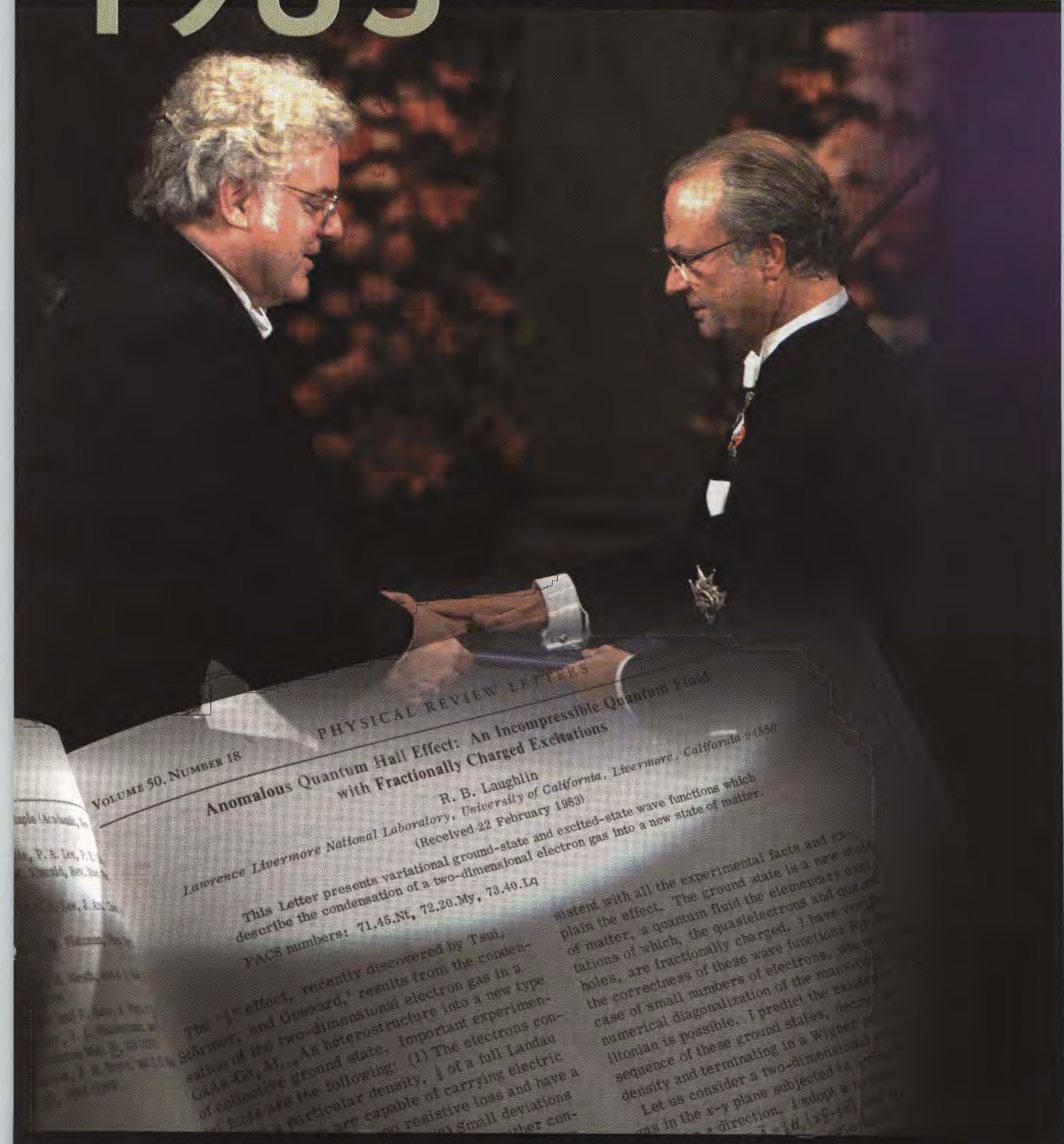
Since work started on it in 1976, DYNA3D has blossomed from a small 5,000-line computer code into a 150,000-line package. Another version of DYNA3D for parallel computers, called ParaDyn, went into production use in 2000.

With the first Cray 1 arriving in 1979, Cray Research was the principal provider of mainframe machines to the Laboratory until the transformation to massively parallel computing in the 1990s.

Getting to the Heart of the Matter

In the early 1990s, as bioengineers looked to computer modeling to better understand complex human health problems, some turned to DYNA3D for help. One researcher, in a study associated with Duke University Medical Center, used the Livermore computer code to simulate the experimental response of arteries to balloon angioplasty. Other researchers employed DYNA3D to undertake studies showing the effect of impacts on the human chest and helmets. In addition, DYNA3D was even used in the design of some medical equipment.

1983 LAUGHLIN NOBEL WORK



VOLUME 50, NUMBER 18

PHYSICAL REVIEW LETTERS

Anomalous Quantum Hall Effect: An Incompressible Quantum Fluid with Fractionally Charged Excitations

R. B. Laughlin

Lawrence Livermore National Laboratory, University of California, Livermore, California 94550

(Received 22 February 1983)

This Letter presents variational ground-state and excited-state wave functions which describe the condensation of a two-dimensional electron gas into a new state of matter.

PACS numbers: 71.45.Nt, 72.20.My, 73.40.Lq

Award-Winning Science and Technology

The road to the Laboratory's Nobel Prize in physics was a 15-year journey, one that winner Robert B. Laughlin credits to Livermore's strength in team science.

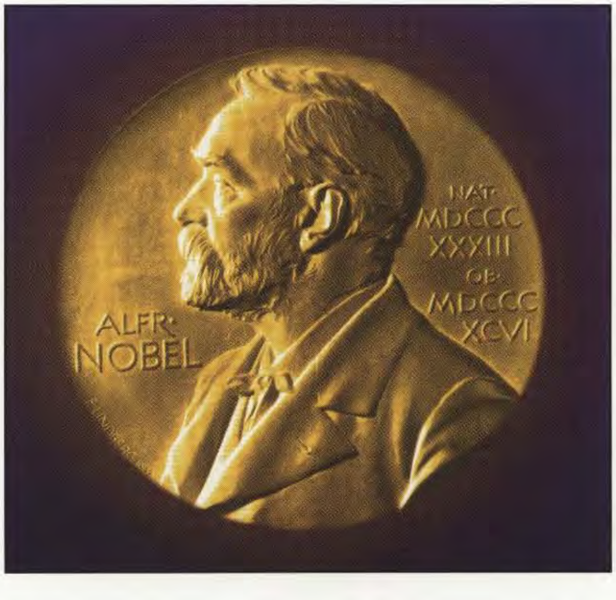
Laughlin earned his Nobel in 1998, but it was in 1983 that *Physical Review Letters* published his elegant theoretical work explaining the so-called fractional quantum Hall effect. The effect had been experimentally discovered in 1982 by Horst Stormer of Columbia University and Daniel Tsui of Princeton University, who shared the Nobel with Laughlin. Its key surprise is that collective motions of electrons can behave like a fraction of the electrical charge for one electron. Previously, the only example of fractional charges in nature had been quarks.

By the time Laughlin's research was lauded in ceremonies held in Stockholm, Sweden, on December 10, 1998, Laughlin had become a professor of physics at Stanford University. But the work that led to that Nobel Prize was born in the Laboratory's condensed matter physics division. It was there that Laughlin, a solid-state postdoctoral physicist, benefited from Livermore's multidisciplinary approach to science—first championed by Laboratory co-founder and Nobel winner Ernest O. Lawrence.

Laughlin learned the ins and outs of plasma physics, and the mathematics of classical hot liquids, from physicists such as Hugh DeWitt, David Young, Marvin Ross, and Forrest Rogers. While waiting for his security clearance, he passed time by learning Monte Carlo simulation methods, studying the experimental literature of fluids, and making computer models of fluids. While thinking of the possibilities for the quantum Hall wave function, Laughlin realized "it was a fluid problem." He believes that he would not have seen that if he had not been interacting with fellow H Division physicists, who understood fluids. Although some experts think the fractional quantum Hall effect research could lead to advances in computers or power generation, Laughlin sees the main value of his work as revealing fundamental insights into quantum mechanics.

Laughlin has the distinction of being the first national laboratory employee ever to win the Nobel Prize. He is the seventy-first winner who worked or conducted research at a Department of Energy institution or whose work was funded by DOE, and he is the eleventh University of California employee to receive a Nobel Prize in physics.

Though Laughlin spends most of his time at Stanford, he continues his association with the Laboratory. His work stands as the hallmark of the world-renown science conducted at Livermore, work that has earned hundreds of other scientists, like Laughlin, E. O. Lawrence Awards, Teller medals, distinctions from every world-wide scientific society, and even the Nobel Prize.



Robert Laughlin (left) received the Nobel Prize for physics from Swedish King Carl XVI Gustaf at the ceremonies in Stockholm, Sweden, on December 10, 1998.
(AP photo/Jonas Ekstromer)

1984 NOVA

In 1984, when it began operation, Nova was the world's most powerful laser. Laser pulses were produced with 10 beams (top), which were directed to a 5-meter-diameter target chamber (far left). Inside the chamber (left), the laser light was focused on BB-size targets.

Breakthrough Laser Science and Technology

In the early 1980s, researchers were exploring how to produce x-ray laser beams initiated by nuclear explosives at the Nevada Test Site. At the same time, success was achieved creating a soft-x-ray (about 200 angstroms) laser in a laboratory setting using the Novette laser, which was a test bed for the design of Nova. Nova became operational in December 1984, enabling further groundbreaking research in x-ray lasers and many other areas of laser science and technology.

Ten times more powerful than Shiva, its predecessor, Nova was the world's most powerful laser. Its 10 beams produced laser pulses that delivered up to 100 trillion watts of infrared laser power for a billionth of a second. For that brief instant, its power was over 25 times greater than the combined power produced by all the electrical generating plants in the United States.

In 1986, in inertial confinement fusion experiments, Nova produced the largest laser fusion yield to date—a record 11 trillion fusion neutrons. The following year, Nova compressed a fusion fuel pellet to about 1/30th its original diameter, very close to that needed for high gain (fusion energy exceeding energy input). The laser exceeded its maximum performance specifications in 1989 when Nova generated more than 120 kilojoules of laser energy at its fundamental infrared wavelength in a 2.5-nanosecond pulse. In addition, in 1996, one arm of Nova was reconfigured as a petawatt laser. Record-setting laser shots produced pulses with more than 1300 trillion watts, or 1.3 petawatts, of peak power. The laser pulse lasted less than one-half trillionth of a second—more than a thousand times shorter than shots typically produced by Nova's 10 beams.

About 30 percent of Nova's shots were used by the nuclear weapons program. When the United States ceased nuclear testing, laser facilities became even more important for defense research, and the portion of Nova shots dedicated to the weapons program increased considerably. Researchers using Nova continued obtaining high-temperature data necessary to validate the computer codes used to model nuclear weapons physics.

Livermore also developed increasingly sophisticated diagnostic instruments to measure and observe what was happening with the laser beam, in the target, in the interaction between the laser light and the plasma, and in the fusion process. Some of the technologies provided spin-off advances, such as improved medical technologies, femtosecond laser machining, and techniques for using extreme ultraviolet light for lithography to produce faster computer chips (see Year 1999).

Nova served as the proving ground for the 192-beam National Ignition Facility (NIF). Achievements on Nova helped scientists to convince the Department of Energy of the viability and probable ultimate success of achieving thermonuclear ignition on NIF (see Year 1997).

Nova Shutdown

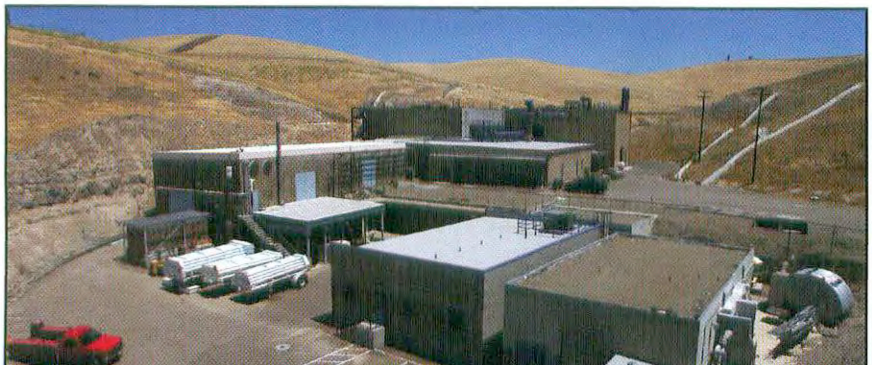
An era ended at the Laboratory in May 1999 when Nova fired its last shot. After 14 years and more than 14,000 experiments, Nova sent its last 10 beams of light down its 280-meter tubes in an experiment for the Stockpile Stewardship Program.

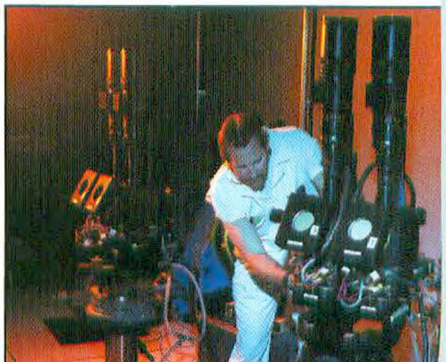
"It was very much a bittersweet moment," said Kim Budil, Laser Programs physicist and lead experimenter on the final shot. "The excitement of the shot was dampened by the realization that this was absolutely the last experiment we would ever perform with Nova."

"Nova has been an extremely successful facility," said John Emmett, associate director for Laser Programs when Nova was designed and built. "It's been a lot more productive than anyone thought it would be."

Nova was dismantled and some parts were shipped to other research facilities for their laser fusion and science programs.

1985 BUNKER 801





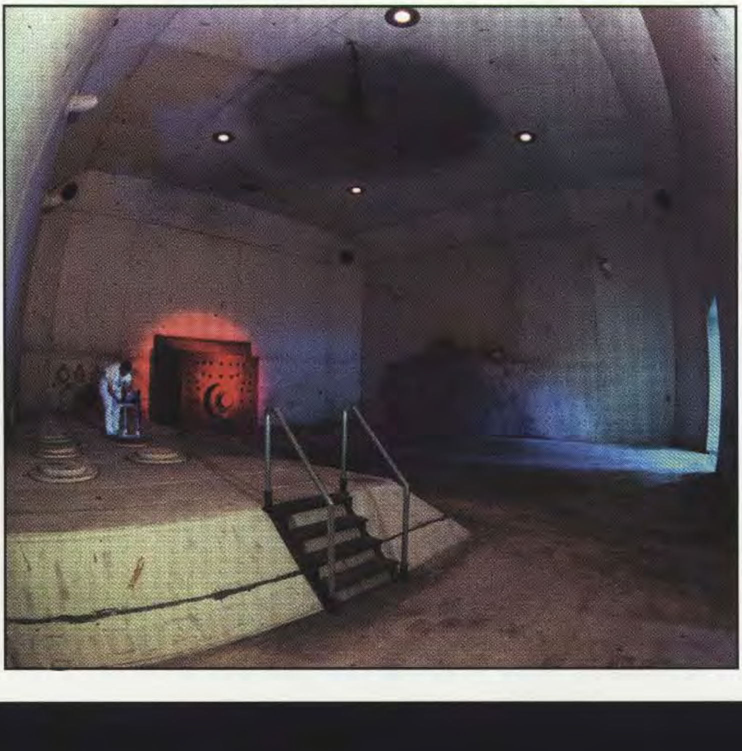
Improving Implosion Images

In 1985, Livermore completed the Bunker 801 project to upgrade what was in fact the very first facility (then called Bunker 301) at Site 300, the Laboratory's remote experimental test site. The newly refurbished bunker—actually a complex of protected enclosures, largely underground—became a fully modernized hydrodynamic test facility to gather data crucial for assessing the operation of a nuclear weapon's primary stage. Until project completion, weapon designers relied largely on technologies from the 1960s for much of their hydrodynamics experimentation.

After the upgrade, Bunker 801 contained the most modern diagnostics available. They included a Fabry–Perot interferometer to measure the velocity of explosion-driven surfaces, 10 high-speed cameras to capture the progressive movement of a pit's outer surface, and an electrical-probe diagnostics system for recording data from hundreds of shorting pins that time the arrival of the interior surface. Additionally, an important diagnostic tool was the Flash X Ray (FXR), a 16-megaelectronvolt linear-induction accelerator (see Year 1960 on the development of linacs). Electrons from the FXR strike a target to produce an intense burst of x rays, which are used to image a mock nuclear weapon primary as it implodes. Built between 1978 and 1982, the FXR produced five times the x-ray dose of previous machines in one-third the pulse length. Much denser objects could be radiographed and with less blur because of the shorter pulse.

Continual upgrades to Bunker 801 since 1985 have kept the facility equipped with the most modern capabilities. For example, in the 1990s, Laboratory scientists and engineers improved the beam quality of the FXR so that a higher overall x-ray dose is produced. More recently, a double-pulse feature was added to take two radiographs in one experiment. In addition, the Laboratory developed a gamma-ray camera to record the radiographic images produced. The system is 70 times more sensitive than the radiographic film it replaced. With these upgrades, scientists in 1998 were able to carry out the first "core punch" experiments on mock pits for two stockpiled weapons—the W76 submarine-launched ballistic missile warhead and the B83 strategic bomb. In core punches, images are obtained of the detailed shape of the gas cavity inside a highly compressed pit.

In 2001, Bunker 801 became the Contained Firing Facility after another major upgrade, the addition of a firing chamber to the complex. The debris from test explosions is contained in a more environmentally benign manner than ever—dramatically reducing particle emissions and minimizing the generation of hazardous waste, noise, and blast pressures. With walls up to 2 meters thick and protected by steel plating, the firing chamber is designed to withstand repetitive tests that use up to 60 kilograms of high explosives.



Before completion of the Contained Firing Facility in 2001, tests at the Bunker 801 complex were conducted outdoors (top left). Now the complex (far left) includes an indoor firing chamber (right), which will contain debris and minimize the environmental consequences of tests that use up to 60 kilograms of high explosives. The facility is equipped with the latest diagnostics, including electronic image-converter framing cameras (middle).

1986 W87

Strategic Warheads with Modern Safety Features

In March 1986, the first production unit of the W87 warhead for the Peacekeeper intercontinental ballistic missile (ICBM) was completed at the Pantex plant in Amarillo, Texas. This event culminated a four-year advanced development program executed by the Laboratory in close coordination with Sandia National Laboratories, the Air Force and its contractors, particularly AVCO, which was responsible for the Mk21 reentry vehicle. Peacekeeper carries 10 independently targetable Mk21 reentry vehicles with W87 warheads.

The W87 design is unique for strategic ballistic missile systems in its use of an insensitive high explosive (see Year 1976) and a fire-resistant pit design; both features help to minimize the possibility of plutonium dispersal in the event of an accident. First incorporated in Livermore's W84 warhead design for the ground-launched cruise missile, a fire-resistant pit includes in the weapon primary a metal shell that is able to keep molten plutonium contained. Both the W84 and W87 also include detonator strong links that provide additional safety assurance.

The enhanced safety design features of the W87 were incorporated at an early stage of the development program when Air Force plans called for Peacekeeper, at that time known as MX, to be based in the Multiple Protective Shelter mode. To improve missile survivability in an attack, a large number of moderately hardened shelters would be built, and the ICBMs would be clandestinely shuttled among them, forcing an attacker to target all shelters or to guess which held a missile. Although this plan was later abandoned in favor of basing the missile in Minuteman silos, the enhanced safety features were included in the W87 because they were accommodated within the weight allowance and they provided additional insurance against plutonium dispersal if an accident occurs during operations.

Engineering tests supported the development of the W87 warhead for the Peacekeeper missile, which carries 10 Mk21 reentry vehicles with W87s. Through an ongoing Stockpile Life Extension Program, W87 warheads are being refurbished to extend their long-term use on Minuteman III ICBMs.

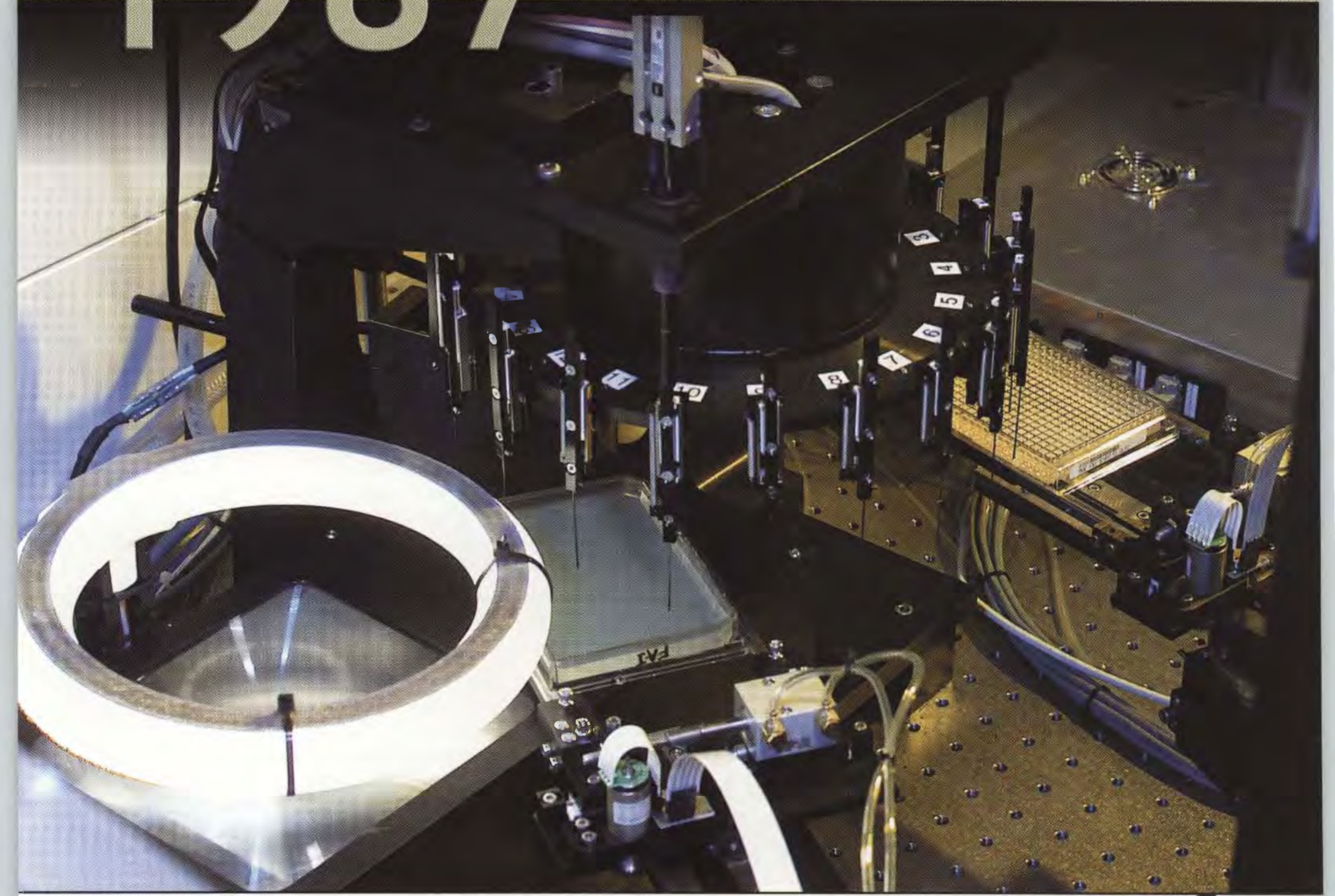
The U.S. has decided to retire Peacekeeper ICBMs and to deploy a large fraction of its W87 warheads on Minuteman III missiles. To prepare for long-term continuing deployment of the W87, a Life Extension Program for the W87 was initiated in 1995 to make some mechanical modifications. The first refurbished warhead under this program was produced in 1999, with all units to be completed in 2004. Extensive ground and flight testing together with detailed calculations using the newly available Blue Pacific supercomputer preceded formal certification of the refurbished W87s in April 2001. Certification without nuclear testing was an important early demonstration of new capabilities developed under the Stockpile Stewardship Program.

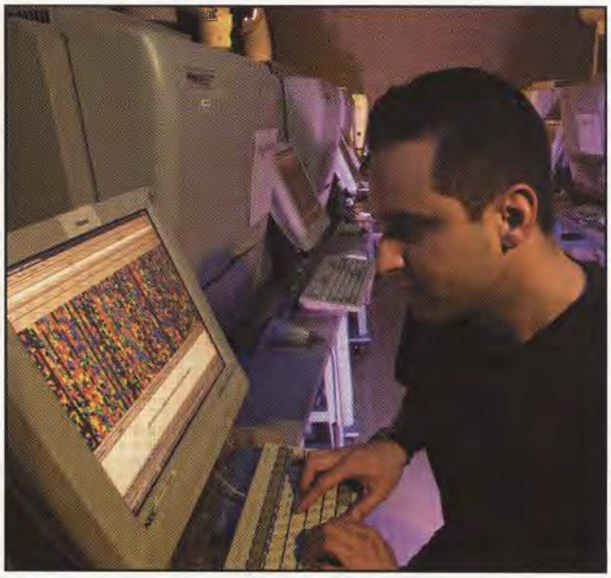
Studies of MX Basing

In 1982, President Reagan set up a commission led by Professor Charles M. Townes (University of California at Berkeley) to evaluate basing options for the MX missile. The commission sought input from a variety of sources, including weapon systems analysts from Livermore's D Division.

Upon conclusion of the study, Townes wrote to University President David Saxon: "It was clear that most of the industrial organizations were quite cautious about giving information or making conclusions which would be contrary to Pentagon policy. I was personally impressed that the many persons who helped us from Livermore seemed completely objective in examining the technical facts, in investigating what needed to be looked into, and in being willing to state plainly, though diplomatically, where they did not agree. . . . I make the above point because I think, contrary to some opinions, Laboratory personnel are often important in giving helpful perspective and ameliorating U.S. nuclear policy, and that this is partly because they are protected by the management structure from the obvious pressures to which commercial or governmental laboratories are subjected."

1987 HUMAN GENOME PROJECT





The sequencing process at the Joint Genome Institute (JGI) has numerous steps, four of which are shown here: Colonies of cells containing human DNA are selected from a cell culture plate (above). The CRS robot system (upper right) places a DNA sample plate onto a plate washer for purification of the DNA. A JGI researcher (lower right) removes a plate of purified DNA from a plate washer. A JGI research technician (far right) reviews the sequencing data produced by one of JGI's 84 DNA capillary sequencers.

Deciphering the Human Genetic Code

In 1987, Livermore biomedical researchers began studying chromosome 19. At the same time, Los Alamos began work on chromosome 16 while Lawrence Berkeley was considering decoding chromosome 5. Work had begun in what grew to be an international effort to decode the human genome.

Livermore's involvement in genetic research stretches back almost to its first biological program, chartered in 1963 to study the radiation dose to humans from radiation in the environment (see Year 1963). A natural extension was to explore how radiation and chemicals interact with human genetic material to produce cancers, mutations, and other adverse effects. The Laboratory's work on chromosome 19 dates to a project that examined three genes on chromosome 19 involved in the repair of damaged DNA. By 1984, Livermore and Los Alamos were working together to build human chromosome-specific gene libraries. Advanced chromosome-sorting capabilities, essential to the genome initiative, had been developed at both laboratories.

In 1984, the Department of Energy's Office of Health and Environmental Research (OHER) cosponsored a meeting in Alta, Utah, that highlighted the value of acquiring a reference sequence of the human genome. Leading scientists were invited by DOE OHER to a subsequent international conference, held in March 1986 in Santa Fe, New Mexico, where participants concluded that mapping and then sequencing the human genome were desirable and feasible goals. DOE became the first federal agency to commit to the goal by launching its Human Genome Initiative. This decision was endorsed in an April 1987 report by a DOE Biological and Environmental Research Advisory Committee, which noted that DOE was particularly well-suited for the task because of its demonstrated expertise in managing complex, long-term multidisciplinary projects.

In 1990, DOE joined with the National Institutes of Health and other laboratories around the world to kick off the Human Genome Project, the largest biological research project ever undertaken. Thanks to the commercial development of automated, high-throughput sequencing machines, a rough draft of the sequence of the entire 3 billion base pairs of our DNA—all 23 chromosomes—was completed in 2001, several years ahead of schedule. DOE's Joint Genome Institute (JGI), a sequencing production facility in Walnut Creek, California, sequenced chromosomes 5, 16, and 19. The JGI combines the efforts of Lawrence Livermore, Lawrence Berkeley, and Los Alamos national laboratories.

Since the completion of the draft human genome, the JGI has gone on to sequence mouse DNA, many microbes, and other organisms. The mouse is especially interesting because about 99 percent of its genes are similar to our own. The similarities indicate which parts of the genome are particularly important. A focus of continuing genetic research at the Laboratory, comparative genomics is a useful tool for studying the functions of genes, inherited diseases, and evolution.

Collaboration on Genetic Kidney Disorder

Laboratory bioscientists collaborate in the discovery of sources of genetic diseases. As an example, in 1993, researchers from Sweden and Finland had narrowed their search to chromosome 19 for the gene for congenital nephrotic syndrome, a usually fatal inherited kidney disease that occurs primarily in families of Finnish origin. They contacted the Laboratory for assistance. Livermore bioscientists expedited completion of a physical map of the genetic region in question and sequenced an area that contained 150,000 base pairs. The collaboration paid off. In 1998, researchers announced the breakthrough discovery of one particular gene that was mutated in the families carrying the disease, and the protein associated with the gene was well expressed in the kidneys.

1988 JOINT VERIFICATION EXPERIMENT

Heralding a new era of cooperation, U.S. and Soviet flags fly side by side atop the experiment tower at the Nevada Test Site during the first of two Joint Verification Experiments.

Reducing the Nuclear Threat

In 1988, a landmark event in U.S.–Soviet relations occurred when Soviet and U.S. teams for the first time conducted measurements of nuclear detonations at each other's nuclear testing sites. The event, called the Joint Verification Experiment (JVE), allowed Soviet and U.S. scientists to become more familiar with characteristics of the verification technologies that were proposed to monitor compliance with the Threshold Test Ban Treaty and the Peaceful Nuclear Explosions Treaty. The intent of both treaties was to limit the yield of nuclear explosions to no more than 150 kilotons.

Planning for the JVE took place in Geneva and at the two nation's nuclear test sites. A U.S. delegation made a familiarization visit to the Semipalatinsk Test Site early in January 1988, and a Soviet delegation visited the Department of Energy's Nevada Test Site a short while later.

Russian scientists were on hand to witness the Kearsarge event that was detonated August 17, 1988, on Pahute Mesa at the Nevada Test Site. As a symbol of international good faith and cooperation, the Soviet Union flag was raised to the top of the emplacement tower next to the U.S. flag.

Nearly 150 people from the U.S. traveled to the Semipalatinsk test site to participate in the preparation of the Shagan test on September 14, 1988. Forty-five U.S. personnel witnessed the event, standing just 4 kilometers from the test ground zero.

Both nuclear tests were in the yield range of 100 to 150 kilotons of explosive power. Livermore personnel were heavily involved in fielding the two explosions, with the Laboratory contributing equipment, instrumentation, and technical advice.

For each of the two tests, both sides made hydrodynamic yield measurements in the emplacement hole and in a satellite hole located about 11 meters from the emplacement hole. U.S. scientists carried out CORRTEX (continuous reflectometry radius versus time experiment) measurements. CORRTEX is a technology that measures nuclear yield based on close-in observations of the velocity of the shock wave generated by the nuclear explosion. The Soviets made CORRTEX-like measurements as well as a hydrodynamic measurement using switches. The satellite holes at the test sites were drilled by U.S. personnel with U.S. equipment because of a professed Soviet lack of such capability.

JVE was a turning point in Soviet relations with the West. Many American–Russian friendships were forged, and the more open atmosphere anticipated the post–Cold War era. Since the collapse of the Soviet Union, Laboratory scientists have traveled thousands of miles between Livermore and Russia and the newly independent states. They have monitored and assisted the progress of arms reductions; pursued cooperative efforts to better protect, control, and account for nuclear materials; and collaborated with scientists on nonweapons-related projects.

Associate director J. I. Davis leads a tour of the Nova laser for senior managers from Arzamas and Chelyabinsk (the Russian counterparts to Los Alamos and Livermore) as part of a groundbreaking series of U.S.–Russian lab visits in 1992.

Livermore leads the U.S. team that works with the Russian Navy and Icebreaker Fleet to improve the security of nuclear fuel for their nuclear-powered vessels.

1989 COMPUTING IN PARALLEL

First available from Bolt, Beranek and Newman Advanced Computers Inc. in 1989, the BBN-ACI TC-2000 had a multiprocessing architecture that allowed individual processors to be partitioned into clusters and dynamically reallocated. Because data could be shared within and between clusters, the computer was able to integrate distinct segments of a complex calculation.

Exploring the Future of Scientific Computing

In October 1989, the Laboratory Directed Research and Development office funded the ambitious Massively Parallel Computing Initiative (MPCI), which cut across directorates at the Laboratory and helped redefine high-performance computing as massively parallel computing. The exploratory work performed as part of the initiative—and comparable efforts at Los Alamos and Sandia national laboratories—paved the way for the Accelerated Strategic Computing Initiative (or ASCI, now the Accelerated Simulation and Computing program), which is a vitally important part of the Stockpile Stewardship Program.

Led by Eugene D. Brooks III, the three-year initiative explored the relevance to Laboratory computer applications of then-accelerating trends in commercial microprocessors. Advances in very large-scale integration had increased both computer chip speed and reliability so much that massive, coordinated clusters of microprocessors were sometimes rivaling the performance of custom-designed supercomputers. For example, early tests here with radiation transport codes (used in weapons simulations) suggested a factor of 20 advantage for the massively parallel approach.

In 1990, the MPCI project acquired Livermore's first substantial, onsite massively parallel resource, a 64-node BBN-ACI TC-2000 machine that was upgraded to a full 128-node configuration a year later. Scientists from across the Laboratory's technical directorates probed the software development challenges of effectively using this new architecture by running a variety of computer problems on the MPCI machine. By 1992, early results were already available in such diverse areas as particle-physics event simulation, multidimensional numerical analysis, parallel graphics rendering algorithms, and sedimentation modeling. Each MPCI annual report not only encouraged use of this new approach to scientific computing but also summarized the latest trial programming techniques and output evaluations for Laboratory researchers.

One rewarding long-term effect of the early MPCI work was a heightened desire to widely share centrally managed massively parallel computing resources among many unclassified projects at the Laboratory. In 1996, a formal Multiprogrammatic and Institutional Computing (M&IC) initiative began providing fast, high-capacity parallel computers to program collaborators on and off site, managed by the Livermore Computing program. A Cooperative Research and Development Agreement between the Laboratory and Compaq Computer Corporation led to further design improvements and to the delivery of serial number 1 of the M&IC Tera Cluster 2000 parallel computer in 2000.

The Laboratory's continued investment in such massively parallel computers, in addition to the supercomputers acquired through ASCI, has repeatedly enabled unclassified simulations on groundbreaking projects that complement the classified ASCI work. High-resolution modeling of the response of materials to extreme temperature and pressure, of the consequences of global warming and climate change, and of the interaction of proteins and genes have all resulted from software innovations developed using these parallel computational resources at Livermore.

CIAC: Keeping Cyberspace Safe

On February 1, 1989, the Department of Energy formed the Computer Incident Advisory Capability (CIAC) at Livermore. A continuous stream of security incidents had begun the previous year, affecting computer systems and networks throughout the world. Crackers and intruders made bold headlines with their stealthful entry into government computers, commercial equipment, and telephone systems. The world of computers was proving to be a dangerous one, and clearly something needed to be done. CIAC's primary mission has been to help and protect the DOE computer community. The list of federal clients has grown to encompass other agencies, and in several instances, CIAC has worked with the Federal Bureau of Investigation to respond to incidents.

The Nineties

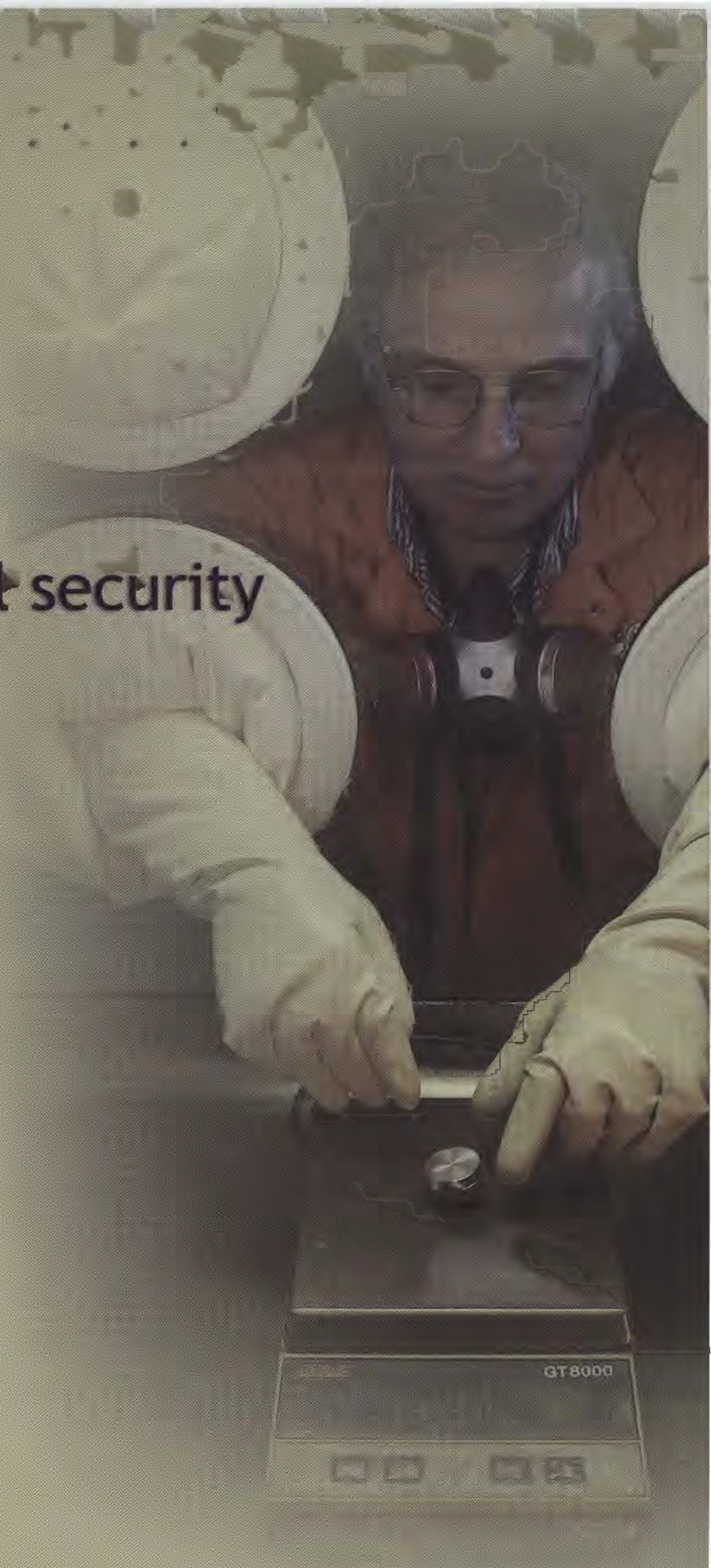
New Leadership

C. Bruce Tarter
(1994•2002)

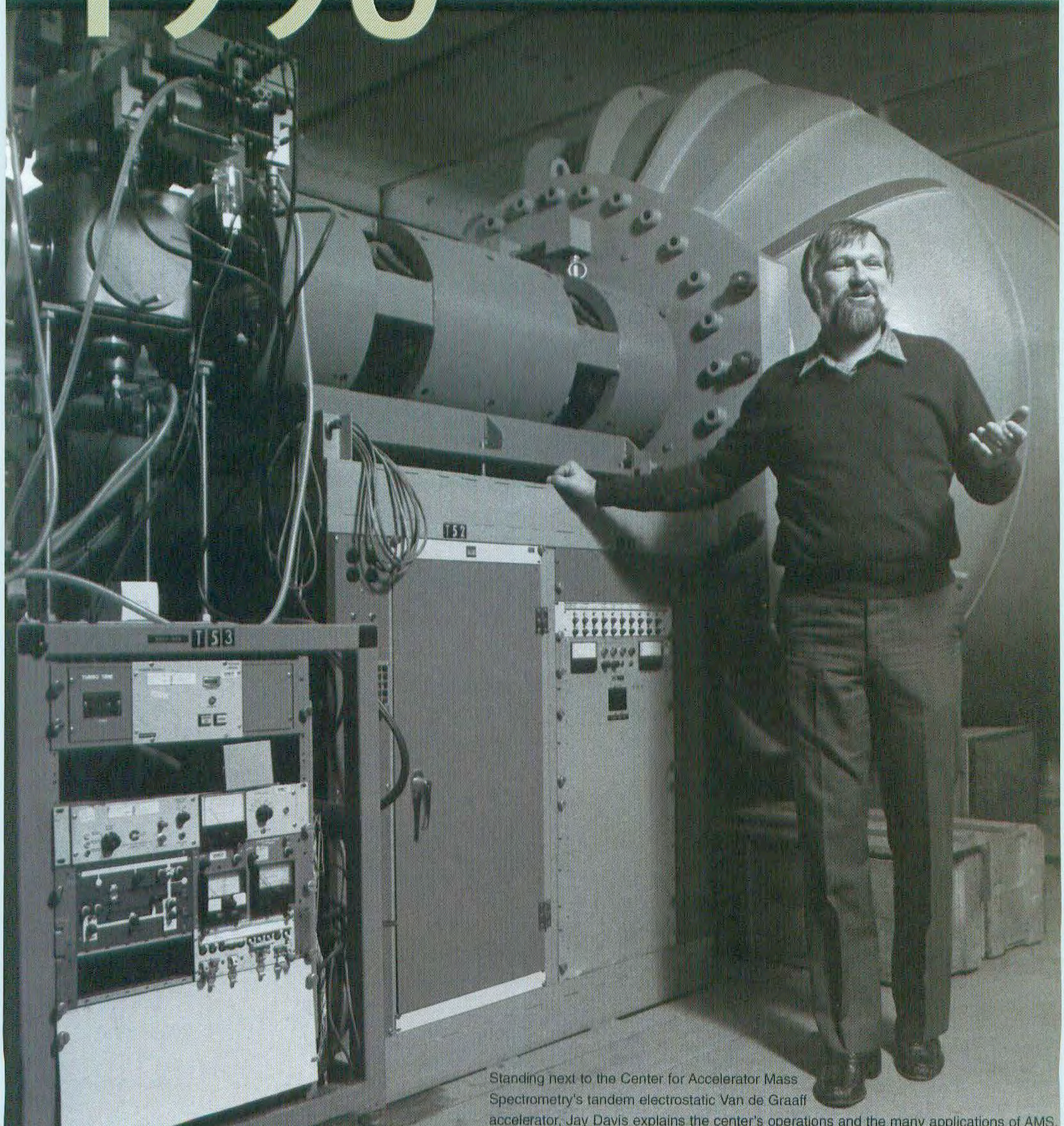
The Berlin Wall came down in 1989, the Cold War ended, and significant reductions were being made in strategic arsenals. Both the Soviet Union and the United States entered a nuclear testing moratorium in 1993 while recognizing an important continuing role for nuclear weapons in the post–Cold War world. The United States formally began its Stockpile Stewardship Program to maintain a safe, secure, and reliable nuclear deterrent in 1995. As a National Nuclear Security Administration laboratory, Livermore is a principal contributor to the program.

A focus on national security

In the post–Cold War world, the Laboratory broadly contributes to the nation's science and technology base, but its defining mission remains national security. That mission is broader than stockpile stewardship. The invasion of Kuwait in 1990 and the subsequent discovery of aggressive Iraqi programs to develop weapons of mass destruction made clear that the world remained a dangerous place—complicated by the uncertain status of nuclear weapons and materials in a fragmented Soviet Union. Livermore responded by quickly expanding its analysis and technology-development program to prevent proliferation at its source, detect and reverse proliferant activities, and respond to the threat or use of weapons of mass destruction.



1990 CENTER FOR ACCELERATOR MASS SPECTROMETRY



Standing next to the Center for Accelerator Mass Spectrometry's tandem electrostatic Van de Graaff accelerator, Jay Davis explains the center's operations and the many applications of AMS.

Detecting One in a Quadrillion

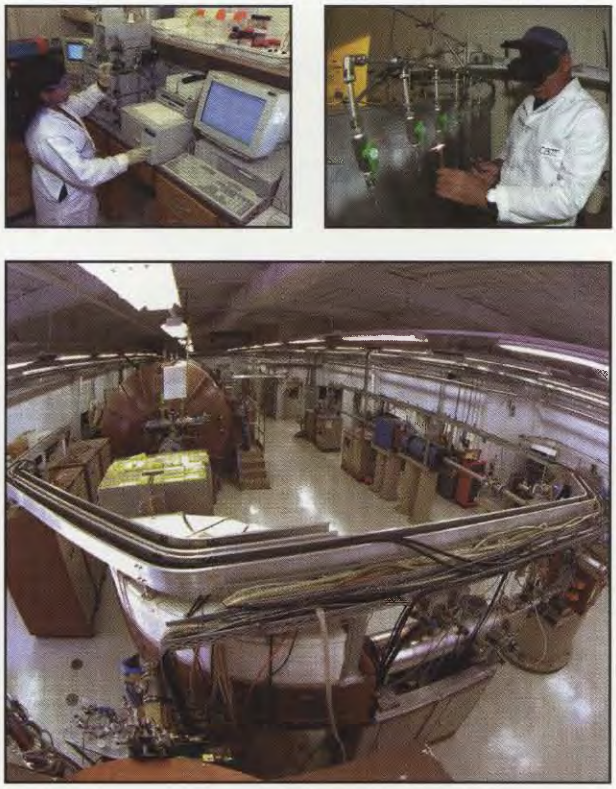
In 1990, soon after the Center for Accelerator Mass Spectrometry (CAMS) started operations, the first biomedical experiment using AMS was performed at Livermore. It measured the effects on rat DNA of a suspected carcinogen that results from cooking meat. From the beginning, CAMS was proving to be a highly versatile research facility, contributing to the success of a wide range of Laboratory programs and the research projects of many external users.

AMS is a sensitive technique for measuring concentrations of specific isotopes in very small samples—able to seek out, for example, one carbon-14 isotope out of a quadrillion (million billion) other carbon atoms. The technique enables Laboratory researchers to diagnose the fission products of atomic tests and monitor the spread of nuclear weapons to other countries by detecting radioisotopes in air, water, and soil samples. In addition, AMS supports studies in environmental quality, climate change, seismology, archaeology, biomedical science, and many other areas of scientific research.

The need for a multiuser AMS capability was recognized by Jay Davis, who at the time was a division leader, and he "sold shares" in the new accelerator facility to programs throughout the Laboratory, promising to get the facility built if they would help pay to run it. Additional support came in the form of one of Livermore's first large-scale initiatives in its Laboratory Directed Research and Development program. Davis also sold the idea to The Regents of the University of California (UC), winning funding from them in January 1987 to help support construction and continuing use of CAMS by UC faculty. To help lower costs, the designers used as many spare components as they could find. The accelerator came from the University of Washington, and a couple of the largest magnets had previous lives in an electron beam accelerator at Stanford University.

Established in 1988, CAMS was unique from the start because of the use of high-quality beam optics and a computer-control system that allows large numbers of high-precision measurements to be taken. The capabilities exceeded those of other AMS facilities because of the particularly demanding needs of the Laboratory's programs. An initial optimistic projection was that CAMS could someday handle 5,000 to 10,000 measurements in a year. Today, CAMS analyzes some 30,000 research samples annually—accounting for approximately one quarter of the worldwide AMS analyses performed per year. The center's scientists are participants in approximately 70 collaborative research projects with universities worldwide.

CAMS recently added a much smaller spectrometer that is dedicated to analyses of carbon-14 for biomedical and environmental research. In addition, the center operates a nuclear microprobe that has been used to develop pioneering applications in bioscience and environmental research. Since 1999, CAMS has been designated by the National Institutes of Health (NIH) as a National Research Resource for biomedical applications of AMS. It is midway through a five-year NIH grant that makes CAMS available to biomedical researchers around the world.



CAMS began operation in 1989 and now processes nearly 30,000 samples per year for its users (above). A recent addition to AMS capability at the Laboratory is a smaller spectrometer (not shown) dedicated to biomedical analyses.

1991 IRAQ INSPECTIONS


Laboratory engineer Bill Nelson inspects the bombed-out reactor and nuclear research facilities at Tuwaitha (just outside Baghdad) during the first inspection after Desert Storm.

Inspecting for Weapons of Mass Destruction

At the end of Operation Desert Storm, the world was full of rumors about Iraq's nuclear capabilities and how much of them remained following an intense bombing campaign. In May 1991, a specially selected team, under the auspices of the United Nations Special Commission (UNSCOM) and the International Atomic Energy Agency (IAEA), was assembled for the first inspection of Iraqi nuclear facilities under UN Security Council Resolution 687. Laboratory engineer Bill Nelson was a member of that team.

The first and subsequent UNSCOM/IAEA inspections uncovered evidence of an advanced Iraqi nuclear program, code-named Petro-Chemical Project 3. At Tarmiya, inspectors uncovered Project 946, a uranium enrichment production facility that the Iraqis attempted to hide by removing railings from the floor of the building, pouring a new layer of concrete, and putting rubble on top. They had developed a first-class electromagnetic isotope separation capability, with supporting research and industrial infrastructure. Production of 10 to 30 kilograms of highly enriched uranium, a key component of nuclear weapons, might have occurred within two years.

Perhaps the defining moment came in September 1991, when UNSCOM/IAEA Team 6 discovered a large cache of documents. Two Laboratory scientists were on the team; another was at the UN supporting the operation. For five days, there was a standoff in Baghdad between the team of inspectors, which wanted to remove the documents from where they were found, and hundreds of heavily armed Iraqi soldiers. Sleeping on pieces of cardboard in the building's parking lot and sometimes without even water, the group refused to leave without the papers they considered to be the smoking gun. The documents indeed proved critical in establishing a knowledge baseline of the Iraqi program.

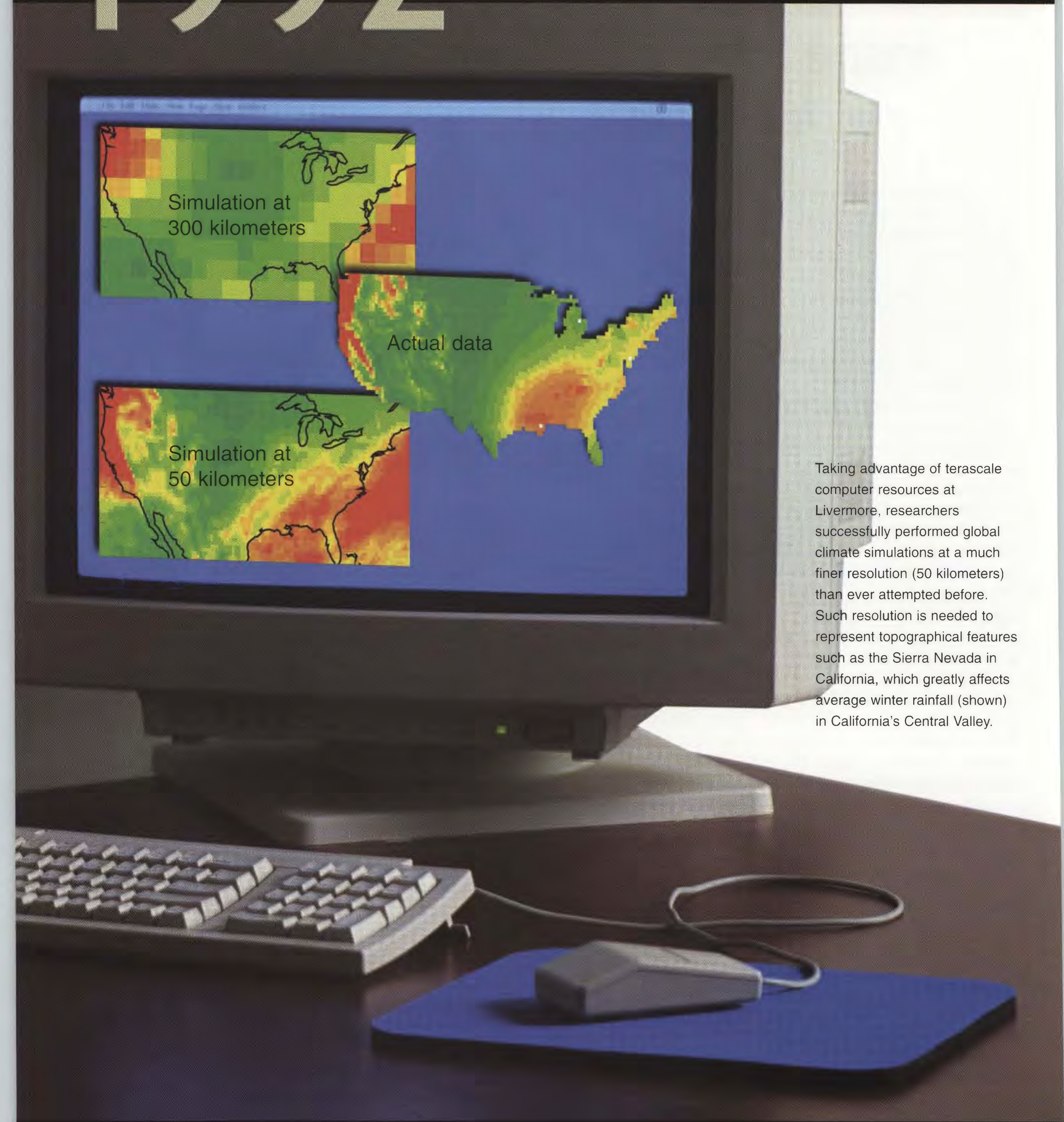
Iraqi facilities were inspected for any evidence of weapons of mass destruction—not just nuclear, but also chemical and biological weapons and ballistic missiles—and equipment was destroyed, seized, or subjected to monitoring. In all, over a dozen Laboratory researchers took part in various inspections until the UN removed all personnel in 1998 because of an increasingly hostile atmosphere. Livermore scientists also developed, installed, and maintained sophisticated inspection and monitoring equipment in Iraq, such as automated cameras and microwave communication links for remote surveillance of facilities that could be used in missile production.

Livermore continues to provide technology, analysis, and expertise to help prevent the spread or use of weapons of mass destruction. Soon after the Iraq inspections began, Laboratory Director John Nuckolls formed the Nonproliferation, Arms Control, and International Security (NAI) Directorate. The new directorate merged a variety of related activities into a comprehensive program to address all steps in the nonproliferation process, including prevention, detection and reversal, and response to potential proliferant states and terrorists.

Iraqi Calutrons

Laboratory physicist Jay Davis, twice a member of UNSCOM/IAEA inspection teams, found the Iraqi isotope separation technology was similar to that developed at the University of California (UC) at Berkeley in the late 1940s to enrich uranium for America's first atom bomb. Called the calutron because of its UC origin, the technology was abandoned by the U.S. because of cost. However, it was an excellent choice for Iraq in that calutrons required few outside resources. Davis estimated the Iraqi Manhattan Project-style effort at between 6 billion dollars and 8 billion dollars and noted that the quality of work was "every bit as good as we could do today."

1992 SETTING MODEL STANDARDS



Taking advantage of terascale computer resources at Livermore, researchers successfully performed global climate simulations at a much finer resolution (50 kilometers) than ever attempted before. Such resolution is needed to represent topographical features such as the Sierra Nevada in California, which greatly affects average winter rainfall (shown) in California's Central Valley.

Better Global Climate Models and Analysis

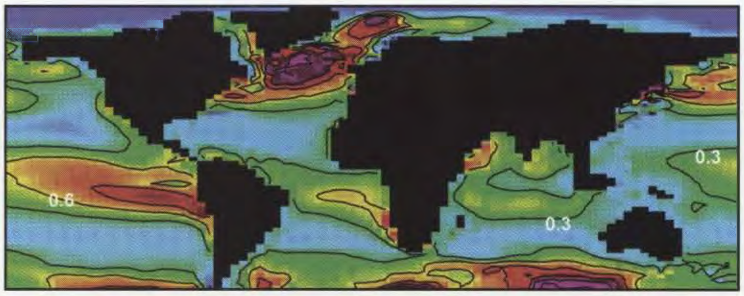
In 1992, Laboratory atmospheric scientist Larry Gates issued *The Validation of Atmospheric Models*, the first of a continuing series of reports that would radically alter global climate change research and the way models characterize climate. The report came five years after Gates, an atmospheric science professor at Oregon State University, had come to the Laboratory on a sabbatical. One year later, Gates and fellow atmospheric scientists formed a new group at the Laboratory—the Program for Climate Model Diagnosis and Intercomparison (PCMDI).

PCMDI quickly became an internationally recognized institution for climate model analysis. The program integrates the talents of physical (atmospheric) scientists and computer scientists, following the approach of other interdisciplinary programs at Livermore. PCMDI's mission is not to make new models but rather to set a standard by which all climate models adhere so as to lend validity to the models themselves. The ultimate goals are to develop improved methods and tools for the diagnosis, validation, and intercomparison of global climate models and to conduct research on a variety of problems in climate modeling and analysis. PCMDI's software system is recognized around the world for its efficiency and flexibility.

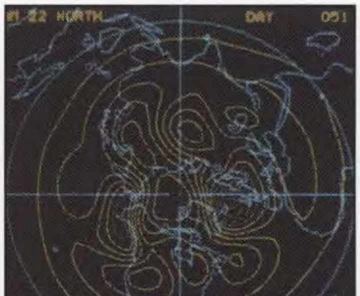
The need for standards in both modeling and analysis has become increasingly apparent as more complex models are developed. The disagreements among models and between models and observations remain significant and poorly understood. The nature and causes of these conflicts must be accounted for in a systematic fashion before models can be confidently used for climate prediction studies in support of global change research.

PCMDI's work goes beyond the nation's borders. The group is coordinating the Atmospheric Model Intercomparison Project (AMIP) on behalf of the Working Group on Numerical Experimentation of the World Climate Research Programme. In this project, some 30 international modeling groups are simulating the climate of the decade 1979–1988, and PCMDI is evaluating the results. In addition, PCMDI has extensively studied the effects of resolution on climate simulations performed with the European Centre for Medium-Range Weather Forecasts' atmospheric model.

Atmospheric scientists at PCMDI have also been key participants in international efforts examining the evidence for climate change due to human activities. Ben Santer, who received the prestigious MacArthur Foundation "genius award" in 1998, served as lead author for Chapter 8 ("Detection of Climate Change, and Attribution of Causes") of the *1995 Second Assessment Report of the Intergovernmental Panel on Climate Change*. The report concluded that "the balance of evidence suggests a discernible human influence on global climate." In addition, Santer and Karl Taylor have received awards for their work on global warming from the World Meteorological Organization.



Ocean circulation models are used to study northerly movement of the carbon dioxide soaked up by cold water in the Southern Ocean. Efforts are under way to develop an integrated climate and carbon-cycle model.



In the late 1950s, Laboratory physicist Cecil "Chuck" Leith and his group applied numerical methods used for weapon physics to develop the first global general circulation model, able to simulate the behavior of large weather systems. Results were displayed in a movie (left) of the model's weather on a map centered at the North Pole.

1993 DYNAMIC UNDERGROUND STRIPPING

Dynamic underground stripping cleans up underground hydrocarbon spills. The method is used in combination with other Livermore-developed monitoring and remediation technologies to rapidly remove contaminants from groundwater or destroy them in place.

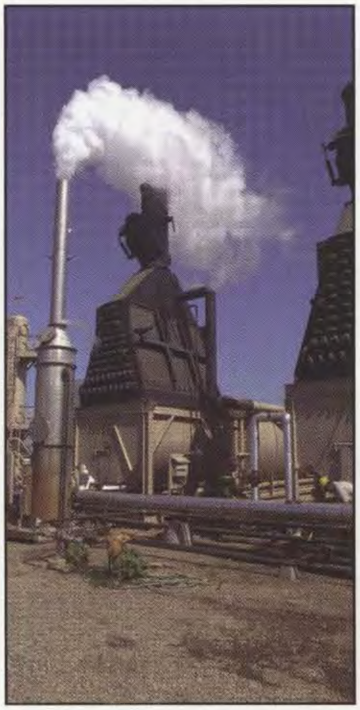
Hot Technology Removes Contamination

If the Laboratory had used conventional methods in 1993 to clean major leaks from its underground gasoline tanks, the project would still be under way. Estimates had pegged the time at 30 to 60 years to remove thousands of gallons of gasoline that had leaked into the soil beneath the shipping and receiving area north of East Avenue. But instead of decades or even years, the 7,600 gallons of gasoline were mopped up in about four months using remediation technologies developed by Laboratory scientists Roger Aines, Robin Newmark, and John Ziagos in collaboration with a University of California at Berkeley researcher.

The technique, called dynamic underground stripping, involves injecting steam to heat the ground. Contaminants are vaporized and driven to extraction wells, where they are easily removed from soil and water. The heat and forced air chemically break down many contaminants in place, leaving harmless compounds. Electric currents heat soils that are too impermeable for steam to penetrate. The treatment of contaminants is even more effective when dynamic underground stripping is combined with two related remediation technologies subsequently pioneered by Livermore researchers: electrical resistance tomography, for monitoring an underground clean-up in real time; and hydrous pyrolysis/oxidation, which destroys pollutants where they are found underground.

Department of Energy officials have estimated that the Livermore-developed environmental technology has the potential to remediate up to one-quarter of the nation's 1,300 Superfund sites. Already, the technology has achieved remarkable success cleaning a Superfund site in Visalia, California, between 1997 and 1999. For nearly 60 years up to 1980, Southern California Edison had treated utility power poles with carcinogenic wood preservatives such as creosote and pentachlorophenol, some of which leaked into the ground. Using older clean-up methods at Visalia, about 275 pounds of contaminants had been removed in one nine-month period. However, with the use of the Livermore technology, Southern California Edison, working with the Laboratory and a licensee, was able in a similar nine-month period to pull about 540,000 pounds of pollutants—almost 2,000 times more. During the entire three-year Visalia clean-up, about 1.2 million pounds of contaminants were removed from the four-acre site using the dynamic underground stripping technology. Now many sites that were considered uncleanable like Visalia are being considered for the steam approach.

To date, three California companies—SteamTech Environmental Services of Bakersfield, Southern California Edison of Rosemead, and Integrated Water Resources Inc. of Santa Barbara—have licensed the Livermore environmental technologies. Beyond the Visalia clean-up project, these three companies have or will be using the dynamic underground stripping technologies to clean nine U.S. sites contaminated with difficult underground pollutants. The sites include Cape Canaveral, DOE's Savannah River Site and Pinellas Plant, and Beale Air Force Base.



Two complementary technologies pioneered at Livermore are successfully cleaning up contaminated groundwater and soil at facilities in several states. Hydrous pyrolysis/oxidation combined with dynamic underground stripping are destroying contaminants in situ as well as bringing them to the surface at 5,000 times the rate of other technologies.

1994 CLEMENTINE

A mosaic of 1,500 images taken by Clementine reveals for the first time a 300-kilometer-wide depression near the Moon's lunar south pole.

Using six on-board cameras designed and built at the Laboratory, the *Clementine* satellite mapped the entire surface of the Moon in 1994 at resolutions never before attained.

Advanced Sensors Map the Moon

The Clementine Deep Space Experiment, sponsored by the Ballistic Missile Defense Organization, was launched on January 25, 1994—22 months after the effort began. At a mission cost of less than $100 million, it was the first U.S. spacecraft to visit the moon in over two decades. The Clementine mission collected over 1.7 million images during its two months in lunar polar orbit. The data has enabled global mapping of lunar-crust rock types and the first detailed investigation of the geology of the lunar polar regions and the lunar far side.

The *Clementine* spacecraft included new advanced technology sensors and space component technologies that provide the basis for a next generation of lightweight satellites for civilian and military missions. It incorporated 23 advanced subsystem technologies and had a dry mass of only 500 pounds. The spacecraft's payload consisted of an advanced sensor suite weighing less than 16 pounds that was designed, fabricated, integrated, and calibrated by Laboratory scientists and engineers with the support of industrial contractors. The Naval Research Laboratory designed, integrated, and operated the spacecraft. NASA provided mission design and operational support.

Clementine carried an ultraviolet-visible camera, a shortwave infrared sensor, a longwave infrared sensor, an imaging lidar (light detection and ranging) instrument, and two Star Tracker cameras. These instruments successfully mapped the entire lunar surface in 11 spectral bands. By laser ranging, the lidar system also generated a global topographical data set. The topography of the moon's many ancient impact basins was measured, and a global map of the thickness of the lunar crust was derived. In addition, bistatic radar measurements made over the Deep South polar depression indicated the presence of frozen water on the moon.

Sensor system technologies were derived from Livermore's space-based interceptor development program. The Strategic Defense Initiative Organization (SDIO) funded related research beginning in 1985, and in November 1987, the Brilliant Pebbles effort formally commenced. The concept was to deploy a constellation of sophisticated, inexpensive, lightweight spacecraft in low Earth orbit—Brilliant Pebbles—that could detect and hunt down missiles over distances of thousands of kilometers without external aid. In the summer of 1989, Brilliant Pebbles was adopted by SDIO as the new baseline for the space-based segment of a national missile defense system.

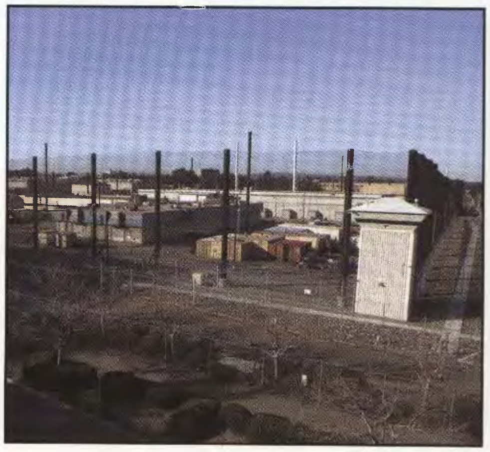
A wide variety of projects to develop state-of-the-art sensor technologies at the Laboratory are building on the success of the Clementine program. One example is the development of a large-format digital camera system that uses charge-coupled device detectors. The 16-million-pixel cameras have been used by astronomers in the search for massive compact halo objects (MACHOs), a form of dark matter.

O Group

Under the leadership of physicist Lowell Wood, O Group pursued a variety of imaginative research projects in the late-1970s and the 1980s. O Group included many extremely talented young scientists, some of who came to the Laboratory as Hertz Foundation fellows. An exceedingly ambitious early project was the design of the S-1 supercomputer, an effort which led to the development of computerized design methods, including Structured Computer-Aided Logic Design (SCALD), that successfully spun-off from the Laboratory. O Group pioneered the development of x-ray lasers and gave birth to the concept of Brilliant Pebbles.

Lowell Wood presented President George Bush with a conceptual model of Brilliant Pebbles when the President visited the Laboratory in 1990.

1995 STOCKPILE STEWARDSHIP



The Livermore Superblock (far left) is home to one of only two defense plutonium research and development facilities in the U.S. For the nation's Stockpile Stewardship Program, trained fissile material handlers prepare samples for nonnuclear tests (left), conduct experiments to study the properties of plutonium, and examine parts of selected weapons from the stockpile for signs of aging (above).

Understanding the Details of Nuclear Weapon Performance

In 1995, the Stockpile Stewardship Program formally began when President Clinton reached two critical decisions that established the course for future nuclear-weapons activities in the United States. At the time, both the U.S. and Russia were reducing the size of their nuclear arsenals, both nations had been observing a moratorium on nuclear testing for three years, and the U.S. had halted its programs to develop new nuclear weapons.

First, on August 11, 1995, the President announced that the U.S. would pursue a Comprehensive Nuclear Test Ban Treaty. In making that decision, he also reaffirmed the importance of maintaining a safe and reliable nuclear weapons stockpile. Then, on September 25, 1995, the President directed necessary programmatic activities to ensure continued stockpile performance. Under the leadership of Vic Reis, the Department of Energy's Assistant Secretary for Defense Programs, DOE national security laboratories and the weapons production facilities worked with DOE Defense Programs and the Department of Defense to formulate the Stockpile Stewardship Program.

The program was launched as an ambitious effort—not without risks—to significantly improve the science and technology base for making informed decisions about an aging nuclear weapons stockpile without relying on nuclear testing. All aspects of weapons must be understood in sufficient detail so that weapons experts can assess the performance of the nation's nuclear weapons with confidence and make informed decisions about refurbishment, remanufacture, or replacement of weapons as needs arise.

To succeed, the three DOE national security laboratories, now part of the National Nuclear Security Administration, needed much more advanced experimental and computational capabilities. At Livermore, the National Ignition Facility is under construction (see Year 1997), and new supercomputers are being acquired as part of the Advanced Simulation and Computing (ASCI) program (see Year 2000). As new capabilities are coming on line, they are contributing to surveillance of stockpiled weapons to determine their condition, assessment of weapon safety and reliability, activities to extend the lifetime of weapons, and certification of refurbished warhead systems. The new experimental and computational capabilities also are being used to train and evaluate the skills of the next generation of stockpile stewards, who depend on these tools to help maintain the nuclear stockpile.

To date, the Stockpile Stewardship Program is making excellent technical progress. For example, researchers are dramatically improving their understanding of the properties and aging of materials in weapons, and the sophistication and resolution of three-dimensional simulations of weapon performance are rapidly increasing. In addition, Livermore has successfully completed engineering development work on its first stockpile life-extension program (see Year 1986). However, many of the toughest challenges probably lie ahead as weapons continue to age. The long-term success of stockpile stewardship depends on a continuing strong national support for the program and on the skills and capabilities of future generations of weapons experts at the nuclear weapon laboratories.

Expansion of Livermore's computing power requires construction of the $92-million Terascale Simulation Facility (TSF), which began in April 2002 with a groundbreaking ceremony. The TSF is designed to accommodate a 60- to 100-teraops machine (ASCI Purple) that will move scientists closer to the goal of performing full-scale simulations of weapon performance based on first-principles physics. The TSF will also house a growing support staff and researchers who work on projects such as developing new tools to assimilate the vast amount of data generated.

1996 LASER GUIDE STAR

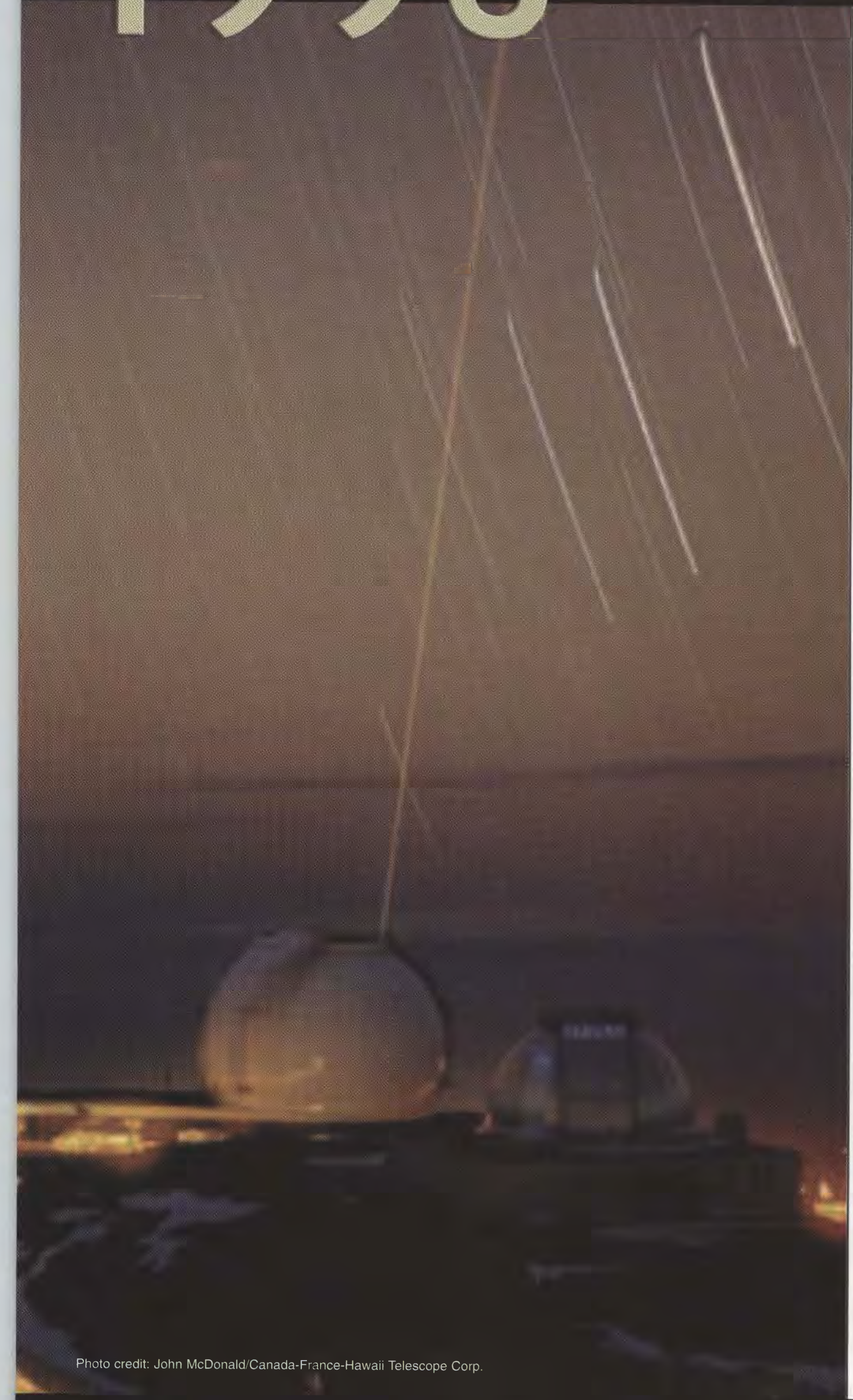
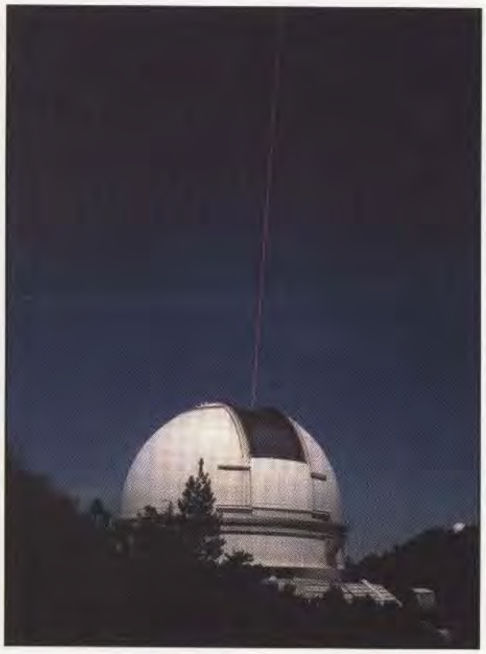


Photo credit: John McDonald/Canada-France-Hawaii Telescope Corp.

The Shane telescope's Livermore-developed adaptive optics subsystem (below and bottom) was the first such laser system on a major astronomical telescope. Adaptive optics were installed in the Keck telescope (left) in 1998, and in 2001, a laser guide star system was added.



Heralding a New Era in Astronomy

In September 1996, observers at University of California's Lick Observatory, atop Mount Hamilton near San Jose, California, obtained their first image that was significantly improved through use of a laser guide star and adaptive optics. The event heralded a new era in astronomy. Atmospheric distortions, which cause stars to twinkle and have haunted astronomers since Galileo, no longer need limit the performance of Earth-based telescopes.

Two years earlier, a Livermore-designed adaptive optics system was installed on Lick's 3-meter Shane telescope. To correct for atmospheric turbulence, an adaptive optics system uses a large number of computer-controlled actuators to precisely adjust the shape of a deformable mirror up to several hundred times per second. The technology has benefited from the efforts of many researchers, including the team at Livermore, which developed adaptive optics for use as part of the Atomic Vapor Laser Isotope Separation (AVLIS) program (see Year 1973). Adaptive optics are also central to the design of the lasers for the National Ignition Facility (see Year 1997).

The adaptive optics system alone benefits astronomers only if the object being studied has a sufficiently bright nearby star that can be used to determine the atmospheric distortions that must be corrected. In most cases, there is no such star, and one has to be created—a "laser guide star." The team of Laboratory and University of California researchers working on the Lick project, led by Livermore's Claire Max, installed a laser guide star system at Lick in 1996. A 15-watt dye laser system, a technology developed as part of the AVLIS program, was retrofitted onto the Shane telescope. Light from the laser reflects off a layer of sodium atoms in the upper atmosphere (about 100 kilometers altitude), creating the needed artificial star.

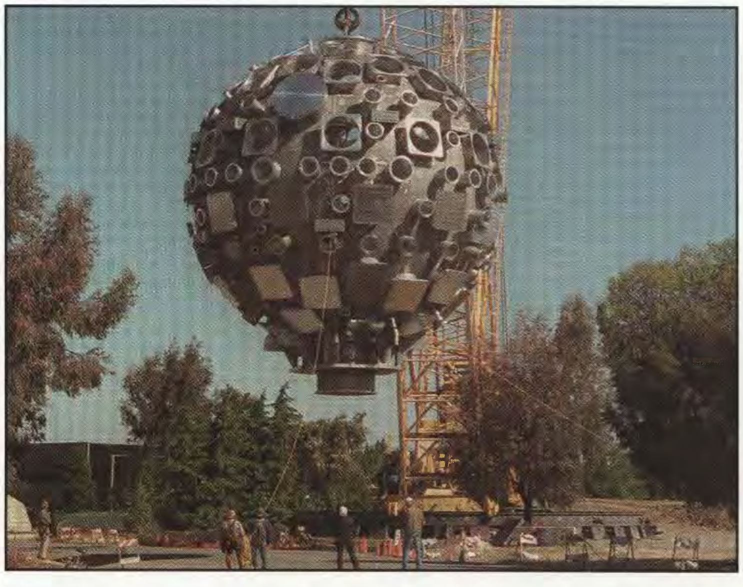
Subsequently, a team from Livermore, the University of California, and the California Institute of Technology installed adaptive optics and a laser guide star system on the 10-meter telescope at Keck Observatory in Hawaii. Since first observations in 1998, the adaptive optics have enabled astronomers to obtain infrared-light images of unprecedented resolution—four times better resolution than the Hubble Telescope's. For example, astronomers using the Keck telescopes have obtained the best pictures yet of Neptune. The images reveal a wealth of information about small-scale features in Neptune's atmosphere and suggest violent methane storms with wind speeds reaching more than 1,700 kilometers per hour.

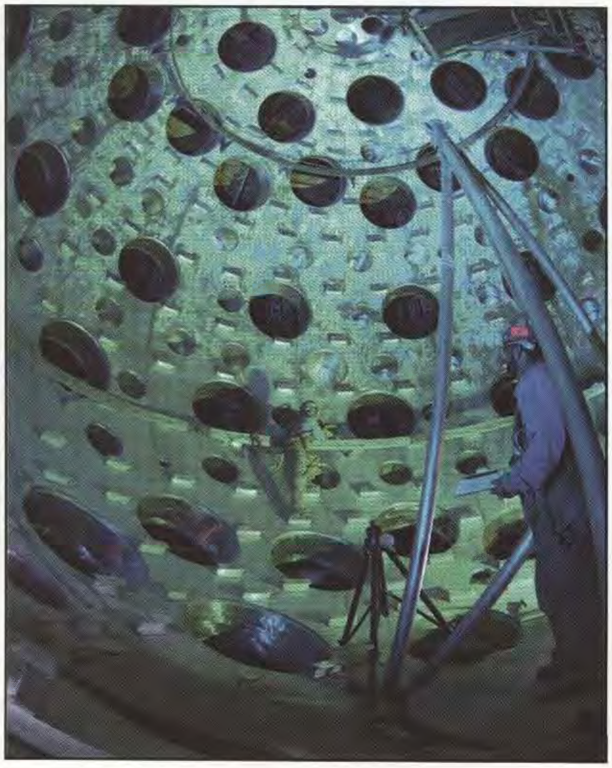
In December 2001, "first light" was achieved with a newly installed laser guide star system for Keck. When the laser guide star is fully integrated with adaptive optics systems in 2002, new frontiers of research and new kinds of observations—perhaps including images of a planet orbiting a distant star—will become possible.

Astrophysics at Livermore

Because astrophysics and nuclear weapons physics have many similarities, it is not surprising that the Laboratory has a long history of contributing to the advancement of scientific understanding about our universe and developing instrumentation used by astronomers. Pioneering work in the 1960s includes seminal papers on gravitational collapse and supernova explosions by Laboratory researchers including Sterling Colgate, Montgomery Johnson, Michael May, Richard White, and James Wilson. Current efforts range from laser guide star development and use to the search for dark matter (massive compact halo objects, or MACHOs) and the development of a three-dimensional stellar evolution simulation model.

1997 NIF GROUNDBREAKING





The 192-beam National Ignition Facility during construction in 2001 (top). The 10-meter-diameter target chamber (above and right) was moved into the facility in 1999.

Thermonuclear Ignition and Matter at Extreme Conditions

Groundbreaking for the stadium-sized 192-beam National Ignition Facility (NIF) took place in May 1997. An extremely ambitious and technically challenging project, NIF is the culmination of a series of increasingly larger lasers built over the past 30 years. It will be the world's most energetic laser when completed. With NIF, scientists will perform vitally needed thermonuclear weapons physics experiments. The facility is a cornerstone in the U.S. nuclear weapons Stockpile Stewardship Program to ensure the safety and reliability of the nuclear deterrent. NIF also will serve as a national and international center for the study of inertial confinement fusion (ICF) and the physics of matter under conditions of extreme temperature, energy density, and pressure.

NIF is designed to deliver 192 laser beams with a total energy of 1.8 million joules of ultraviolet light to the center of a 10-meter-diameter target chamber. This energy, when focused into a volume less than a cubic millimeter, can provide unprecedented energy densities in a laboratory setting. In ICF experiments, NIF's laser beams will converge on a target containing a BB-size capsule of deuterium–tritium fuel causing the capsule to implode and create fusion ignition and burn with the release of approximately 10 times more energy than was used to drive the implosion. Additionally, scientists will use NIF to study a variety of materials under high-energy-density conditions to provide valuable data for national security, energy security, basic science, and nuclear weapons effects.

In June 1999, after two years of construction, the 132-ton aluminum target chamber was transported from its assembly building to the target bay where it is now aligned to better than a millimeter accuracy. While excellent progress was being made on all technical fronts and construction continued on the $270-million conventional facility, the NIF project was rebaselined to enhance the planned method for assembling the lasers and to ensure that strict cleanliness requirements would be met.

In September 2001, conventional facility construction was completed on schedule and on budget. Inside the building, the beampath infrastructure for the first 48 beams was completed the next month. This significant milestone was accomplished through the successful partnership of the installation contractor, Jacobs Facilities, Inc., Laboratory staff, and the local building trades. In early 2002, assembly work stations were commissioned in the Optics Assembly Building, where over 7,000 large-aperture and over 10,000 smaller optical components required by NIF will be received, cleaned, assembled, aligned, and transported to the laser.

The NIF schedule calls for project completion in FY 2008, and the NIF team's goal in the coming year is to achieve "first light" by delivering four laser beams to the target chamber.

Target Chamber Construction

The 10-meter-diameter target chamber was assembled from 18 four-inch-thick aluminum sections fabricated by Pitt-Des Moines, Inc., of Pittsburgh, Pennsylvania, in a special-purpose building adjacent to the National Ignition Facility. After verifying that the vessel was leak-free in June 1999, the 132-ton vessel was hoisted by one of the largest cranes in the world and carefully installed onto its support pedestal in the target building. Surprisingly, this breathtaking event took only about 30 minutes. The seven-story walls and roof of the target bay were then completed, and the target chamber was coated with a special 16-inch-thick neutron shielding concrete shell. Now weighing about 1 million pounds, the complete target chamber has been precision aligned to better than 1-millimeter accuracy.

1998 MULTISCALE MATERIALS SCIENCE

Livermore materials simulations are closely coupled to a program of laboratory experiments. Researchers measure the atomic transport properties of radiation damage defects in metals, including plutonium. The data are used to refine codes that simulate and predict the performance of stockpiled nuclear weapons.

Delving into Radiation Damage

Inherently a multiscale phenomenon, radiation damage can occur over a scale of 100 nanometers and in a small fraction of a second, but the effects build up over decades. Radiation damage can produce unacceptable changes in the plutonium used in nuclear weapons, shorten the lifetime of pressure vessels in nuclear power plants, and limit the choice of materials for fusion energy research. Livermore's scientists have a long-standing interest in the topic; the Livermore Pool-Type Reactor, which operated on site from 1957 to 1980, provided neutrons to study radiation damage to materials.

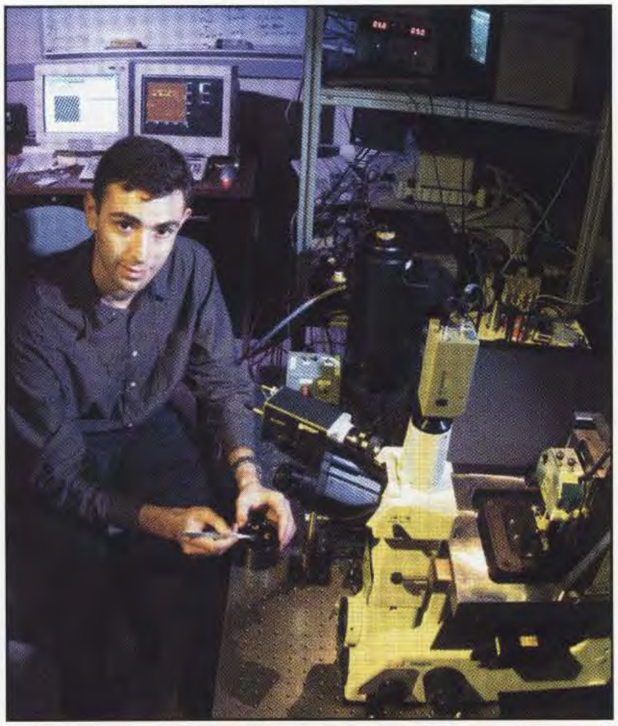
Material Properties from Atomic to Large Scales

For years, scientists have longed for computer simulations that could accurately predict material performance from atomic to engineering scale. In 1998, researchers at the Laboratory made great strides toward this goal, developing experimentally verified, three-dimensional simulations that bridge these extreme scales. The first simulations focused on the mechanical behavior of molybdenum, using information generated at the atomic scale (measured in nanometers) to model phenomena occurring at the microscale (micrometers). The results of these microscale simulations—the strength properties of molybdenum—were then passed on to codes that model phenomena on longer scales. Researchers validated their codes by comparing their simulations to experimental results. Ultimately, the validated codes will be used to predict changes in properties in other materials of particular interest to Laboratory programs.

The multiscale modeling approach only became possible with the advent of powerful, multiprocessor supercomputers in the last decade. Using the massively parallel computers of the National Nuclear Security Administration's Advanced Simulation and Computing (ASCI) program (see Year 2000), Livermore's researchers can now model material behavior over length scales ranging from nanometers to meters and time scales ranging from billionths of a second to tens of years.

Through multiscale modeling and experiments, scientists are gaining a better understanding of the effects of radiation damage on materials. The issue is of particular importance to scientists in the Stockpile Stewardship Program who are concerned about the aging of materials in nuclear weapons. In 2000, a Livermore team headed by materials physicist Tomas Diaz de la Rubia used multiscale modeling and experiments to demonstrate for the first time the underlying connection between radiation damage (in crystalline metals), which occurs at ultrasmall scales (nanometers and picoseconds), to degradation over time of the material's mechanical properties.

Many other research activities at the Laboratory are also benefiting from the work. At the National Ignition Facility (NIF), scientists are applying experimentally verified multiscale modeling to predict the lifetime of optics subjected to NIF's high-intensity laser light. The multiscale approach is also being used to model materials that could be used in future fusion reactors and to model the long-term performance of canisters being considered for storing high-level nuclear waste at Yucca Mountain (see Year 1980). In the future, multiscale modeling may provide insights into the manufacturing processes used in the semiconductor industry and simulate biochemical processes to aid in the study of DNA.



Livermore scientists are examining how materials are organized on surfaces and are conducting their examinations on an atom-by-atom and molecule-by-molecule basis. At this nanometer scale, scientists must use only the most powerful imaging tools, such as the extremely high-resolution atomic force microscope.

1999 R&D 100 AWARDS

The Ultra Clean Ion Beam Sputter Deposition System, developed at Livermore, produces precise, uniform, highly reflective masks in the lithographic process of printing features on computer chips. In a collaboration of national laboratories and industry, Livermore supplies expertise in optics, precision engineering, and multilayer coatings.

Technologies Spin Off to Industry

In 1999, *R&D Magazine* recognized Livermore with 6 of the 100 awards it grants annually for the most technologically significant new products and processes. The magazine, a publication for scientists and engineers, has been holding the R&D 100 Awards competition since 1963 to recognize important technological advancements that can be commercialized and that promise to improve people's lives. Over the years, Livermore has won 90 of these coveted awards. That large number is a credit to the outstanding science and engineering work at the Laboratory as well as to Livermore's excellent track record in working with industry.

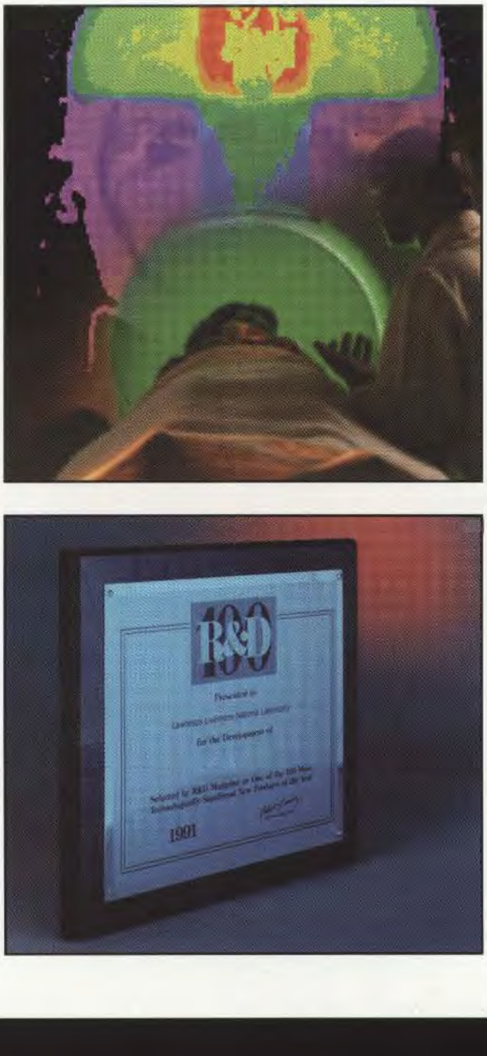
Two of the 1999 awards are indicative of the Laboratory's wide variety of partnerships with U.S. industry and how technologies developed for national security applications often lead to broader societal benefits. One award was for PEREGRINE, a revolutionary new tool for helping doctors to plan radiation treatment on a patient-specific basis. Its modeling explicitly accounts for inhomogeneities in the body such as air, muscle, and bone that are identified on the patient's computed-tomography scan. The power and accuracy of PEREGRINE are based on Livermore's storehouse of data on nuclear science and radiation transport combined with Monte Carlo statistical techniques.

Livermore licensed the PEREGRINE technology to the NOMOS Corporation of Sewickley, Pennsylvania, in 1999. The U.S. Food and Drug Administration approved it for use in 2000.

Another R&D 100 Award in 1999 was for a multilayer, thinfilm deposition system, a technology that is key to the development of extreme ultraviolet (EUV) lithography. EUV lithography promises to allow computer chip manufacturers to print circuit lines at least as narrow as 0.03 micrometer (1/3,000th the width of a human hair), which will extend the current pace of semiconductor innovation at least through the end of the decade.

The technology is being pursued by a unique industry–government collaboration that began in 1997. It involves the Lawrence Livermore, Lawrence Berkeley, and Sandia national laboratories and a consortium of semiconductor companies called the EUV Limited Liability Company (LLC). The consortium, which has committed $250 million to the project, includes Intel, Motorola, Advanced Micro Devices, Micron Technology, Infineon Technologies, and IBM. In October 2001, EUV LLC extended the cooperative research and development agreement to 2005.

Drawing on optical technology and precision engineering that supports its laser programs, the Laboratory brings to the project expertise in creating precision reflective optical coatings from multilayered materials, advanced optical testing methods, and defect inspection technologies. In the future, Livermore will directly benefit from the more powerful computers that will be made possible by EUV lithography.



Winner of an R&D 100 Award in 1999, PEREGRINE (top left) helps doctors to better plan radiation treatment. The computer simulation of the dose received uses detailed, patient-specific information gathered through a computed-tomography scan. The Laboratory has won a total of 90 R&D 100 Awards (bottom left).

Two Thousand and Beyond

New Leadership

Michael Anastasio
(2002-)

As a DOE National Nuclear Security Administration 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. The Laboratory's exceptional scientific and technical staff is engaged in projects that make use of a wide range of special

A national resource

facilities and capabilities to meet a variety of important national needs—maintaining a safe, secure, and reliable nuclear weapons stockpile; preventing proliferation and fighting the war on terrorism; developing technologies for reliable, clean energy and for environmental restoration; and contributing broadly to the nation's science and technology base.

The Laboratory's responsiveness to national needs was vividly demonstrated in 2001. Ongoing research and expertise, prototype development, and field-testing enabled Livermore to respond quickly to the events of September 11. The Laboratory's tools and systems are contributing to homeland security.

Livermore's exceptional capabilities to advance scientific understanding are exemplified by the ASCI White supercomputer, the world's largest and fastest machine, delivered to Livermore in 2000 and contributing to efforts to maintain the nation's nuclear weapons stockpile. Terascale computing offers unprecedented opportunities for scientific discovery.

2000 ADVANCED SIMULATION AND COMPUTING

An array of 15 projectors (far left) is used to display the results of ASCI computer simulations in unprecedented detail on the Powerwall (above), a nearly 20-million-pixel screen. Scientists also use arrays of flat panel displays (left) in their work centers and individual offices to visualize the results of ASCI calculations.

ASCI White Arrives

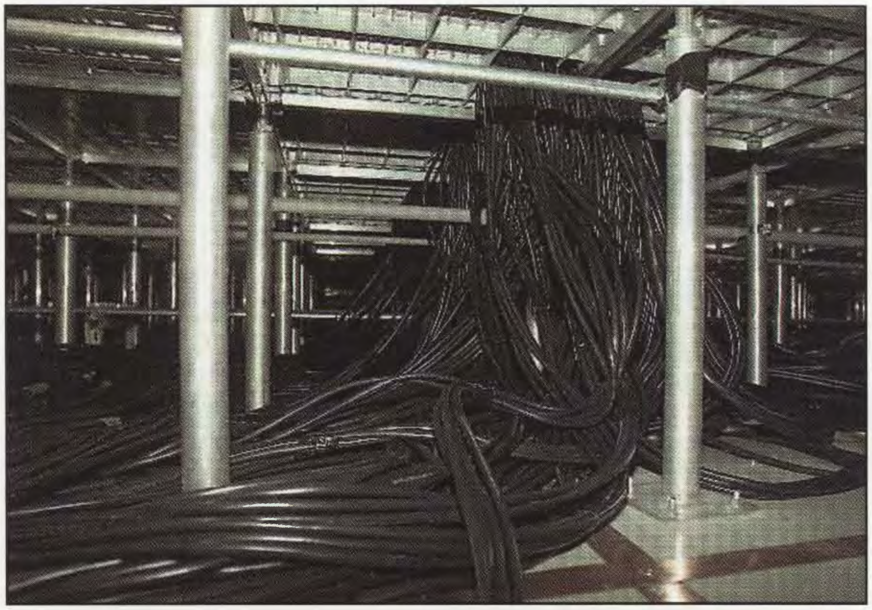
During the summer of 2000, 28 moving vans carried the pieces of the world's fastest supercomputer, called ASCI White, from IBM's development facilities in Poughkeepsie, New York, to Livermore. To accommodate the sheer physical size of this massively parallel machine, together with its wiring and cooling system demands, the Laboratory had doubled the size (and the underfloor space) of the computer room in Building 451.

This latest addition to the Laboratory's computing resources was deployed in three parts, all of which shared versions of IBM's RS/6000 SP hardware technology. ASCI White consists of 8,192 central processor units clustered into 512 nodes. Intended for large, highly parallel batch jobs, the machine demonstrated a processing speed of 12.3 teraops (trillion operations per second), about 3 times more than any other available computer at that time.

ASCI White's arrival marked the successful third step in a five-stage plan by the Department of Energy to sponsor development of a 100-teraops supercomputer by 2004. Launched in 1995 as the Accelerated Strategic Computing Initiative (ASCI), this collaboration of Livermore, Los Alamos, and Sandia national laboratories with U.S. industry and academia was later renamed the Advanced Simulation and Computing program. The goal was to significantly improve capabilities to simulate with high resolution the performance of weapons in the nation's nuclear stockpile. ASCI, and hence the White machine, is one of the cornerstones of the Stockpile Stewardship Program of the National Nuclear Security Administration.

Effective use of a computer like ASCI White required sophisticated software and network support. Laboratory innovations to transfer and store the massive data sets generated by ASCI White simulation runs—and to analyze that data visually—enhanced the practical value of this machine. Locally designed tools enabled the efficient parallel storage of vast output files. And local software (called a terascale browser) displayed data visualizations on wall-size screens to allow faster interpretation of results and bug detection.

ASCI White's benefits were soon evident. Use of the machine for pioneering scientific simulations began even as component upgrades continued on ASCI White's nodes. By the spring of 2002, scientists at Livermore and Los Alamos, using separate approaches to parallel code development for ASCI White, successfully completed two of the most refined computer simulations ever attempted, the first full-system three-dimensional modeling of a nuclear weapon explosion. Livermore's simulation alone used more than 1,024 White processors and took 39 wall-clock days to run. The Los Alamos work, executed remotely at Livermore by using a secure network connection to New Mexico, took over 120 days. High-bandwidth connections to Los Alamos and Sandia, coupled with extensive user support services at Livermore, have allowed this machine to be used effectively by all three laboratories.



The ASCI White supercomputer needed a floor with an extra 2 feet underneath it to accommodate airflow, switches, and 40 miles of cable connecting all the computer nodes.

2001 BIODETECTORS RESPOND

Specialists from Livermore and Los Alamos national laboratories deployed the Biological Aerosol Sentry and Information System (BASIS) for the 2002 Winter Olympics in Salt Lake City, Utah. BASIS was developed under the sponsorship of NNSA's Chemical and Biological National Security Program.

Defending against Terrorism

The events of September 11, 2001, lent new urgency to the Laboratory's efforts to apply its technologies, tools, and expertise to better prepare the nation to defend against terrorist use of weapons of mass destruction (WMD). The prospect of a devastating bioterrorist attack became even more real a few weeks later when a terrorist sent anthrax through the mail, killing a number of people. Livermore researchers were able to provide immediate help because they had begun addressing the threat of WMD terrorism long before September 11. As part of the National Nuclear Security Administration's Chemical and Biological National Security Program, the Laboratory takes a comprehensive approach to the problem, developing technologies and tools to counter threats and working closely with response agencies to ensure that the technological solutions meet real-world operational needs.

Post–September 11, the Laboratory provided analysis and assessments as well as information tools and expert personnel to the Intelligence Community. Livermore's Nuclear Threat Assessment Center operated seven days a week to evaluate numerous smuggling incidents and nuclear-related threats. In addition, the Counterproliferation Analysis and Planning System (CAPS), developed at Livermore and extensively used by the Department of Defense, supported U.S. military efforts with evaluations focused on sites of concern in and around Afghanistan.

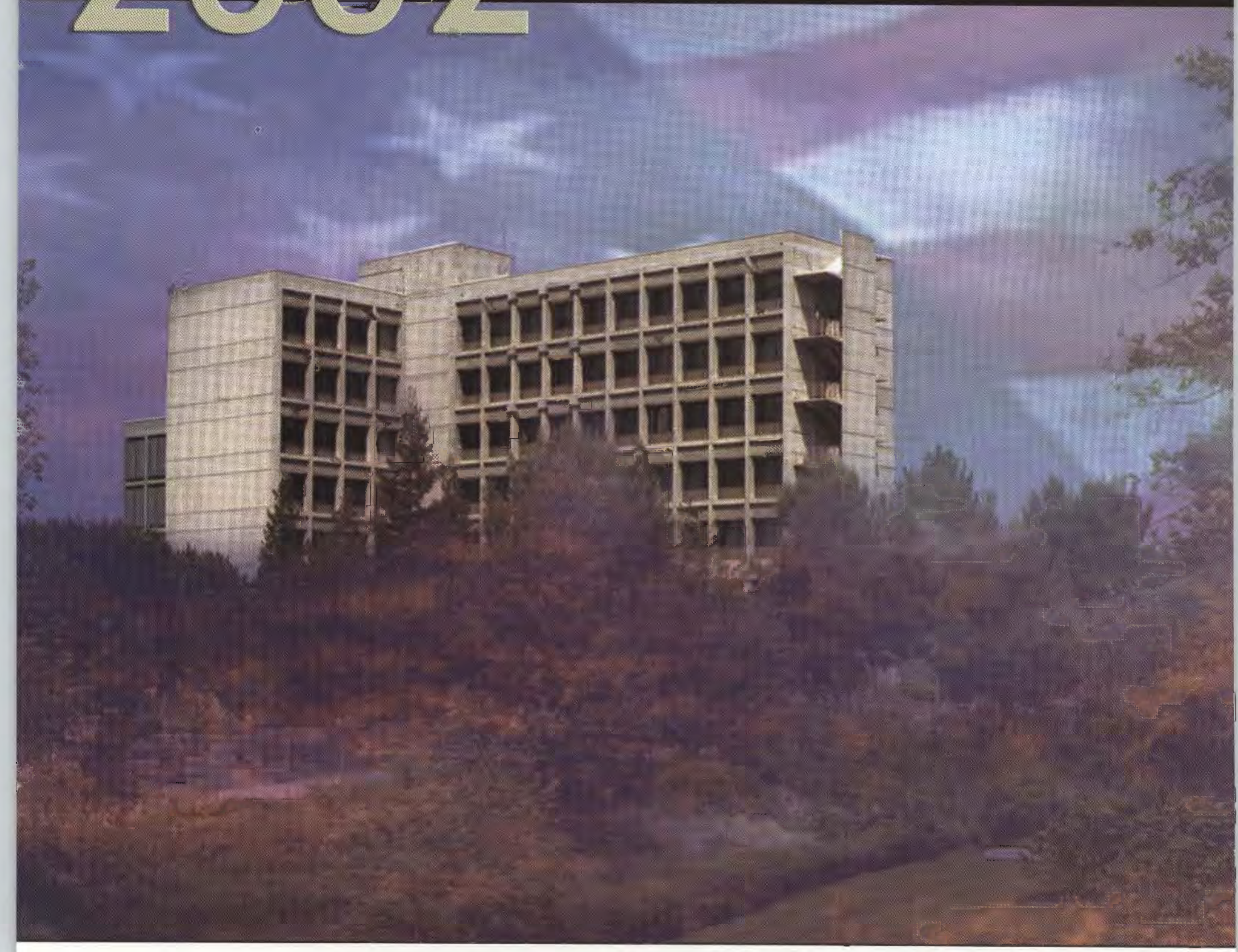
As the anthrax mail cases illustrated, the U.S. is vulnerable to bioattack. Livermore technologies are at the core of the nation's biodefense capabilities. The Laboratory's miniaturized DNA analysis technology has been commercialized by Cepheid Inc. as the Smart Cycler and is being commercialized by Environmental Technologies Group as a handheld instrument. With both instruments, results are available in minutes. They are based on technology breakthroughs in biodetection instrumentation made by Laboratory researchers, who pioneered the miniaturization and ruggedization of DNA identification devices. In 1998, the technology was successfully demonstrated in field tests at Dugway Proving Ground, Utah, and an early version of the handheld instrument was delivered soon after to selected users.

In addition, the Biological Aerosol Sentry and Information System (BASIS), developed jointly by Livermore and Los Alamos, was deployed to Salt Lake City in 2001 as part of the overall security strategy for the 2002 Winter Olympic Games. Smart Cycler biodetectors are the heart of the BASIS field laboratory. Because biodetectors require unique antibodies or DNA sequences to identify and characterize pathogens, Livermore is also developing "gold standard" DNA signatures and assay protocols. They are then validated by the Centers for Disease Control and Prevention (CDC) and distributed by the CDC to the public health community.

The Laboratory is poised to make additional contributions to homeland defense through the development of more advanced technologies to defend against both current and future threats.

Livermore is developing an array of DNA pathogen signatures against which a biological-agent detector matches the samples it gathers. DNA signature development involves a multidisciplinary team of microbiologists, molecular biologists, biochemists, geneticists, and computer experts.

2002 A BRIGHT FUTURE



50 YEARS OF MAKING HISTORY

Reflecting on the Past and Preparing for Tomorrow

Anniversaries are a time to reflect on one's accomplishments, learn from and be reinvigorated by them, and set goals for the future. The Laboratory's 50 years of accomplishments are a credit to the outstanding individual and team efforts of Livermore employees—now and in the past—in service to the nation. These achievements are indicative of a tradition of scientific and technical excellence that comes from being part of the University of California. The accomplishments would not have been possible without public support, funding from sponsors, and in numerous cases, the cooperative efforts of research partners. Livermore's principal sponsors have been the Atomic Energy Commission (1952–1975), the Energy Research and Development Administration (1975–1977), the Department of Energy, and now DOE's National Nuclear Security Administration (NNSA).

Commemorative events in 2002 contribute to the celebration of a rich 50 years of history, while other events during the year shape the Laboratory's future—new research facilities and capabilities as well as new leadership at Livermore.

On April 4, 2002, two groundbreaking ceremonies were held at Livermore. The $25-million International Security Research Facility will consolidate Livermore's nonproliferation and intelligence-related operations into a single building with cutting-edge information technology tools. The new facility will help the Laboratory meet the U.S. Intelligence Community's need for accurate and timely expert analysis about the proliferation of weapons of mass destruction. The demand for these assessments has accelerated since the September 11 attacks.

Groundbreaking also took place for the $92-million Terascale Simulation Facility, which will house Livermore's next-generation supercomputer in NNSA's Advanced Simulation and Computing (ASCI) program for stockpile stewardship. The 253,000-square-foot facility will include over one acre of computer floor and an office complex for 288 scientists and engineers. It will hold ASCI Purple, a machine capable of greater than 60 trillion operations per second, which is planned for delivery in 2004 and will keep Livermore at the forefront of terascale supercomputing.

On June 4, 2002, The Regents of the University of California appointed Michael Anastasio as Laboratory Director, effective July 1, 2002. He succeeds Bruce Tarter, who led the Laboratory through the establishment of the Stockpile Stewardship Program, tremendous growth in Livermore's experimental and computational capabilities, and rapid expansion of programs to counter the proliferation and use of weapons of mass destruction.

"First light" at the National Ignition Facility during the coming year will lead the Laboratory into its second half-century of service to the nation. With unique experimental facilities and computational capabilities, a vital national security mission, multidisciplinary capabilities able to address important, complex problems, and an outstanding work force, Livermore continues its tradition of being a "new ideas" laboratory. We are dedicated to ensuring national security and applying science and technology to the important problems of our time.

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