The Sixties

New Leadership

Harold Brown
(1960•1961)

John S. Foster, Jr.
(1961•1965)

Michael M. May
(1965•1971)

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

Multidisciplinary team science

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.

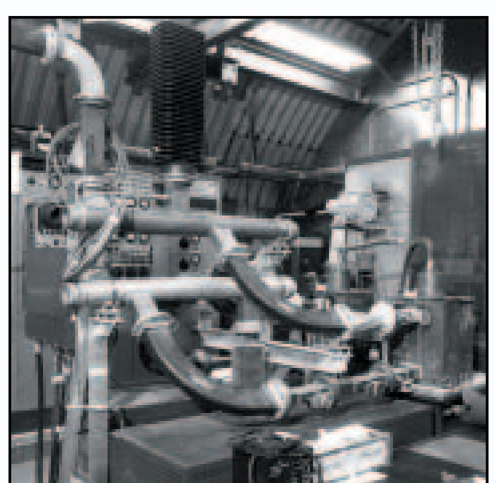
Improved Nonnuclear Testing Capabilities

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The linac for Bunker 351 superceded the capabilities of Bunker 312's XR2 machine, which had been moved from Sugar Bunker at the Nevada Test Site to Site 300 in the late 1950s.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.

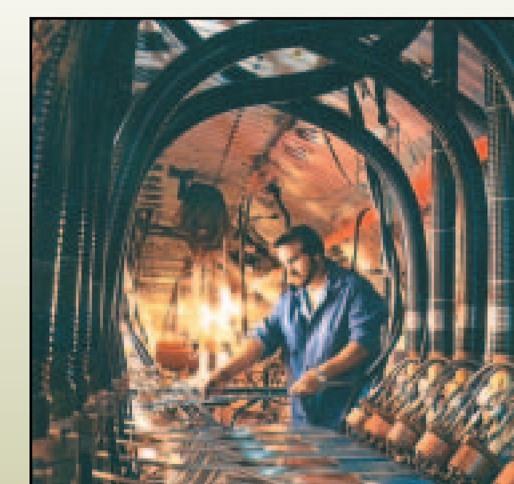
Induction linacs are now the heart of the nation's two most modern hydrodynamic testing facilities—the Contained Firing Facility at Site 300 (with the Flash X Ray machine) and the Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos. Built in 1982 and subsequently upgraded, the Flash 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.



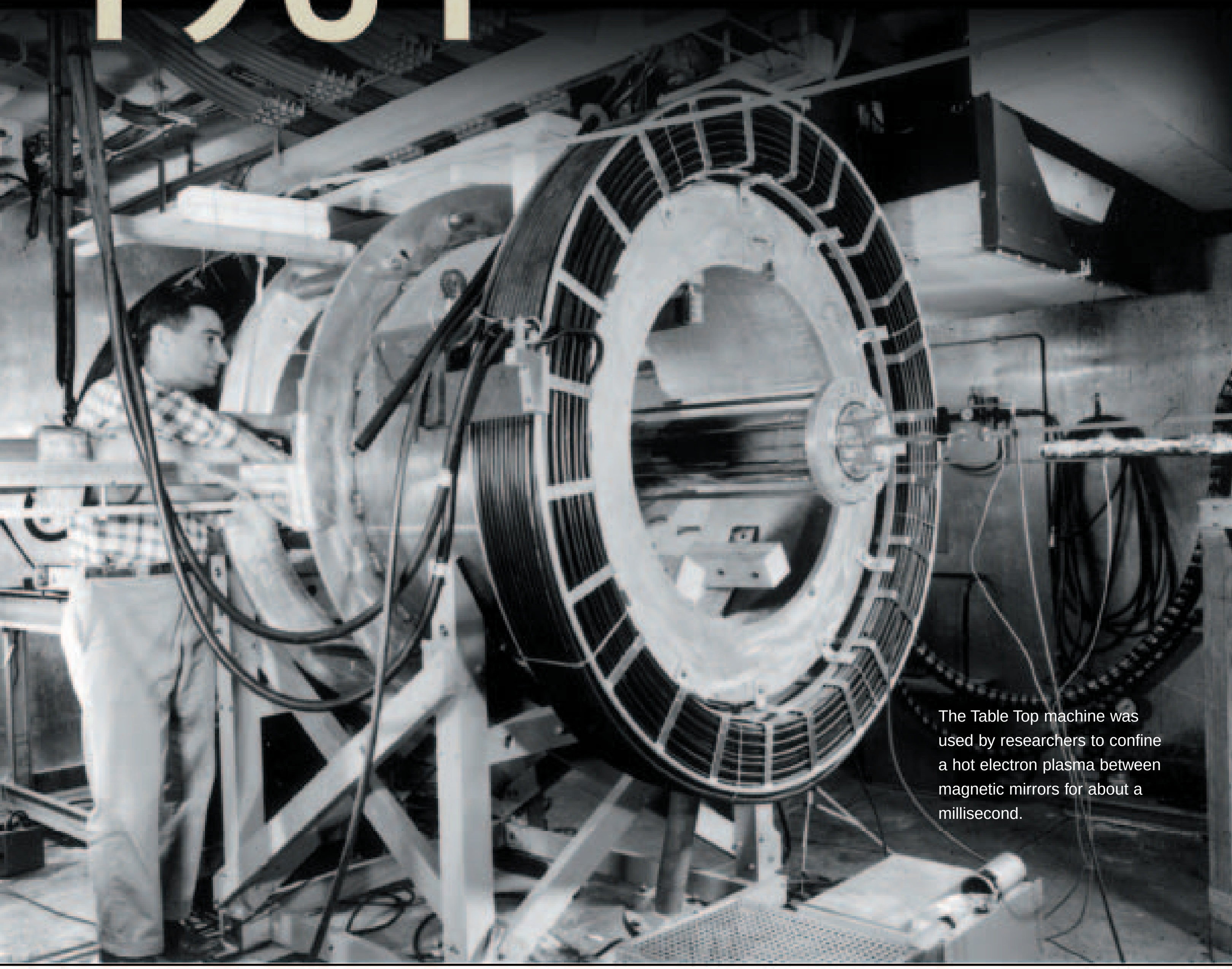
The XR2 machine (above and left) was located in Sugar Bunker (far left) at the Nevada Test Site (NTS) until it was moved to Site 300 near Livermore. There, it provided the Laboratory's first primitive radiographic capability until a new linear accelerator was delivered in 1960.

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.

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.

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.

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.

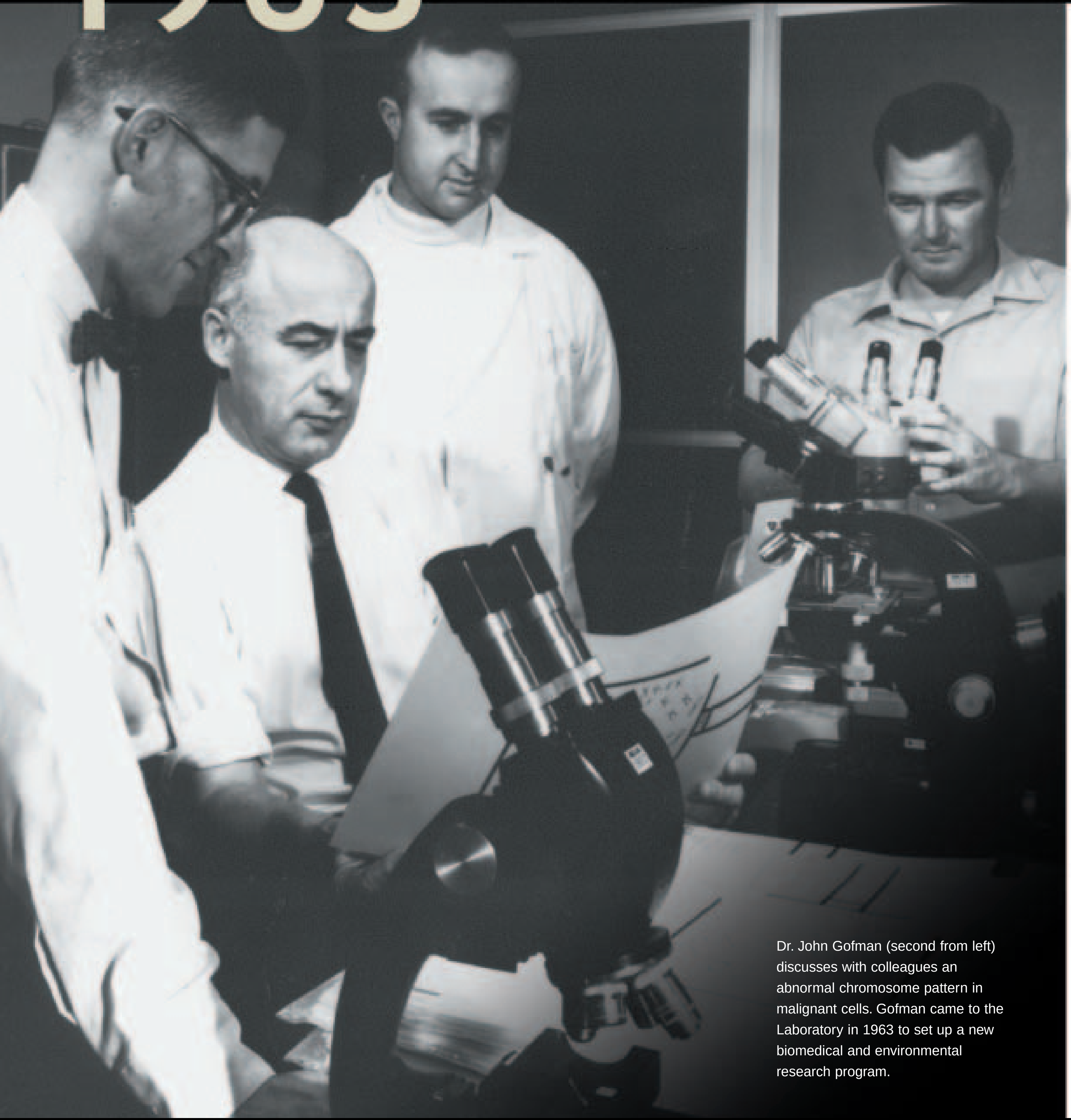
Operation Dominic experiments proof-tested weapons introduced into the stockpile during the moratorium. The most dramatic experiment was Frigate Bird, in which the USS *Ethan Allen* launched a Polaris missile, and the Livermore-designed warhead successfully detonated over the open ocean. Most of the 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.



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

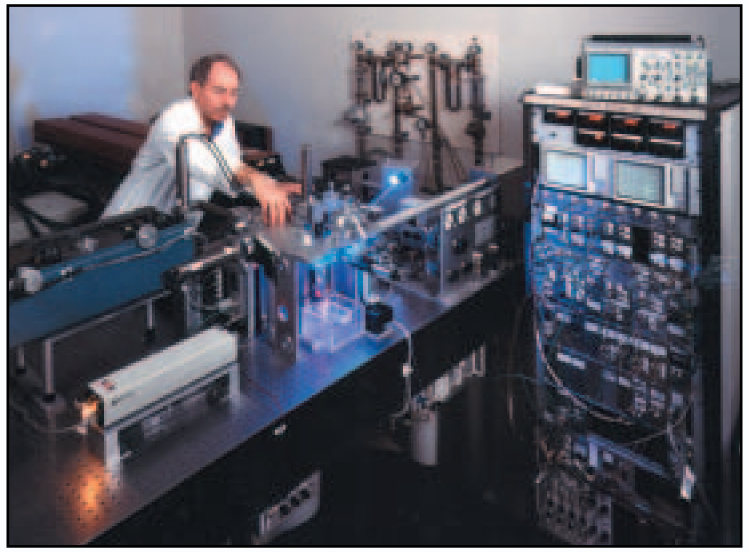
The first biomedical and environmental research program began at Livermore in 1963. The Atomic Energy Commission had been conducting research into the biological consequences of fallout radiation since 1954. As the need grew for a bioenvironmental presence at the Nevada and Pacific test sites, the decision 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.

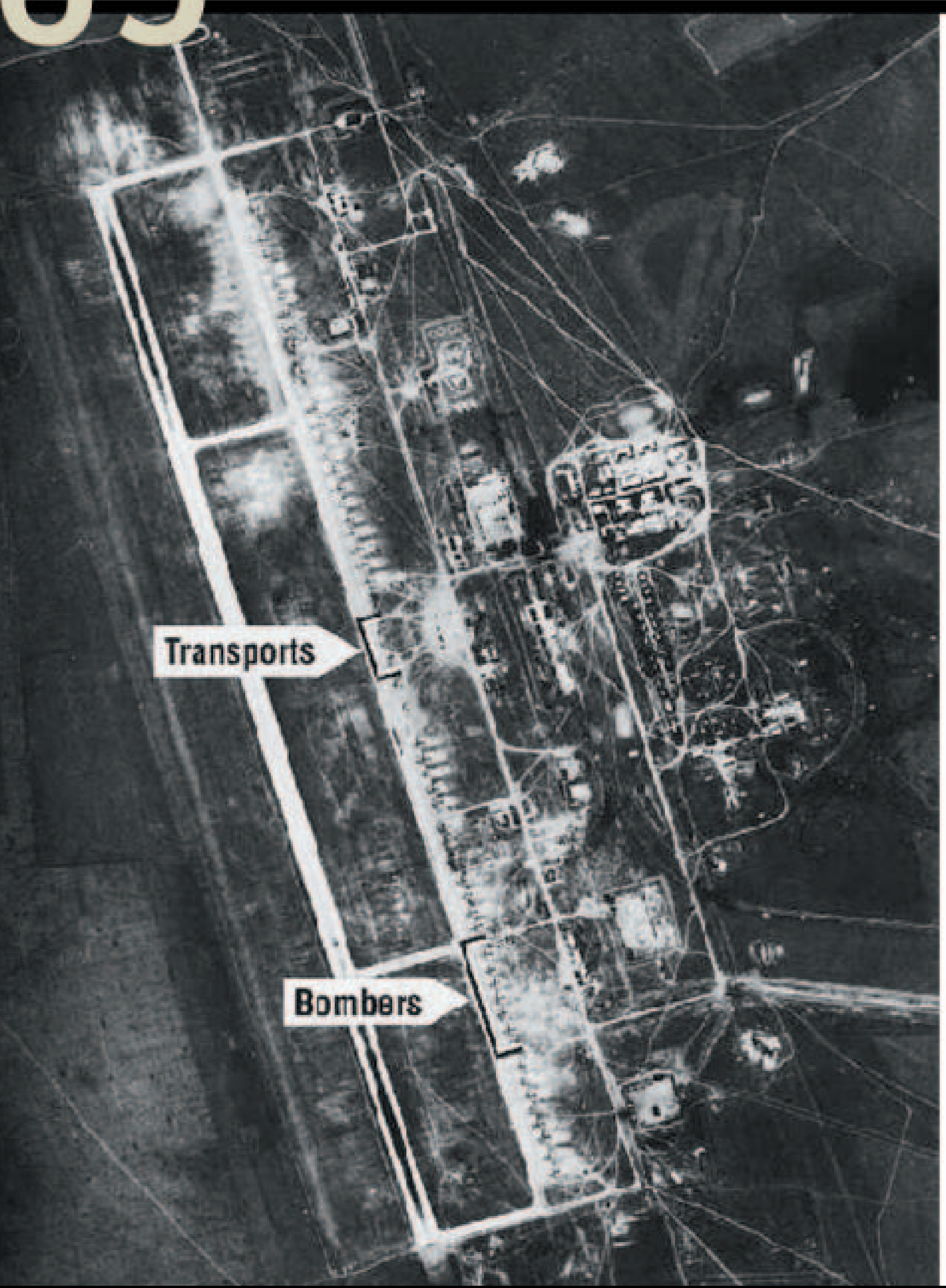
In tribute to Teller's unflagging commitment to science education and to the guidance he provided to generations of scientists, the Fanny and John Hertz Foundation gave $1 million to the University of California in 1999 to endow a chair in Teller's name in the Department of Applied Science. More recently, 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.



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

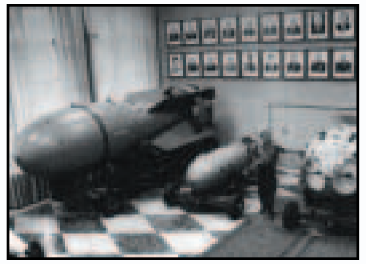
Since the early days of Livermore, intelligence agencies have sought Laboratory expertise in nuclear weapons design to analyze atmospheric nuclear tests conducted by the Soviets and to develop an understanding of the Soviet nuclear program and weapon designs. The Soviet Union's first test of an atomic 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.

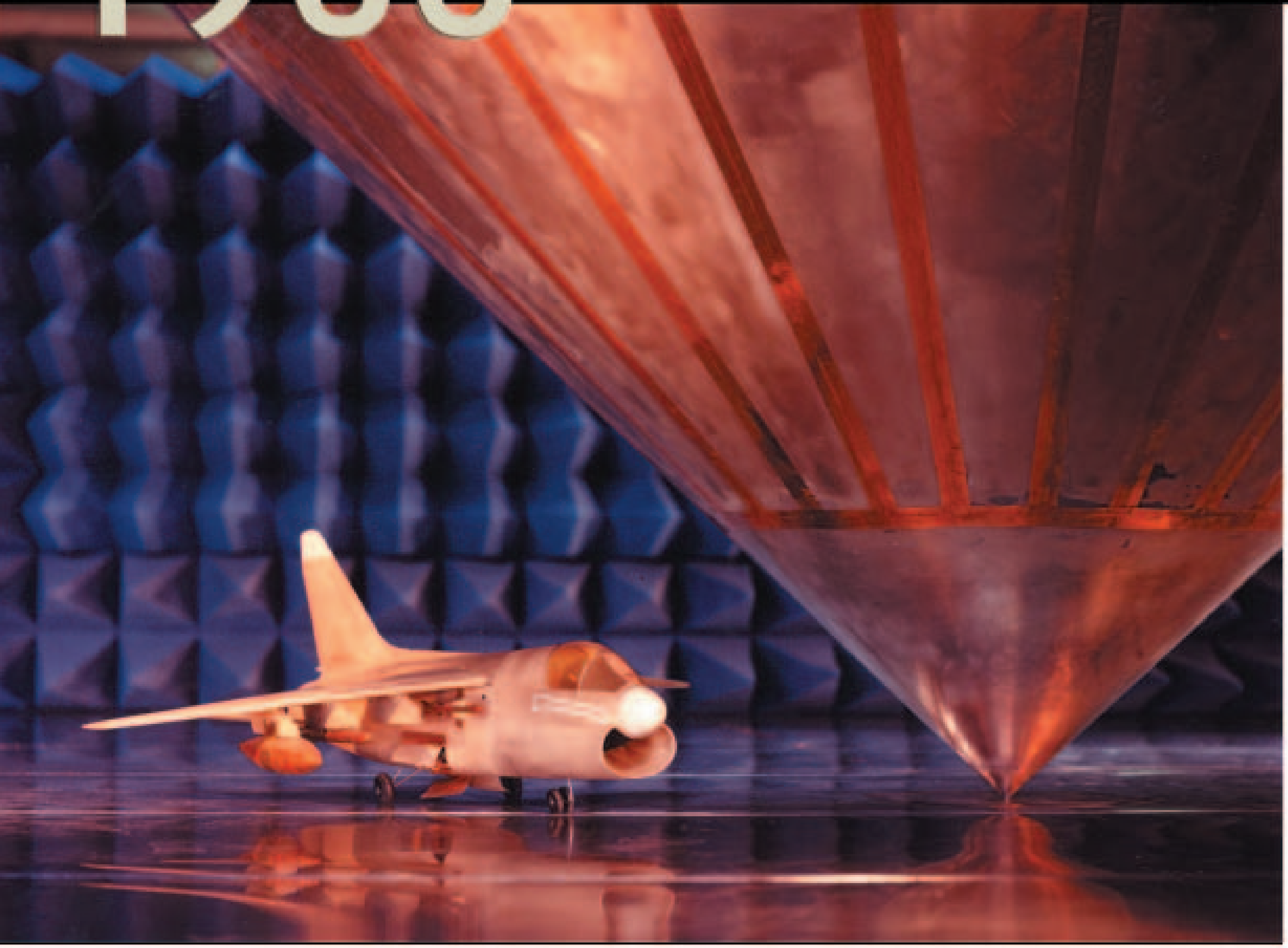
Anticipating that nuclear proliferation could become a major problem, Z Division started a proliferation monitoring program in the mid-1970s. That effort has continued to grow together with the Intelligence Community's need for all-source analyses of the nuclear programs of an expanding list of countries 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).

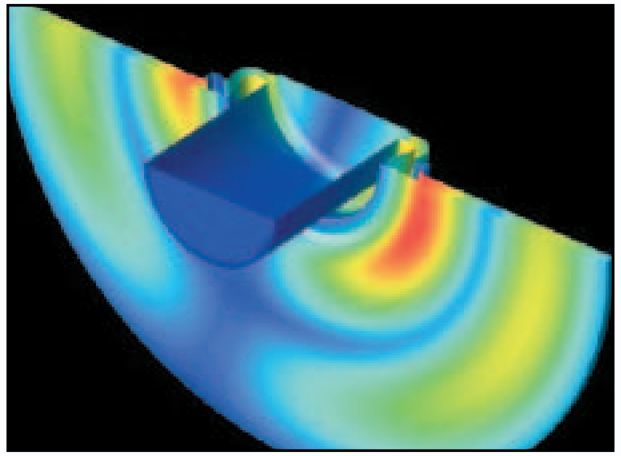


Models of early Soviet nuclear weapons are on display at the Nuclear Weapons Museum at Arzamas-16, the Soviet Los Alamos, shown in an early photograph.

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.



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.

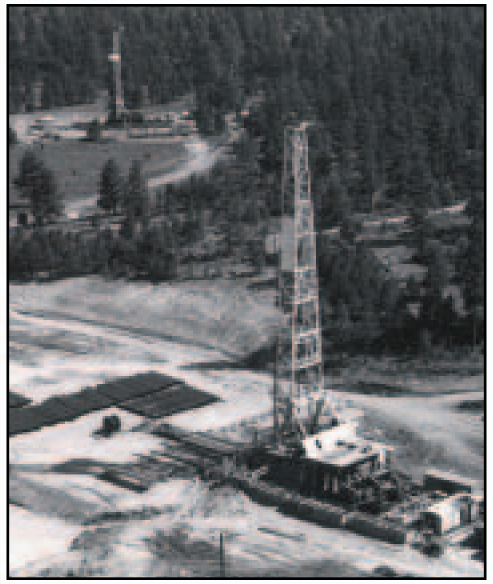
Theoretical work and the development of computer codes were complemented by experimental efforts to generate and measure fast transients for model validation. For example, to measure coupling of radio waves into structures, a large cone antenna (EMPEROR) was built at Livermore, and scale models of military 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.

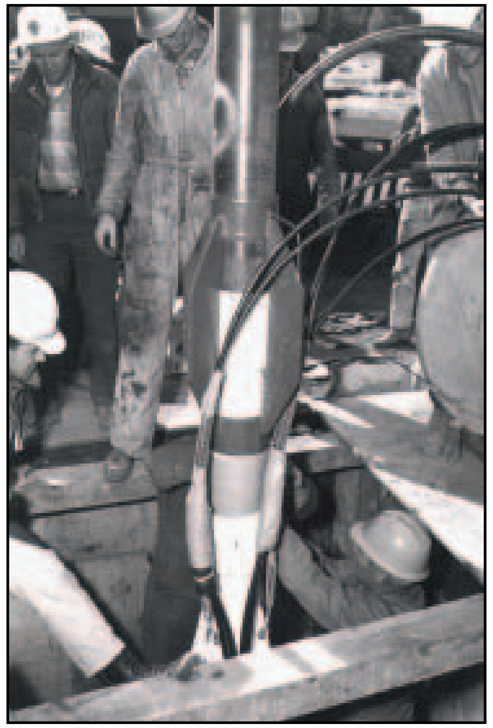
Spin-offs of EMP research have taken Livermore to the forefront of many areas of technology: innovative use of solid-state and low-cost silicon electronics; pulsed-power systems that have been employed in laser and accelerator research; cross-borehole electromagnetic imaging and tomography to produce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

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.