Fifty Years of Innovation through Nuclear Weapon Design

WHEN the Livermore branch of the University of California Radiation Laboratory (UCRL) opened its gates on September 2, 1952, the nation was fighting a “hot” war in Korea and a “cold” war with the Soviet Union. The Soviet Union had detonated its first nuclear device three years earlier—much ahead of U.S. expectations. Nuclear weapons were a new and growing part of the U.S. arsenal and seen as essential for deterring Soviet aggression in Europe. Today, the Cold War is history. Relationships with Russia and other countries of the former Soviet Union are more cooperative than confrontational, but new international dangers have emerged. The development of new U.S. nuclear weapons ceased in 1991; presently, the focus is on improving our scientific capabilities to understand weapon performance in the absence of nuclear testing and to refurbish weapon systems as necessary to keep the existing nuclear stockpile reliable, safe, and secure.

> **“Research on nuclear weapons has provided the United States with the ability to deter the use of nuclear weapons throughout the past half century.”**
> —Edward Teller,
> *Memoirs: A Twentieth-Century Journey in Science and Politics*

Throughout the half century since its inception, the “Rad Lab at Livermore” (which became Lawrence Livermore National Laboratory in 1979) has helped the nation meet important challenges through innovations in science and technology. The initial challenge, the one that set the stage for all that followed, was the design of nuclear weapons.

The Heart of Innovation

At first, Livermore scientists and engineers were mainly responsible for developing diagnostic instrumentation to support tests of thermonuclear devices “in close collaboration with the Los Alamos Scientific Laboratory.” The Joint Committee on Atomic Energy also hoped “that the group at UCRL (Livermore) will eventually suggest broader programs of thermonuclear research to be carried out by UCRL or elsewhere.” Under the direction of Herbert York—a 32-year-old physicist designated by UCRL Director Ernest O. Lawrence to “run the place”—the Laboratory’s mission rapidly evolved. It was not long before Livermore became the second U.S. nuclear weapons design laboratory.

“Weapons are an integral part of the past and present of the Laboratory,” says retired weapons designer Bill Lokke, winner of an E. O. Lawrence Award for innovative weapons design work in the 1960s. “Livermore is one of the two ‘go-to’ laboratories for nuclear weapons research in the nation, along with Los Alamos. A key attribute of our success is our attitude toward innovation. . . . We want to do things the best possible way, find the best possible solution to a scientific problem. Even if it means inventing something new.”

Livermore used this approach to explore the heart of nuclear weapons work—improving the performance of fission and thermonuclear weapons through better designs that contributed to better systems for the U.S. military. The Laboratory did not hesitate to tackle bold designs that appeared to be the best solutions, even though pursuit of these solutions had no guarantees of success. Livermore’s weapon designers were willing to take risks and to accept failures as

part of the process. And failures did occur, a number of them right at the start.

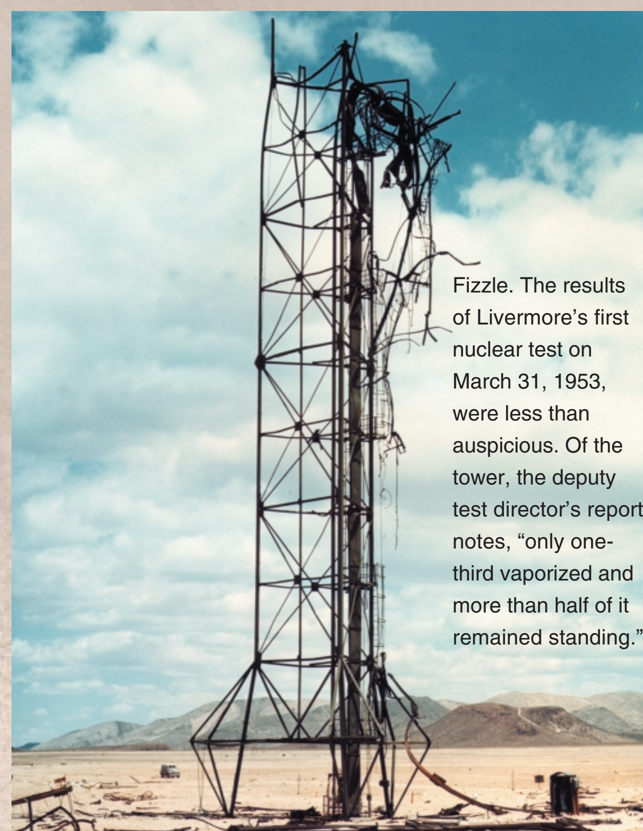
For its first nuclear test, just six months after its founding, Livermore planned to detonate a fission test device of unusual design. The test was to shed light on certain thermonuclear reactions key to two Livermore hydrogen bomb tests planned for 1954. The test device was fastened to a 90-meter-tall tower at the test site in Nevada. When the smoke cleared after the countdown, the tower was still there, albeit in somewhat reduced form. The sad remains of this "fizzle" were immortalized in a photograph that one still finds pinned up in various offices at the Laboratory. The photo, below right, is a vivid reminder of the Laboratory's humble beginnings and, more importantly, its willingness to take chances on innovative approaches.

Pushing the Limits

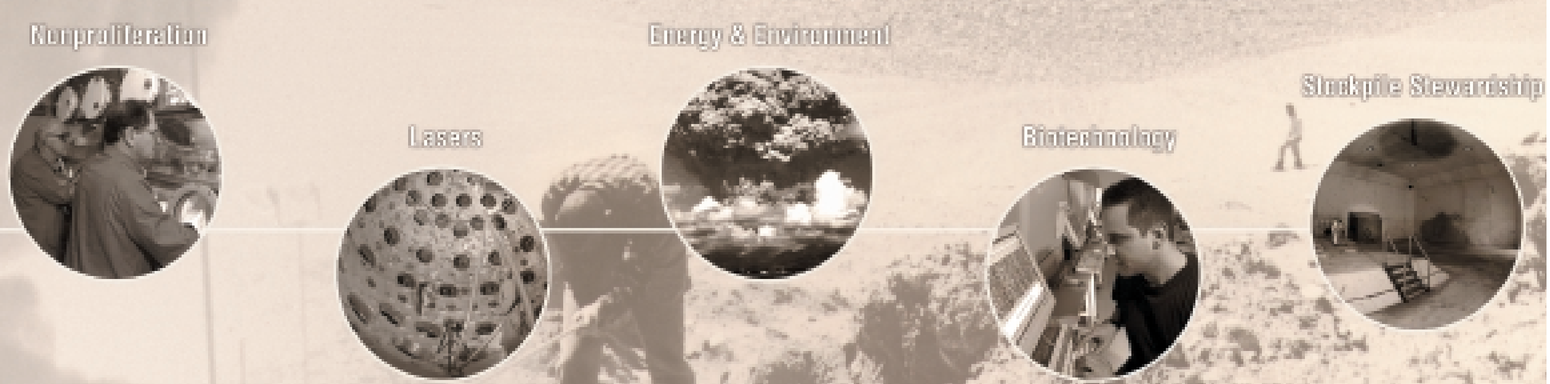
In August 1953, York submitted a formal proposal to the Atomic Energy Commission (the forerunner to the current National Nuclear Security Administration within the Department of Energy) for expanding Livermore's research to small fission weapons. A principal goal of the program, as outlined by York, would be the development of small, lightweight nuclear warheads for air-to-air defense missiles and improved atomic artillery shells. The design objectives were to develop reasonably efficient fission weapons of relatively small size, weight, and yield. The small weapons research being pursued by Livermore was of interest particularly to the Army, which could use the designs in artillery shells. Up to that time, fission weapons were enormous and heavy. For instance, "Fat Man"—the fission bomb dropped on Nagasaki, Japan, to help end World War II—weighed over 4,500 kilograms. Another reason for Livermore's interest in small fission weapons was the important goal of developing small primaries to shrink the size of thermonuclear weapons. (A thermonuclear weapon has two basic nuclear components: the primary, which is a fission device that serves as the nuclear "trigger" to set off the secondary, which produces most of the weapon's yield.)

In the 1950s, Livermore designers, led by physicists Harold Brown and John Foster, were increasingly successful in producing innovative designs. The table on p. 6 lists the systems Livermore developed. In 1955, joint responsibility for the warhead for the Navy Regulus II system was assigned to Livermore and Los Alamos; in 1956, Livermore shouldered the nuclear design of an atomic demolition munition for the Army and the warhead for the Navy Terrier system. With the assignment in 1957 of developing the warhead for the Navy's Polaris missile, the Laboratory really came into its own. "Polaris was a turning point in nuclear weapon design," notes Kent Johnson, chief of staff for Livermore's Defense and Nuclear Technologies Directorate.

Physicist Edward Teller, a driving force behind Livermore's founding and its director from 1958 to 1960,



Fizzle. The results of Livermore's first nuclear test on March 31, 1953, were less than auspicious. Of the tower, the deputy test director's report notes, "only one-third vaporized and more than half of it remained standing."



Livermore's Contributions to the Nation's Nuclear Stockpile

Strategic nuclear weapons

Category	System	Service	Date assigned to Livermore
Intercontinental ballistic missiles (ICBMs)			
W38	Atlas/Titan	Air Force	February 1959
W56	Minuteman	Air Force	December 1960
W62	Minuteman	Air Force	June 1964
W87	Peacekeeper	Air Force	February 1982
Submarine-launched ballistic missiles (SLBMs)			
W47	Polaris	Navy	August 1957
W58	Polaris	Navy	March 1960
W68	Poseidon	Navy	December 1966
Air-launched missiles			
W27 (cruise)	Regulus	Navy	September 1955*
Ground-launched missiles			
W84	Cruise	Air Force	October 1978
Bombs			
B41	B52	Air Force	February 1957
B83	Modern strategic bomb	Air Force	January 1979
Defensive nuclear warheads			
W71	Spartan	Army	March 1968
Tactical nuclear weapons			
Atomic demolition munitions (ADM)			
W45	ADM	Army	November 1956
Missile warheads			
W45	Little John	Army	November 1956
W70	Lance	Army	April 1969
W70 (Mod. 4)	Lance	Army	April 1976
Artillery-fired atomic projectiles (AFAPs)			
W48	155-mm howitzer	Army/Marines	August 1957
W79	8-in. artillery gun	Army	January 1975
Fleet antisubmarine (surface-to-air missile) warheads			
W45	Terrier	Navy	November 1956
W55	Submarine rocket	Navy	March 1959

*Joint Livermore–Los Alamos assignment.

championed the effort to develop small, efficient thermonuclear weapons that could be carried by submarine. For Polaris, Livermore designers came up with radical new designs for the primary and secondary as well as novel ways to minimize the overall mass. The result—a weapon for a reentry vehicle carried by a solid-fueled missile—fit inside a submarine and met Navy specifications for yield and weight. Polaris was a critically important breakthrough, greatly adding to the stability of the nuclear deterrent.

"This development [of Polaris] made it impossible for the Soviets to attack the United States and prevent retaliation," noted Teller. "Indeed, rocket-delivered explosives are hard to shoot down, and the submarines that carry them are hard to detect." The innovative design for the Polaris warhead was first validated in 1958. In 1960, the first Polaris submarine armed with Livermore-designed warheads took to sea, ahead of the most optimistic schedule.

The design improvements introduced in the Polaris warhead had far-reaching effects. "Small, lightweight designs, whose evolution can be traced to the Polaris W47, were adopted in most subsequent U.S. strategic nuclear weapons," says Johnson. "They set the tone and stage for the modern nuclear stockpile."

The 1960s were an extremely productive time for the Laboratory, which was assigned to develop warheads for the second-generation Polaris system and the Poseidon missile, both for the Navy. Livermore design teams also developed the warheads for the Air Force Minuteman II and III missiles. Throughout the decade, the Laboratory maintained a strong focus on strategic missile systems, particularly on those that carried multiple reentry vehicles (MRVs) and, later, multiple independently targetable reentry vehicles (MIRVs). Livermore's designs made it possible to meet the severe size and weight constraints placed on the warheads and still fulfill yield requirements for these systems.

Variations on a Theme

Livermore was also at the forefront of designing new types of nuclear explosives with tailored output. For example, increasing the fraction of energy generated by nuclear fusion rather than fission produced a "low-fission" nuclear weapon, which would produce less fallout. In addition, in 1957, Laboratory scientists began to explore possible peaceful uses of nuclear explosives through Project Plowshare. Reduced amounts of residual radiation—fewer fission products from the explosion and less induced radioactivity of the ground—were necessary to make feasible peaceful applications such as earth moving and power production. The design approaches to reduce residual radiation in these early efforts proved critical to the Laboratory's development of warhead concepts that were deployed on the Spartan and Sprint antiballistic missile systems in the early 1970s. Development of the high-yield W71 warhead for Spartan, which was designed to intercept a cloud of reentry vehicles and decoys in space, was a major undertaking for Livermore.

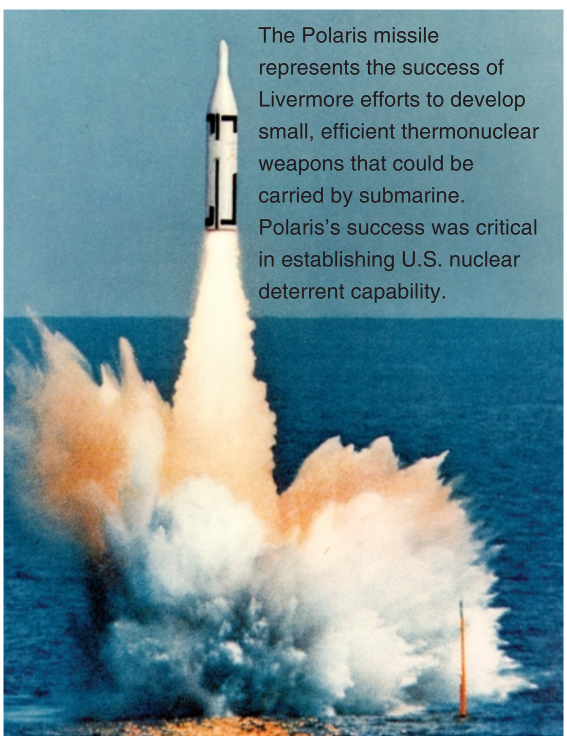
Tailoring the output of low-yield tactical nuclear weapons was also a focus of the Laboratory. Enhanced radiation weapons, which had low total yield yet produced large amounts of neutrons, were designed to be effective against military units while limiting the collateral blast damage to noncombatants. Nuclear weapon designs with specifically tailored effects were also the springboard for exploring the feasibility of third-generation, or directed-energy, weapons, such as nuclear-powered x-ray lasers, for use in strategic defense.

The Laboratory also applied innovation to enhancing the safety of nuclear weapons. The most modern safety features in U.S. nuclear weapons are incorporated in the Peacekeeper intercontinental ballistic missile warhead (W87), the ground-launched cruise missile warhead (W84), and a modern strategic bomb (the B83)—all first deployed in the 1980s. They include features such as high explosive that is virtually impossible to detonate inadvertently (developed by Los Alamos and Livermore in the 1970s) as well as creative features that enhance electrical nuclear detonation safety and make the weapons safe in the event of fire.

Testing the Designs

Innovation was also key to Livermore's Test Program, which was given the task of experimentally testing nuclear devices to prove the designs. Project Plowshare was one way that Livermore staff gained valuable experience and expertise in underground testing that helped to prepare the U.S. for the Limited Test Ban Treaty, which ended atmospheric nuclear testing in 1963. For instance, one Plowshare idea was to use nuclear explosives to generate large volumes of heat for electrical production. The Laboratory tested this idea in underground salt domes, which contain the explosion. When the end of atmospheric testing came, Livermore scientists were already knowledgeable about containment and how to measure results underground.

Innovation also gave rise to a host of new technologies and exotic instruments and measurement techniques. For example, as the Laboratory explored designs with tailored nuclear output in the mid-1960s, those research efforts made necessary more detailed characterization of the x-ray output of various test "x-ray bombs." Hal Mallett, who headed the X-Ray Measurements Group from 1977 to 1986, notes, "This need



The Polaris missile represents the success of Livermore efforts to develop small, efficient thermonuclear weapons that could be carried by submarine. Polaris's success was critical in establishing U.S. nuclear deterrent capability.

A comparison of (a) "Fat Man," the bomb dropped on Nagasaki, Japan, in 1945, and (b) a modern reentry vehicle, 10 of which are mounted in the nose of a Peacekeeper intercontinental ballistic missile, shows how Livermore's innovative designs allowed the U.S. to reduce the size and weight of nuclear warheads without compromising the systems' yield requirements.

In an underground test, a nuclear device was placed down a hole, typically 300 meters deep. A separate canister above held the diagnostic instruments. The explosion would vaporize the detectors, apparatus, and cables in a fraction of a second. But by that time, all the data needed had been fully recorded a safe distance away. (Top) The need to test underground led to a burst of engineering innovation. For example, mammoth drilling rigs, available nowhere else in the world, were specifically designed to dig the deep vertical shafts. (Bottom) Data signals from the test explosion moved up and out of the hole through cables, which in turn fanned out on the surface to trailers that housed instruments for reading the signals. As a signal flashed across the face of an instrument—often a specially designed oscilloscope—a camera snapped its picture. In later years, much data moved "up hole" in digital form, eliminating the need for recording analog signals.

provided an impetus for a renaissance in x-ray diagnostics here at the Lab. From that time through the 1980s, basic x-ray physics technology and knowledge grew, as did our experimental development and calibration capabilities."

It Started with Weapons

The Laboratory's willingness to try out new ideas and new approaches to solve problems began with nuclear weapons design and came to embrace all areas of research the Laboratory was asked to pursue. Whether the challenge lies in stockpile stewardship, computations, engineering, bioscience, lasers, national security, chemistry, or energy and the environment—in one way or another, that challenge can probably trace its lineage to the early days of the Laboratory.

—*Ann Parker*

Key Words: 50th anniversary, nuclear weapon design, nuclear stockpile, Polaris missile, Project Plowshare, Test Program.

For further information about the Laboratory's beginnings, see the following Laboratory Web sites:

On the history of Lawrence Livermore
www.llnl.gov/timeline/
www.llnl.gov/llnl/02about-llnl/history.html

On Ernest O. Lawrence
www.llnl.gov/str/October01/Lawrence.html

On Edward Teller
www.llnl.gov/str/07.98.html

On Herbert York
www.llnl.gov/llnl/history/york.html

Making History, Making a Difference

Throughout 2002, Livermore Laboratory will be celebrating its 50th anniversary. We invite our readers to join us on the journey of remembering our past accomplishments, discovering their influence on the present, and pondering their potential for future achievements.

This article on Livermore's origins in innovative nuclear weapons design research is the first in a series of 10 articles that will appear in *S&TR* throughout this anniversary year. For more information about other activities planned for the 50th anniversary celebration, see www.llnl.gov/50th_anniv/.

This list of anniversary-related events and publications will be updated and expanded in each issue of *S&TR*.