Edward Teller's Centennial

Celebrating the

Man and His Vision

Science and Technology Review*'s series of articles tracing the intellectual contributions of Edward Teller, one of Lawrence Livermore's cofounders, concludes with the remembrances of his colleagues on the centennial of Teller's birth—January 15, 2008.*

(Opposite page) A photographer captures Edward Teller at home in Palo Alto, California, while wife Mici looks on. (Left) Teller's son Paul receives an early introduction to science as Teller chats with famed physicists Julian Schwinger and David Inglis. (Above) Teller was an avid musician.

PHYSICIST, visionary, patriot, cofounder of Lawrence Livermore, adviser to presidents, educator, musician, friend, colleague, husband, and father, Edward Teller deeply influenced the 20th century both in the scientific and policy arenas. Teller died September 9, 2003, at the age of 95. This year marks the 100th anniversary of his birth, prompting the celebration and reflection of one of the giants of the Golden Age of Physics who was an inspiration for countless researchers.

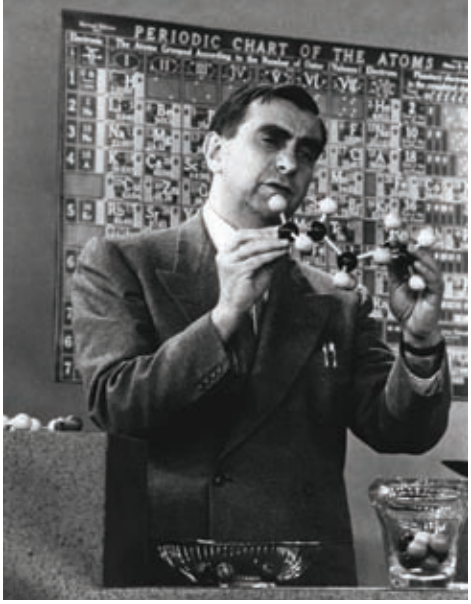
"Teller was always pondering new ideas and approaches," says Livermore physicist Stephen Libby. "Many of his ideas changed science—and the world." Teller helped invent the weapons that played key roles in ending the Second World War and the Cold War. He was often far ahead of his time, for example, in his advocacy as early as the 1940s for advanced safeguards for nuclear power and in his innovative ideas on how to defend the Western world.

Teller was influential with presidents and members of Congress on issues of national security as well as science research and policy. Speaking at Teller's memorial service in 2003 at Lawrence Livermore, former Secretary of State George Shultz, a colleague of Teller's at Stanford University's Hoover Institution, spoke of Teller's influence in advising President Ronald Reagan and strengthening the president's resolve in negotiations that helped end the Cold War.

At the 1986 U.S.–Soviet summit in Reykjavik, Iceland, during intense negotiations with President Reagan, Soviet General Secretary Mikhail Gorbachev insisted that the U.S. drop its research in strategic defense. President Reagan hung tough, thanks in part to Teller's unflinching support of the Strategic Defense Initiative (SDI), which Teller helped to conceive. "Teller's role was crucial in impressing the Soviets of its potential reality," said

Secretary Shultz. "That was a substantial contribution to the end of the Cold War." Also attending the Livermore service was Hungarian Ambassador András Simonyi who simply stated, "We owe him our freedom."

According to Livermore physicist Lowell Wood, Teller was a "mind warrior" because he fought the Cold War with his brain and not his body. "He persuaded a lot of people to do likewise," says Wood, who worked closely with Teller at the Laboratory. Another measure of Teller's influence can be seen in the indirect effect his ideas had on Soviet military and political leaders. In an effort to accelerate the pace of research and development of thermonuclear weapons, Teller campaigned for the establishment of a second U.S. nuclear design laboratory. Former Soviet officials acknowledged that the creation of Livermore to augment the efforts at Los Alamos convinced them that the Soviet Union also needed a second nuclear design laboratory. That laboratory was created five years after Livermore opened.



Teller's devotion to educating young people was legendary.

Teller believed that strengthening national security was a personal obligation. Former Livermore physicist Edward Turano, now associate director of technology for the Defense Threat Reduction Agency, says, "Teller was obsessed with finding favorable solutions for the advancement of humanity. He pondered how we could create and inspire new science and technology that could be used for good, while stressing the need for international coalitions. Teller and I would discuss how the proliferation of nuclear materials and technology was inevitable. He wanted to counter this threat by encouraging international safeguards and working toward worldwide collaborative concepts such as a global missile defense shield."

President Ronald Reagan introduces Teller to Soviet General Secretary Mikhail Gorbachev (far left) at a Washington, DC, reception.

Complete Understanding of Physics

Several of Teller's major proposals were both politically and technologically controversial, but he was uncompromising in his beliefs and unconcerned about criticism of his ideas. However, in the scientific arena, Teller's former colleagues all agree on his broad knowledge of physics. "He had a mastery of physics," says Livermore physicist Neal Snyderman. "Edward sought to understand everything from a fundamental level."

Teller's approach to thinking through problems from fundamental principles went beyond basic science into the applied arena. "He was so much more than a theoretical physicist," says Laboratory Director Emeritus John Nuckolls. "A lot of people came to his office to think through their ideas with him. During a discussion, they would think they had come up with a convincing argument for their position, but the next morning, he would show up with a retort." Says Wood, "Edward could be ferocious on matters of intellectual combat."

Laboratory Director Emeritus Bruce Tarter recalls of Teller, "When one raised a question to him, he could give a 5- to 10-minute comprehensive, erudite answer that was astounding. He thought about physics all the time. Two of his defining drives in life were an insatiable intellectual curiosity and a powerful desire to understand the universe."

Livermore physicist Mort Weiss recalls, "Teller had a wide range of interests and that made him a lot of fun. He was very open to new ideas. There was nothing small about him." Livermore physicist Berni Alder adds, "Teller was interested in so many things. He talked to everyone. When he smelled something interesting, he got involved. He always questioned people about their current work. He liked imaginative, creative, quick-thinking people. Teller didn't tolerate fools."

Teller once said, "Knowledge may be dangerous. Ignorance is incomparably more dangerous." Because he was always intensely curious in matters of science, Teller enjoyed discussing the latest scientific advances, especially in physics. "He would be interested in the fundamental aspects of a problem," says Wood. "If he could not find the bedrock in a problem, it was just a descriptive exercise, telling what it is, not why it is. By looking into the heart of a problem, he could tell someone what fundamental things were possible."

Teller had extremely high standards for what it meant to understand a topic, for example, particle physics. Snyderman explains, "He wrote papers with fellow giants of physics such as Enrico Fermi, Lev Landau, Richard Feynman, Julian Schwinger, and George Gamow that went straight to the heart of a problem." These renowned papers were more complete than most current published papers.

Wood recalls attending a presentation by Teller in 1959 while an undergraduate at the University of California (UC) at Los Angeles. Teller, who was the director of Livermore at the time, gave a technical seminar on the gravitational constant. His talk argued against the hypothesis that the gravitational constant had varied significantly since the birth of the universe—a hypothesis of Paul Dirac, one of the greatest physicists of the 20th century. In his lecture, Teller stated that if such variations had existed, the Sun would have been so luminous that the oceans would have likely boiled over during past epochs. However, fossil evidence shows life thrived. "His argument combined geology, astrophysics, biology, and paleontology," says Wood. "It was a staggering tour de force. He prepared his talk in his spare time, while he was leading the charge toward modern thermonuclear weapons. I remember thinking, 'Wow, this guy really knows physics.' I never forgot that seminar."

Teller's rare combination of deep knowledge and boundless imagination was evident even in his last years. (See the box below.) Less than two weeks before he died, Teller asked to see new data supporting an accelerating expansion of the universe. Three days before his death, Teller, Wood, and Nuckolls held a long discussion about advanced energy systems for the future.

Impressive Record of Physics

Teller's career can be divided roughly into two overlapping phases. The first, from 1928 to about 1952, was largely devoted to scientific research and university life. In the second phase, which began with the discovery of fission in 1939, he focused on applying physics to defense and, later, on cofounding the Laboratory with Ernest O. Lawrence.

During the first phase, which immediately followed the discovery of quantum mechanics, Teller made contributions to a host of physics

Lunch with Edward

Over the years, Edward Teller enjoyed having wide-ranging discussions over lunch with many scientists at Livermore. In his later years, participants included Brian Wilson, Stephen Libby, Neal Snyderman, Mort Weiss, Edward Turano, Todd Hoover, David Dearborn, Lowell Wood, Ralph Moir, Chuck Leith, John Nuckolls, and Richard More. No topics were set, and discussions lasted an hour or longer. Subjects centered around topics as diverse as fundamental physics, cosmology, mathematics, energy, nuclear proliferation, nuclear weapons projects, recent concepts in defense, politics, cancer, biology, and the human genome. Turano recalls, "Edward would ask, 'What do we need to do now to be where we want to be 50 years from now?'"

Typically, Teller started luncheon discussions with a topic that interested him at the moment, then asked his guests their opinions. Says Snyderman, "He was a social person and enjoyed learning through interactions with others. This characteristic may have stemmed from his friendship with Niels Bohr, who was very social." Although the discussions were often freewheeling, they also generated ideas that guests could exploit in their current national security work.

Even in the last year of his life, Teller's mind and memory appeared sharper than many scientists 30 years his junior. Because he could barely see, he might ask a lunch guest to read a paper to him, if required.

Snyderman says, "He was known as a stubborn person, but he was a physicist, so it was always possible to convince him with empirical evidence and coherent arguments. I enjoyed many long, lively conversations with him on a variety of topics in fundamental physics. I lost a very special friend."

Livermore physicist Lowell Wood was a long-time associate of Teller's.

disciplines, including statistical mechanics, quantum theory, molecular physics, condensed-matter physics, surface physics, magnetism, nuclear physics, and astrophysics. (See the box below.) These contributions remain fundamental parts of current scientific knowledge and understanding.

Teller's early work on molecular physics provided insights to the dynamics of polyatomic molecules, thus deeply influencing subsequent development in the area of physical chemistry. Perhaps the most important part of this work was the discovery of the Jahn–Teller effect describing the distortion of nominally symmetric molecules. The Jahn–Teller effect is ubiquitous in chemical and solid-state physics.

Teller also proposed what became the basic adsorption model in surface physics, the Brunauer–Emmett–Teller equation of state, which accounts for the adsorbate atom's simultaneous tendencies to attach and evaporate. It is still applied in surface physics. In addition, the exactly solvable Ashkin–Teller model in statistical physics continues to provide insight into the thermodynamics of phase transitions. Teller was also a major contributor to the Monte Carlo computational method often called the Metropolis algorithm, which *Computing in Science and Engineering* selected as one of the 10 most important computational algorithms of the 20th century.

In 1936, Teller and Gamow made a key contribution to the rapidly developing field of nuclear physics in their paper on beta decay, which described how a nucleon could flip its spin during the decay transition when emitting an electron and an antineutrino. This phenomenon is now called a Gamow–Teller transition, the discovery of which turned out to be a large step toward the modern Standard Model of elementary particles. The Teller–Gamow paper also unexpectedly led to an understanding of nuclear energy generation in the Sun.

In the late 1940s, with Fermi and Victor Weisskopf, Teller showed conclusively that the mu meson (or muon) could not be the then-sought Hideki Yukawa pi meson (or pion). In another contribution, the Lyddane–Sachs–Teller relation described the dielectric constant needed to explain how photons propagate in salts. This relation proved, in turn, to be a fruitful analogy, leading Maurice Goldhaber and Teller to predict strong universal gamma-ray absorption resonances in nuclei.

Life at the Laboratory

The second phase of Teller's career centered on work done for Lawrence Livermore. In 1951, while still at Los Alamos, Teller's revolutionary contribution to nuclear weaponry was his technical insight that made thermonuclear weapons possible and practical. He was the driving force behind the successful development and testing of the first hydrogen bomb. In 1952, Lawrence and Teller opened the Livermore branch of the University of California Radiation Laboratory (UCRL), and for more than five decades, Teller was a major influence for the extraordinary record of research and development at Livermore. "Teller and Lawrence were an unbeatable combination," reflects Wood.

At Livermore, Teller pushed for novel nuclear weapon designs and smaller warheads. In particular, in 1956, he proposed to the Navy the development of thermonuclear warheads small and light enough to be carried on submarine-launched ballistic missiles. That successful program, much of which was carried out while Teller served as

***Science and Technology Review* articles honoring Edward Teller's life and contributions to science.**

From Sound Waves to Stars Teller's Contributions to Shock Physics	March 2007
A Search for Patterns and Connections Teller's Contributions to Computational and Mathematical Physics	April 2007
Exchanging Insights on Quantum Behavior Teller's Contributions to Condensed-Matter Physics	May 2007
A Gifted Teacher of Applied and Fundamental Physics Teller's Contributions to Education	June 2007
Taking on the Stars Teller's Contributions to Plasma and Space Physics	July/August 2007
From Fission to Fusion and Beyond Teller's Contributions to Applied Physics and Defense	September 2007
Back to Basics Teller's Contributions to Atomic and Molecular Physics	October 2007
Probing Deep into the Nucleus Teller's Contributions to Nuclear and Particle Physics	November 2007
Power to the People Teller's Contributions to Nuclear Power Research	December 2007

Laboratory director from 1958 to 1960, established Livermore's reputation for innovative nuclear design. In 1998, Teller reflected, "The Laboratory is the one thing in my life that I am completely happy about."

In 1960, Teller accepted a joint appointment as professor of physics-at-large for UC and as associate director for Lawrence Radiation Laboratory (both the Berkeley and Livermore sites). In 1965, he was named associate director for physics at Livermore. Upon his retirement in 1975 from UC, Teller became director emeritus at Lawrence Livermore and joined the Hoover Institution at Stanford University as a senior research fellow. At the Hoover Institution, he specialized in international and national policies concerning defense and energy.

In support of SDI during the 1980s, Teller promoted the concepts of x-ray lasers driven by nuclear explosives and nonnuclear "brilliant pebbles" satellites. Even then, at an advanced age, he wanted to contribute to both science and his adopted homeland in any way possible. Above all, Teller believed that being a scientist meant solving the world's biggest problems.

Teller was instrumental in acquiring Livermore's first generations of powerful computers. In this 1960 photograph, he confers with Sid Fernbach (left), who led scientific computing at the Laboratory, and Harold Brown, Teller's successor as Laboratory Director. The Livermore Advanced Research Computer is in the background.

Focus on Applied Science

Teller focused Livermore on applying basic science to national security issues. "He gets enormously big marks for pushing applied science," says Tarter. "He had an unshakable belief in technology to improve the human condition. He felt the Laboratory was a place where that could be carried out." Indeed, Teller recognized that U.S. security and prosperity depended on applied science and technology. According to Wood, Teller believed that the U.S. embraced applied science, unlike Europe, and credited this factor as being one that drove the U.S. to preeminence in the 20th century.

Teller's desire to see practical results from basic science research influenced his leadership of "Teller Tech," the Department of Applied Science at Livermore, which was established as part of the College of Engineering at UC Davis in the early 1960s. His founding of Teller Tech was based on the idea of encouraging young applied scientists to take advantage of the latest developments in basic science.

Teller had always been inspired to teach. In the U.S., he taught successively at George Washington University, Columbia University, University of Chicago, and at several UC campuses, eventually holding the prestigious title of University of California Professor Emeritus. Many of his graduate students went on to become prominent scientists, including Chen Ning Yang from Chicago, who won the Nobel Prize in Physics in 1957. In 1963, at the height of the Cold War, Teller worked with Fannie and John Hertz to found the Hertz Foundation Graduate Fellowship Program to provide training for innovative applied scientists and engineers.

Teller considered the advancement of nuclear power one of the most important applications of science and engineering. In the late 1940s, he served as a member of the General Advisory Committee of the U.S. Atomic Energy Commission and chaired the Reactor Safeguard Committee. In his desire to make nuclear power plants safe, Teller identified operator error as the first problem to be solved, and he conceived the idea of burying reactors to avoid a catastrophic release of radiation. In the late 1950s, during the summer Teller spent at General Atomics in San Diego, he challenged Freeman Dyson, Frederic de Hoffmann, and others to design a small, ultrasafe research reactor. The General Atomics team succeeded with TRIGA®.

During the last year of his life, when Teller was almost completely blind, he wrote a paper with Livermore physicist Ralph Moir on thorium-burning reactors sited underground. This reactor design would use molten salt technology either without reprocessing for proliferation resistance or with reprocessing to maximize resources. Teller argued for leaving the fission products stored underground at the reactor site indefinitely or, if required, eventually transporting them to a dedicated repository. This paper, his last, was published in 2005 in *Nuclear Technology*.

In applying science to issues of national importance, Teller tirelessly supported collaboration and openness. He believed advances in national security and research were stronger when conducted in the open. Teller was instrumental in the declassification of magnetic energy research. Nuckolls recalls that "Teller argued magnetic fusion had little, if anything, to do with weapons and was potentially a major force for good."

One of Teller's great accomplishments at Livermore was promoting the use of computers to advance applied science. He was influenced by his long association with John von Neumann of the Institute for Advanced Study in Princeton, who helped pioneer the first electronic computers. Throughout its history, Livermore has been a world leader in using supercomputers and establishing simulation as a worthy partner with theory and experiment. In the 1950s and 1960s, however, computation in physics was not regarded as entirely respectable. "Real physicists worked with equations, not programs," says Livermore physicist Mal Kalos. "Teller understood better."

Reflecting Teller's Style

Libby observes, "The Laboratory has always reflected Teller's and Lawrence's styles: a place for innovation, imagination, and can-do attitudes. Livermore people have consistently focused on applications with a willingness to try new ideas and not be stopped by conventional thinking." Weiss adds, "We can't lose the spirit of inquiry that Teller brought."

Perhaps the words of President George W. Bush, when he presented Teller with the Presidential Medal of Freedom, best describe this giant of a man: "For a long life of brilliant achievement and patriotic service, America is in debt to Dr. Edward Teller."

—Arnie Heller

Key Words: applied science, Ashkin–Teller model, basic science, Brunauer–Emmett–Teller equation of state, Department of Applied Science University of California at Davis, Edward Teller, Gamow–Teller transition, hydrogen bomb, Jahn–Teller effect, Lyddane–Sachs–Teller relation, Metropolis Method, national defense, national security, nuclear power, physics, Presidential Medal of Freedom, Strategic Defense Initiative (SDI), thermonuclear weapon, x-ray laser.

For further information contact Stephen B. Libby (925) 422-9785 (libby1@llnl.gov).

Teller and Livermore Director's Office administrator Shirley Petty admire Teller's Presidential Medal of Freedom.

Teller presided as grand marshal in several Livermore rodeo parades.