

Los Alamos National Laboratory – 70 Years of Science and Beyond

VISTAS

**EXPERTISE AND
ACHIEVEMENTS IN
MAKING, MEASURING,
AND MODELING**

Through the science of making, measuring, and modeling, the people of Los Alamos National Laboratory discover breakthrough solutions to the most pressing national security challenges.

**PEOPLE BEHIND
THE SCIENCE AND
TECHNOLOGY**

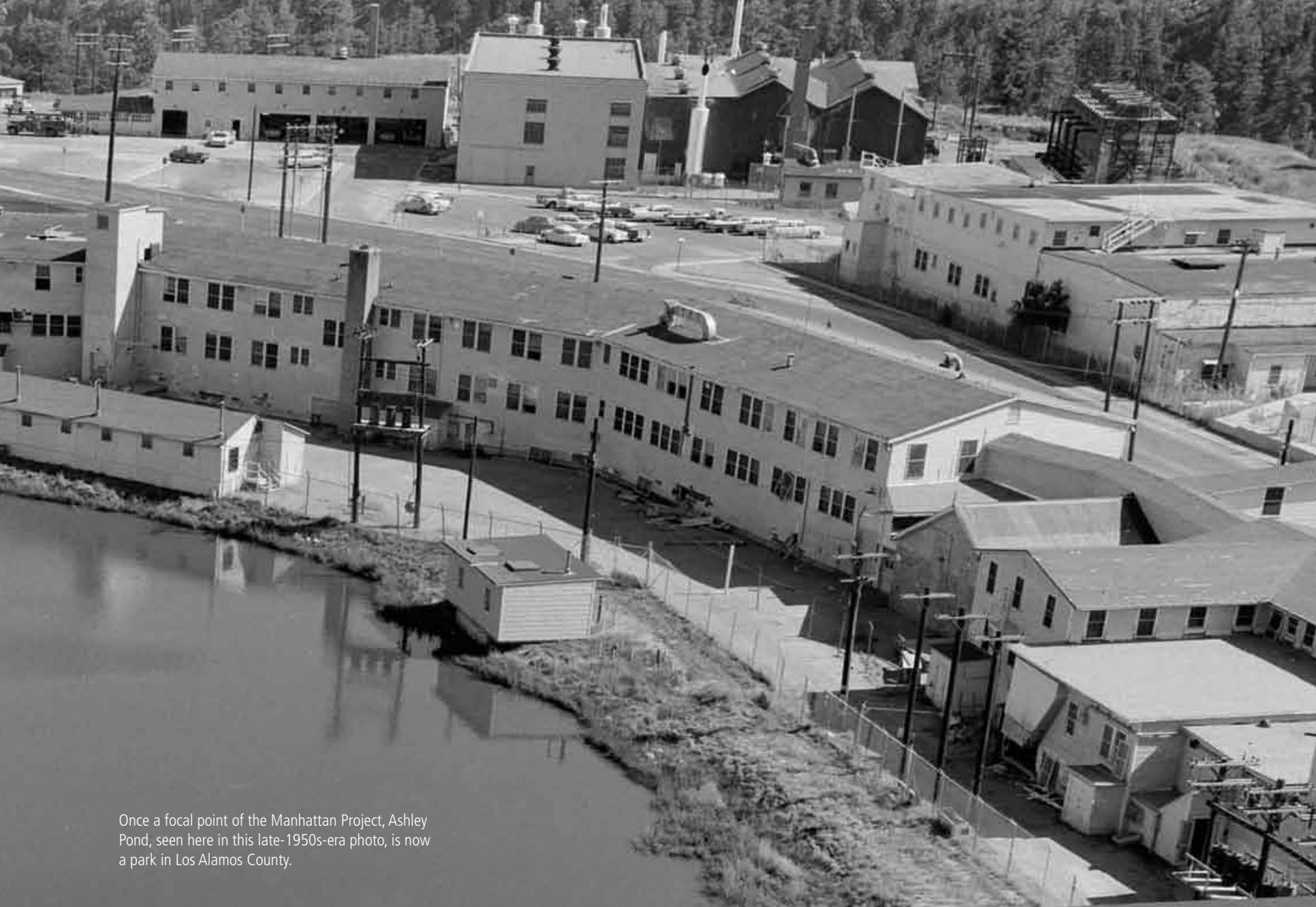
**LOS ALAMOS
MILESTONES**

**LAMPF
TO
MaRIE**

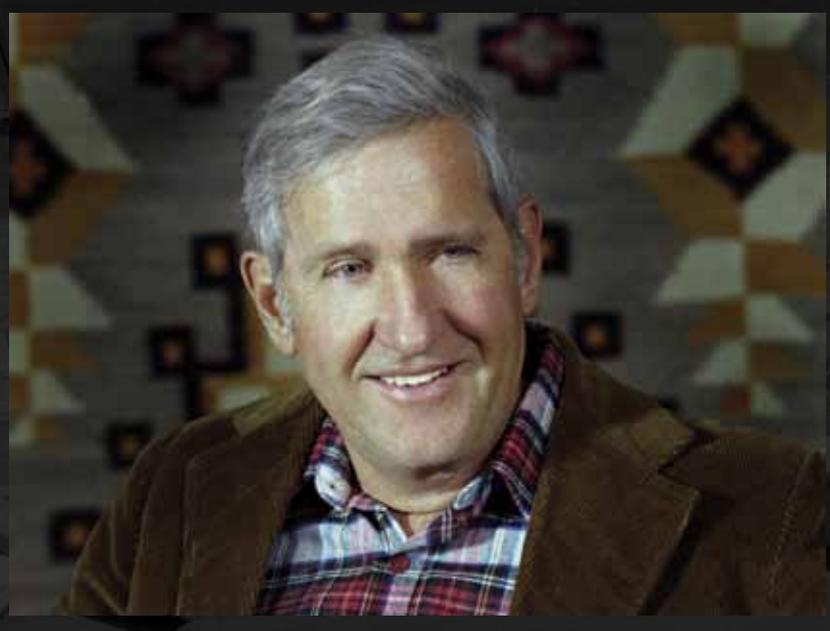
**THE EVOLUTION
OF LOS ALAMOS
SIGNATURE
FACILITIES**



EXPERIMENTAL PHYSICAL SCIENCES



Once a focal point of the Manhattan Project, Ashley Pond, seen here in this late-1950s-era photo, is now a park in Los Alamos County.

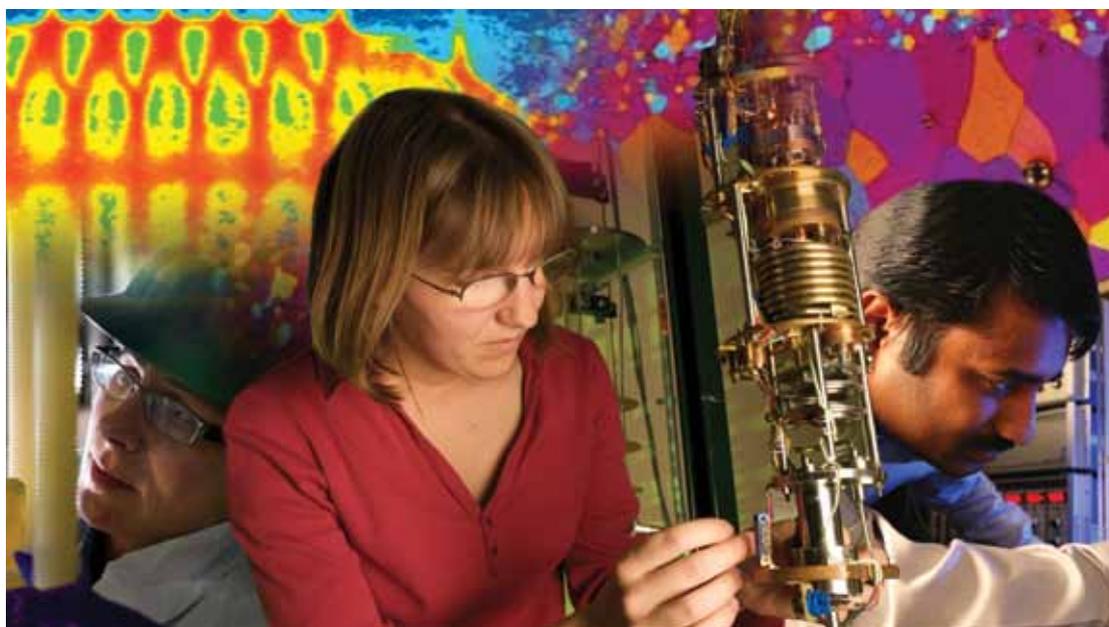


This issue of *Experimental Physical Sciences Vistas* is dedicated to former Laboratory Director Harold Agnew. Under his directorship, Los Alamos National Laboratory expanded the frontiers of making, measuring, and modeling science. During Agnew's nine-year tenure, the Laboratory opened its present Plutonium Facility for production and research, completed the Clinton P. Anderson Meson Physics Facility (now the Los Alamos Neutron Science Center), and acquired the world's first modern supercomputer, the Cray-1.



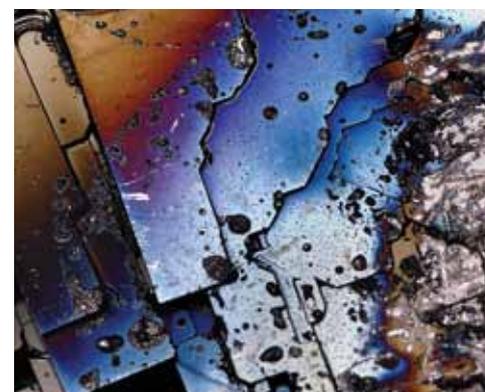
32 The Evolution of Signature Facilities at Los Alamos

From LAMPF to MaRIE, Los Alamos signature facilities are aimed at giving researchers the tools they need to conduct experiments on the frontiers of science. The illustration at left shows proposed MaRIE facilities on the LANSCE mesa.



1 Making, Measuring, and Modeling

Critical to the success of the Manhattan Project, making, measuring, and modeling remain key to fulfilling Los Alamos National Laboratory's national security science mission.



26 Focus

Visualize Los Alamos science, past and present.

Cover: From left, Deniece Korzekwa, Irene Beyerlein, and Frank Merrill represent the forefront of MaRIE making, measuring, and modeling science at Los Alamos National Laboratory. To learn more about MaRIE, please see page 33. (Photos by Sandra Valdez) • Back cover: Louis Rosen, known as the "Father of LANSCE" for his vision and dedication to the development of the Los Alamos Neutron Science Center, is shown with a model of LANSCE's 800-MeV linear accelerator.

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Experimental Physical Sciences

VISTAS

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Fall 2013
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Acknowledgements

Malcolm Andrews, Steven Batha, Konstantin Borozdin, Rod Borup, Hou-Tong Chen, Necia Cooper, Micheline Devaurs, David Funk, Rao Garimella, Mary Hockaday, David Holtkamp, Kevin John, Konstantin Lipnikov, Thomas Mason, David S. Moore, Kathy Prestridge, John Sarrao, Laura Smilowitz, Josh Smith, Caroline Spaeth, Dale Tupa, Sandra Valdez, Roger Wiens, and the many others at Los Alamos National Laboratory who have had a hand in creating the editorial content featured within these pages.
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Page 10: Biographical details, "Cyril S. Smith," accessed October, 2013, www.atomicheritage.org/index.php/component/content/275.html?task=view. Used with permission from the Atomic Heritage Foundation; Quote, Wilhelmy, J.B. 1999. Laboratory report (LA-UR-02-7662).

Page 16: Quote, Reines, Frederick. 1982. Neutrinos to 1960—Personal Recollections. *Journal de Physique* **43** (supplement to 12): C8-237.

Page 22: Quote, Feynman, Richard P. 1976. Los Alamos from Below -- Reminiscences of 1943-1945. *Engineering and Science*, **39** (2). pp. 11-30. Reprinted with the permission of Caltech.

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MAKING, MEASURING, and MODELING

Seventy years of science in support of national security

Making, measuring, and modeling sciences were critical to the success of the Manhattan Project, and they remain key to fulfilling today's national security science mission at Los Alamos National Laboratory.

During the Manhattan Project, world-renowned scientists were recruited in the name of national security for their expertise in nuclear physics, theoretical physics, and metallurgy and chemistry. Their efforts led to the world's first atomic bomb and the abrupt end of World War II.

Nuclear physics questions were at the heart of the initial research and development leading to and during the Manhattan Project. As work progressed, the required materials had to be created, making chemistry and metallurgy increasingly important. The properties of the man-made plutonium material needed to be measured. With only limited quantities of material available at the beginning, there was a real need to predict, or model, whether the devices would work in lieu of conducting many tests.

Susan J. Seestrom

Associate Director, Experimental Physical Sciences



Today, as the Laboratory has evolved into a multidisciplinary science and technology institution, making, measuring, and modeling research remain at the core of the Laboratory's national security mission and basic science discoveries.

The quest for better performance is continuous. Progress requires that we repeat this cycle, and MaRIE (Matter-Radiation Interactions in Extremes), the Laboratory's proposed flagship experimental facility, puts our researchers on the path forward.

In this issue of *Experimental Physical Sciences Vistas*, we define the following as:

Making—discovering materials, fabricating samples and products, and characterizing their properties;

Measuring—performing physics measurements aimed at understanding science questions and providing new tools; and

Modeling—predicting and developing theoretical understanding of performance.

MAKING, MEASURING, MODELING



From the Manhattan Project ...

Nuclear fission had been discovered when the Manhattan Project began in 1939. Yet the gulf between knowing an atomic bomb is theoretically possible and building one is almost unimaginable. With equations in hand and their mission's importance weighing on their minds, Manhattan Project scientists furiously went to work. Breaking down this complex, often overwhelming task, they made materials, measured phenomena, modeled outcomes, and repeated the cycle, gradually scaling up, until July 16, 1945, when the Trinity nuclear test awed those involved with its success and its implications. Less than four weeks later the first atomic bombs were detonated over Hiroshima and Nagasaki. Japan surrendered on September 2, 1945.

Making, measuring, and modeling are inextricably linked throughout the history of Los Alamos.

... to today ...

The impact of the Manhattan Project and the atomic bomb in ending World War II convinced government policymakers of the importance of scientific investment to national security.¹ Although Los Alamos Scientific Laboratory was established in 1943 as a mission-oriented institution, basic research has always been recognized as important to our long-term goals. Fundamental breakthroughs in fundamental science have often, in turn, expanded the scope of our mission.

For example, the Laboratory's need to understand the effects of radiation exposure and to set dosage guidelines for its researchers led to diverse biological programs, including the Laboratory's leadership in the Human Genome

Making, measuring, and modeling science also has been a fundamental organizing structure since the institution's founding. Today's Los Alamos Neutron Scattering Center (LANSCE), Accelerator Operations and Technology (AOT), Physics (P), Materials Physics and Applications (MPA), Materials Science and Technology (MST), Chemistry (C), and Theoretical (T) divisions all trace their lineage to 1944's Chemistry (C), Physics (P), and Theoretical (T) divisions.

OPPENHEIMER		BRADBURY																	AGNEW																	
1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	
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Breakthrough

In 1992 the Limited Test Ban Treaty took effect, and the era of Stockpile Stewardship began. More than ever, we had to improve the understanding of manufacturing and weapons performance because there were no tests. Large-scale computation became increasingly important, and understanding the models built into these codes and designing experiments to validate Laboratory models again drove the need for new measurement techniques. For more details on the role of modeling at Los Alamos, please see page 18.

... and beyond, MaRIE

Making, measuring, and modeling are inextricably linked throughout the history of Los Alamos. This is true for the basic science work at the Laboratory as well. The detailed technical challenges have changed over the years—with the center of gravity shifting to materials science as opposed to nuclear physics. To succeed into the future we will need to integrate these scientific endeavors even more thoroughly using our proposed facility MaRIE.

Please enjoy looking over this issue of *Experimental Physical Sciences Vistas*, which expands on many of these topics and shows examples of what the Laboratory has accomplished. ■

Susan J. Suction

¹ Vannevar Bush — “Science, the endless frontier,” a report to the President on post-war scientific research, U.S. Government Printing Office, 1945.



MODELING

Antibody evolution could guide HIV vaccine development

Observing the evolution of a particular antibody type in an infected HIV-1 patient, a study spearheaded by Duke University, including analysis from Los Alamos, has provided insights that will enable vaccination strategies that mimic the actual antibody development within the body.

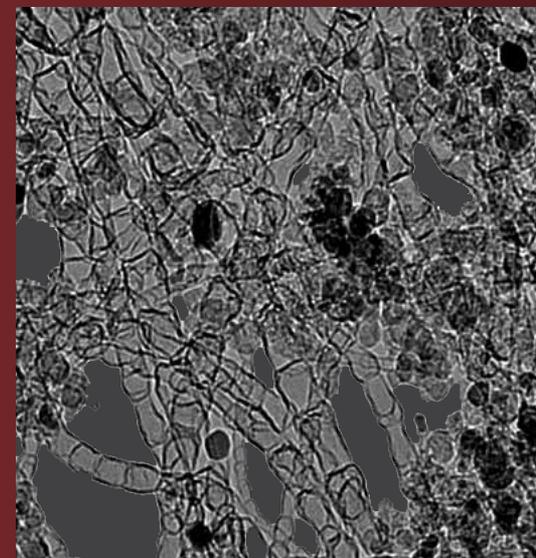
Details of the generation of the broadly cross-reactive neutralizing antibody could provide a blueprint for effective vaccination, according to the study's authors. The observations trace the co-evolution of the virus and antibodies, ultimately leading to the development of a strain of the potent antibodies in this subject, and they could provide insights into strategies to elicit similar antibodies by vaccination.

“Our hope is that a vaccine based on the series of HIV variants that evolved within this subject, that were together capable of stimulating this potent broad antibody response in his natural infection, may enable triggering similar protective antibody responses in vaccines,” said Bette Korber, leader of the Los Alamos team.

“Co-evolution of a broadly neutralizing HIV-1 antibody and founder virus,” *Nature* 496 (April 2013)

Co-evolution of virus and antibody. The evolution of the viral protein (green) from 14 weeks through 100 weeks post-transmission is compared to the maturation of the human antibody.

A high-resolution microscopic image of a new type of nanostructured-carbon-based catalyst developed at Los Alamos National Laboratory that could pave the way for reliable, economical next-generation batteries and alkaline fuel cells.



hs in basic science

MEASURING

Plutonium less mysterious with nuclear magnetic resonance

The faint signal of plutonium-239's unique nuclear magnetic resonance (NMR) signature has been detected by researchers at Los Alamos, including two scientists from the Japan Atomic Energy Agency. The signal promises to become a Rosetta stone for deciphering the complex atomic-scale electronic properties of this perplexing element.

For more than 50 years, chemists and physicists searched for the plutonium-239 magnetic resonance signal. Only now, through a year-long effort at Los Alamos National Laboratory, has this team determined just the right conditions for observing the signal.

“Just as knowing the NMR properties of other nuclei has advanced so significantly our ability to understand complex materials and phenomena as well as to image matter on a microscopic scale,” said Los Alamos researcher Georgios Koutroulakis, “this discovery of the plutonium-239 magnetic resonance promises to revolutionize our understanding of plutonium solid state physics, chemistry, biology, and materials science.”

“Observation of ^{239}Pu Nuclear Magnetic Resonance,” *Science* **336** (May 2012)

MAKING

Economical non-precious metal catalyst capitalizes on carbon nanotubes

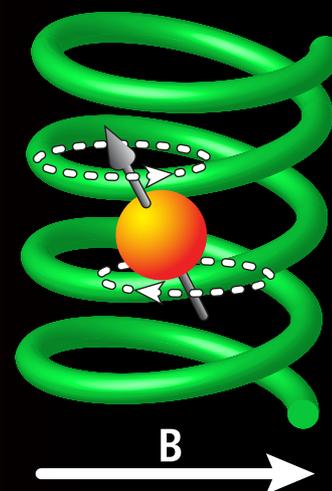
Los Alamos scientists have designed a new type of nanostructured-carbon-based catalyst that could pave the way for reliable, economical, next-generation batteries and alkaline fuel cells, providing for practical use of wind- and solar-powered electricity, as well as enhanced hybrid electric vehicles.

The catalyst has the highest oxygen reduction reaction activity in alkaline media of any non-precious metal catalyst developed to date, activity critical for efficient storage of electrical energy. The new catalyst doesn't use precious metals such as platinum, yet it performs under certain conditions as effectively as many well-known and prohibitively expensive precious-metal catalysts developed for battery and fuel-cell use. Moreover, although the catalyst is based on nitrogen-containing carbon nanotubes, it does not

require the tedious, toxic, and costly processing usually required when converting such materials for catalytic use.

“These findings could help forge a path between nanostructured-carbon-based materials and alkaline fuel cells, metal-air batteries and certain electrolyzers,” said Laboratory researcher Piotr Zelenay. “A lithium-air secondary battery, potentially the most-promising metal-air battery known, has an energy storage potential that is 10 times greater than a state-of-the-art lithium-ion battery. Consequently, the new catalyst makes possible the creation of economical lithium-air batteries that could power electric vehicles, or provide efficient, reliable energy storage for intermittent sources of green energy, such as windmills or solar panels.”

“Active and stable carbon nanotube/nanoparticle composite electrocatalyst for oxygen reduction,” *Nature Communications* **4** (May 2013)



A resonance between the energy levels of the nuclear spin (gray arrow) in a magnetic field (B) is achieved with the help of a coil.

MAKING

Materials for the future

**WORLD-LEADING, INNOVATIVE,
AND AGILE MATERIALS SOLUTIONS
FOR NATIONAL SECURITY MISSIONS**

In just 20 months, the people of Project Y—the Laboratory’s wartime code name—designed and built the world’s first atomic bomb, a “making” milestone instrumental in ending World War II. Through subsequent advancements, the Laboratory’s materials science expertise has been critical in keeping the world safe for more than 60 years. With MaRIE as its future experimental facility for exploring matter-radiation interactions in extremes, Los Alamos will dramatically expand its scientific capabilities, allowing researchers to discover the materials needed for future national security and energy challenges.

PAST

In the earliest days at Los Alamos, it was a feat to fashion plutonium metal into a shiny ball, no bigger than a BB gun would use. Manhattan Project researchers quickly learned how to prepare uranium and plutonium with the required purity, shape, and mechanical properties for atomic bombs. During the Cold War, scientists and engineers helped design, manufacture, and maintain thousands of devices.

PRESENT

As the Laboratory has evolved and missions in threat reduction, defense, energy, and other national challenges have been added, the science of materials

has expanded. For example, the Laboratory produced high-purity plutonium-238 oxide that significantly increased the longevity of space power. Through its work in high explosives, Los Alamos developed environmentally friendly explosives and processes using “green” starting materials. Scientists also created reduced-sensitivity explosives, providing enhanced safety for the warfighter, with impact to the energetic material communities throughout the world.

Making is central to new and nascent research areas as well. Working with the motto of “New Physics from New Materials,” Laboratory scientists discovered so-called heavy-fermion superconductors in the 1980s that contained uranium as the interesting actor. The name arises from the electricity-carrying electrons acting as if they were a thousand times heavier. This phenomenon emerged totally unexpectedly and made Los Alamos into the recognized center of correlated-electron science. Today, materials physicists seek to understand emerging phenomena in new materials, and scientists chart a nanostructure’s path from scientific discovery to integration in macroscale systems.

Making materials continues to underpin the Laboratory’s nuclear deterrence mission. The Labo-



Los Alamos takes over pit production

When Los Alamos unveiled Qual-1, the first fully qualified plutonium pit made after the Rocky Flats Plant near Denver closed, it was big news. The 2003 achievement showed that the United States hadn’t lost the ability to make atomic bombs. These are the cores that initiate a weapon’s nuclear chain reaction when explosively compressed into a supercritical mass. Using casting—whereby plutonium is melted and poured—Los Alamos adopted a new production method and in 2007 delivered the first production pit, for a W88 warhead. By 2009, the program achieved a 100 percent success rate, with every pit produced demonstrating the quality standards required for incorporation into the stockpile.

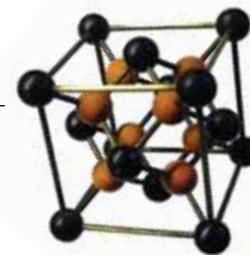
ratory produces the triggers for nuclear weapons and performs prototype-scale manufacturing for most materials in the weapon physics package. Through a combination of chemistry, physics, and computer simulation, scientists determine when weapon parts need to be replaced and design new parts. Los Alamos studies small samples of nuclear materials through destructive and non-destructive methods.

FUTURE

To solve tomorrow’s materials challenges, Los Alamos is pursuing a strategy focused on the intentional control of material functionality. This vision will be achieved through the discovery

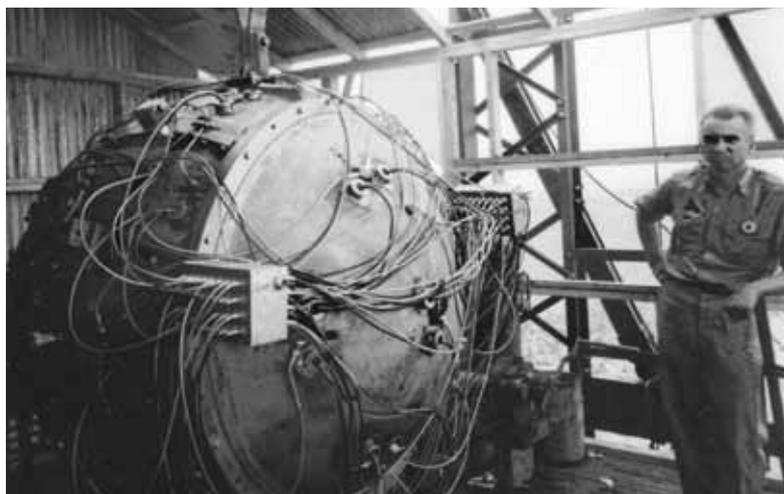
science and engineering required to establish design principles, synthesis pathways, and manufacturing processes for advanced and new materials. With MaRIE, researchers will have the tools needed to develop next-generation materials that will perform predictably and on demand for currently unattainable lifetimes in extreme environments. MaRIE will bring together in one facility a fundamental understanding of physics with advances in materials science, sensing technologies, and computational power to make, model, and measure materials for the future. ■

MAKING milestones



Capturing the crystal structure of pure Pu

Working at Los Alamos in 1957, William H. Zachariasen and Finley Ellinger identified pure plutonium's room temperature crystal structure, which differs wildly from the crystal structure of other metals. Such a measurement was crucial for making weapon parts with structural integrity. Plutonium still holds many secrets. MaRIE could measure plutonium's phases with unprecedented temporal and spatial resolution, laying to rest the question of how best to make durable components for the stockpile.



Making uranium and plutonium parts

To prepare uranium and plutonium for atomic bombs, Los Alamos scientists developed specialized alloying and casting methods. The first weapons made at Los Alamos contained high-precision components and electrical and mechanical parts designed, built, and installed in much the same way as the researchers might have put together a complicated laboratory equipment setup. MaRIE will give researchers the tools to reduce production costs, while making longer-lived weapon components with enhanced performance.



A leader in fuel cell technology

Los Alamos has been a leader in polymer electrolyte fuel cell technology for more than 30 years. By investigating the fundamental mechanisms that determine cost, durability, and performance of fuel cell components, Laboratory researchers provide support to the fuel cell industry to address critical shortcomings and barriers to market entry. Los Alamos fuel cell projects work to reduce or eliminate the need for precious metals, extend the operating lives of fuel cell membranes, develop materials to store hydrogen, and understand the operating degradation mechanisms currently limiting commercialization.



Powering space exploration

From 1955 through 1972, the Laboratory's Project Rover successfully developed the technology for a nuclear-thermal rocket for space applications. As well, beginning in the mid-1960s, the Laboratory developed radioisotope thermoelectric generators (RTGs), which produce heat from the decay of radioactive isotopes, usually plutonium-238, and can provide electrical power and heat for years in satellites, instruments, and computers. Deep space and planetary explorations by NASA that have used RTG heat sources developed at Los Alamos include the Cassini mission to Saturn, the New Horizons mission to Pluto, and the Curiosity rover mission to Mars.



Thorium is now green

Th-ING (for thorium is now green) was developed as a straightforward, cost-effective, and safe method to produce thorium, an element capable of producing more energy than both uranium and coal using significantly lower quantities. Thorium is only slightly radioactive, making it an excellent candidate for a future sustainable energy source. It is so safe that it will never lead to a nuclear meltdown when used in a nuclear reactor.

MAKING milestones



Superconducting materials

Los Alamos has pioneered research on actinide superconductors—from the 1978 discovery of superconductivity of americium to that of uranium superconductors called heavy fermions that soon followed. In 2002, Laboratory researchers found a plutonium compound to be superconducting above 18 Kelvin, unifying heavy-fermion and high-temperature superconductivity. In 1987, the Laboratory's expertise in superconductivity led to the Department of Energy funding the Superconductivity Technology Center, which aimed to boost commercialization of superconductive wire and related technology. In 2003, Los Alamos researchers won an R&D 100 Award for flexible superconducting tape that carries 200 times the electrical current of copper wire.



Keeping a lid on things

For inventing valveless laser processing (VLP), a method of nondestructively examining the contents of sealed containers, Los Alamos and Y-12 National Security Complex won an R&D 100 Award. VLP eliminates the use of valves in hermetically sealed containers by using a laser to access and reseal the containers, thus allowing nondestructive certification and reuse of sampled containers. Originally developed to obtain accurate gas samples of weapon components, VLP applications now range from advancing the safety of sampling high-hazard waste containers to improving leak testing of pacemakers before use. VLP's significant breakthrough is a laser-alloying technique that prevents cracking on materials typically prone to such behavior.

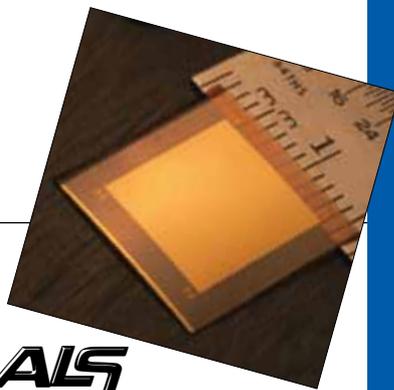
Raising metal forming to a science

In work that garnered a 1976 *Scientific American* cover, Los Alamos raised metal forming to a science. Soon after, the Laboratory created the Center for Materials Science and began modeling the mechanical behavior of materials, developing special expertise in processing and rolling materials. That's how Los Alamos today is able to predict the strength of the materials that go into weapons. Commercial manufacturing has adopted the techniques. MaRIE will be key to advancements in materials processing technology, providing new texture and in situ measurements.



A big focus on tiny materials

At the Center for Integrated Nanotechnologies, researchers from around the world come together to explore materials 10,000 times smaller than the diameter of human hair. Los Alamos scientists are at the forefront of nanoscience—from metamaterial flexible sheets that could transform optics to award-winning NanoCluster Beacons that can be used to probe for diseases that threaten humans.



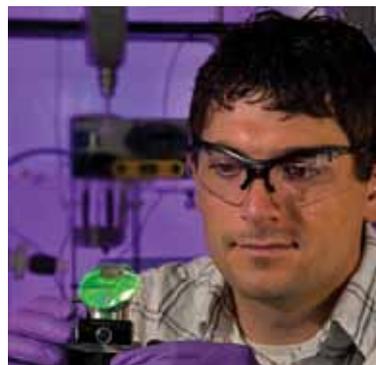
The evolution of Los Alamos materials research

METAMATERIALS

Using metamaterials, scientists can do seemingly impossible things with radio waves and light, such as creating invisibility cloaks. Metamaterials are engineered materials that gain their exotic properties from their sub-wavelength structure rather than their chemical composition. Los Alamos researchers are designing and fabricating functional metamaterials to transform the technological world, with applications in integrated optics, renewable energy, sensing, imaging, and communications.

40s thru 50s

What was the driver for making materials at Los Alamos? Weapons. If the Laboratory didn't make critical nuclear components, nobody else would. That was true in the 1940s, and it remains true today. Following President Eisenhower's 1953 Atoms for Peace speech, the Laboratory parlay its knowledge of nuclear materials into superconductivity, nuclear fuels, and medical isotopes. The Chemistry and Metallurgy Research Facility, one of the world's first experimental facilities for analytical actinide chemistry and metallurgy, is built.



Making energetic materials

Los Alamos has conducted explosives research since its founding days, setting up a special explosives division initially focused on "implosion gadgets" for the Manhattan Project and then transitioning to broader explosives science and engineering today. Scientists continue to discover details about properties of common explosives, such as PETN and HMX. Los Alamos researchers are growing single crystals of explosives and characterizing their fundamental properties. They are developing smaller munitions, replacements for materials that can no longer be manufactured, and energetic binders and burn rate modifiers to enhance energetic performance. With MaRIE, Los Alamos could control manufacturing processes and create materials with characteristics that influence safety, surety, and performance of energetics used in the nation's nuclear deterrent.

U Turn

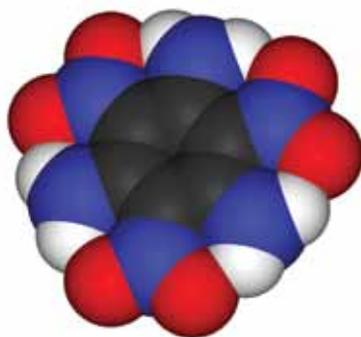
Los Alamos scientists developed a cost-effective, environmentally green, and safe method that produces two new uranium iodide reagents. The method will not only provide a nondestructive path forward for more than 5,300 metric tons of stock-piled nuclear waste, but also stands to revolutionize the use of depleted uranium in chemistry, catalysis, materials science, and energy.

60s thru 70s

In response to Sputnik, which sparked an intense interest in space and nuclear propulsion, Los Alamos builds nuclear rockets and manufactures radioisotope thermoelectric generators. The Plutonium Facility, opening in 1978, becomes a key place in the nation for chemical and metallurgical research.

80s thru 90s

The oil embargo drives substantial research diversification so that by 1980 the Laboratory's funding is approximately half defense and half energy programs. Hydrogen fuel cell research amps up. The Center for Materials Science, the Superconductivity Technology Center, and the Target Fabrication Facility are established. The shift from underground nuclear testing to science-based testing requires novel design and manufacturing efforts for monthly hydrotests.



It's so insensitive

When called upon in 2008 to re-start making TATB, the only insensitive high-explosive molecule approved by the Department of Energy for nuclear weapons, Los Alamos devised a new method within two years that overcame past environmental issues. The technology has since been transferred to industry, and the material is used in nuclear and conventional weapons worldwide.

00s thru 10s

The Center for Integrated Nanotechnologies, a Department of Energy national user facility, opens. The Center for Materials at Irradiation and Mechanical Extremes begins studies to understand and synthesize new materials that can tolerate such conditions.

Today thru ...

The Laboratory anticipates the advent of a new era in materials science—a transition from observing and exploiting the properties of materials to a science-based capability that creates materials with properties optimized for specific functions.

PEOPLE *making science*

Pioneer in Los Alamos materials research

For his contributions to the Manhattan Project, Cyril S. Smith earned a Presidential Medal for Merit. Recruited in 1943, the British-born metallurgist oversaw fabrication of uranium-235 and plutonium into "shapes needed for the gadget," as he put it, and developed many special materials for the world's first atomic bomb. An expert on copper alloys, Smith, who held a ScD (Doctor of Science) from the Massachusetts Institute of Technology (MIT), had previously worked at the National Research Council and American Brass Company. After Los Alamos, he had a distinguished academic career in metallurgy and the humanities at MIT, served on influential national scientific bodies including the U.S. Atomic Energy Commission's General Advisory Committee, and amassed awards.

INSTITUTION	LOCATION (CITY & STATE)
University of California	Santa Fe, New Mexico
Massachusetts Institute of Technology	Do.

DESCRIPTION OF WORK PERFORMED (Do not use materials, processes, etc.)

Organization of metallurgy work at Site for production of uranium 235 and plutonium from by the chemists, and fabricating these into shapes ne production of special tamper materials, including uran and development of many special materials needed for work. The metallurgy groups under Messrs. Jette, Keh bolt, in particular, are under my supervision, but I Kennedy (CH division leader) on broader divisional ad

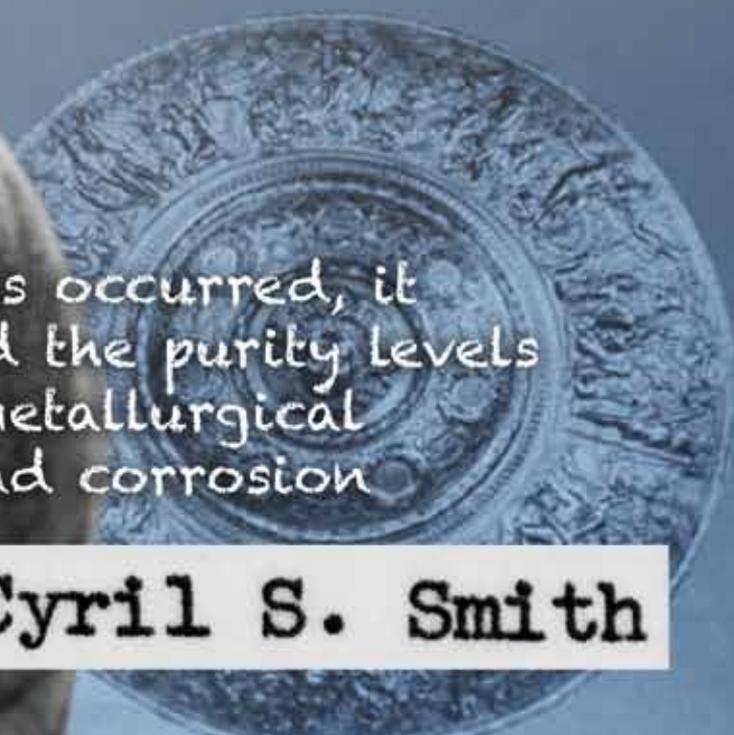


1945

CLASSIFICATION CANCELLED
AFTER DOG REVIEW JAN. 1973

Signature Search for Structure

Selected Essays on Science, Art, and History



When plutonium impurity problems occurred, it was Cyril Smith ... who established the purity levels required to achieve the needed metallurgical physical properties, fabrication and corrosion resistance for plutonium.

Cyril S. Smith

PEOPLE *making science*

Outstanding contributions



Amy Clarke

At Los Alamos we are striving to develop the materials of the future. Using unique x-ray and proton imaging tools at U.S. DOE user facilities, we make movies of metals during melting and solidification. We regularly see unexpected events that provide us with new insights about how fluid flow, structure, and defects develop in metals from the micro- to the macroscopic length scale. Our improved understanding will allow us to predict and control the response of metals while we make them, which will result in smart processing and the creation of materials by design.



Siegfried Hecker

Having been a summer student at Los Alamos in 1965, I returned as a postdoc in 1968 to study multidimensional flow and fracture of metals. With the Lab's incredible people and facility resources, I built an apparatus to simultaneously pull, twist, and pressurize instrumental metal tubes. That work helped transform the art of metal forming to a science when I went to General Motors. It was featured in a 1976 *Scientific American* cover article, by which time I was back at the Lab applying that knowledge to plutonium in weapon systems and uranium in conventional munitions. It's a good example of programmatic benefits that result from Lab sponsorship of young researchers to pursue apparently unrelated science.



Quanxi Jia

The working relationships I've developed at Los Alamos National Laboratory, since coming here in 1993, are very important to me. So many people at the Lab have been respectful and helpful. Together with colleagues in various fields, we have made significant advances in superconductivity, magnetic and ferroelectric materials, thin films, and multifunctional and nanocomposite materials. I am particularly proud of the licensed patents, which means companies find our ideas so useful that they are willing to pay to use them. The polymer-assisted deposition technique we developed at the Lab, for instance, is emerging as a versatile and powerful solution-based strategy to synthesize and process a remarkably broad range of materials for targeted applications.



Jennifer Martinez

I use biological methods to create functional materials. The work, in support of the Lab's materials synthesis and threat reduction missions, is an effort to develop fluorescent nanoclusters for better cancer detection and biological imaging techniques. In addition, my work advances the development of optical and bio-polymer libraries for highly biocompatible materials. I am most proud of the teams I have helped build here at LANL for both fluorescent nanoclusters and in vivo polymer synthesis, leading to new collaborations, recognition of our capabilities in the international cluster community, and development of an important topical area for the Laboratory and its customers.



Haskell Sheinberg

In 1944, the Army posted me at Los Alamos to purify plutonium for atomic bombs under the direction of Art Wahl, a co-discoverer of plutonium. After five-plus years, I transferred to the Chemistry and Metallurgy group, now MST-6 (Metallurgy). I worked in powder form with most non-gaseous elements—and ceramic compounds of many of them. I worked with uranium, thorium, and anything else in particulate form, such as dirt, grass, pine needles, diamonds, and moon dust. We made critical components for almost every Lab device tested in Nevada and Bikini and Nagasaki, as well as for many non-weapons experiments and programs. Perhaps my major achievement at the Lab was inventing and developing the process used for making all the fuel elements used in the Rover nuclear rocket program. The process is still being used today in the graphite industry and the field of space exploration.

MEASURING

Examining and defining physical phenomena

EXPERTISE AND ONE-OF-A-KIND TOOLS TO PRODUCE GROUNDBREAKING DISCOVERIES IN FUNDAMENTAL AND APPLIED SCIENTIFIC RESEARCH

For 70 years, Los Alamos physicists have made measurements in order to fulfill the Laboratory's national security science mission. These measurements have also informed our understanding of the physical world. For example, as an outgrowth of the Laboratory's weapons physics research, Fred Reines and Clyde Cowan Jr. made the first confirmed measurement of the neutrino, a Nobel Prize-winning discovery.

Now, Laboratory physicists are helping to define the next generation of measurements to be carried out at MaRIE, the Laboratory's proposed Matter-Radiation Interactions in Extremes experimental facility. The measuring mechanisms will be very fast imagers and radiographic systems derived from the Laboratory's experience in measuring fundamental nuclear processes, dynamic materials experiments, underground nuclear tests, high energy density plasma experiments, and subcritical experiments.

PAST

With the Laboratory's creation in 1943, an entire division was devoted to nuclear physics

measurements, supporting theoretical and calculational efforts to design nuclear devices that eventually led to the first atomic weapons—the Laboratory's mission. In the years just after the war, physicists concentrated on cross-section measurements and accelerator development. The neutron flux measurements were primitive, and the required accuracy was difficult to obtain. Most work was performed in secrecy, with the results off-limits to publication in open literature.

Then, in the 1960s, a small Laboratory team designed the Los Alamos Meson Physics Facility (LAMPF) accelerator, a half-mile-long linear accelerator that generated a medium-energy proton beam more intense than any other beam in the world. The facility revitalized nuclear physics research at Los Alamos and attracted scientists in academic circles lacking access to exotic elementary particles. By the 1990s LAMPF had become the Los Alamos Neutron Science Center (LANSCE), a Department of Energy national user facility. Today, five state-of-the-art facilities operate simultaneously, contributing to the nuclear weapons program (including actinide and high explosives science), nuclear



1956 neutrino discovery nets Nobel Prize

The elusive subatomic particle was first detected by Los Alamos researchers Frederick Reines (left) and Clyde Cowan Jr. (right).

medicine, materials science and nanotechnology, biomedical research, electronics testing, fundamental physics, and many other areas.

PRESENT

Even as the Laboratory's mission has evolved and expanded, nuclear physics measurements remain at the heart of Los Alamos research. To study nuclear cross sections and fundamental dynamic material properties, Los Alamos uses its Proton Radiography Facility, Dual-Axis Radiographic Hydrodynamic Test Facility, and Weapons Neutron Research Facility. Scientists also travel to the Nevada National Security Site. Los Alamos scientists are developing new technologies for active interrogation of special nuclear materials. The drive to replicate the sun's fusion reactions for weapons and energy applications is ongoing at Los Alamos and in national experiments. Los Alamos continues to make fundamental investigations into neutrinos as part of

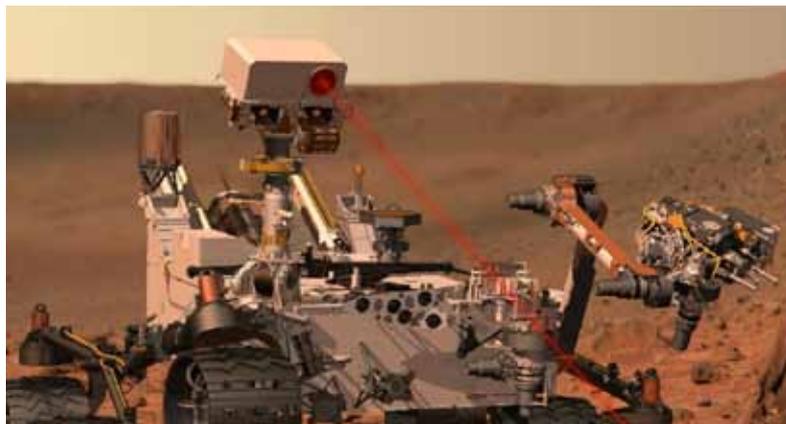
international collaborations and fundamental high-energy measurements at a new observatory in Mexico.

FUTURE

MaRIE will give Los Alamos and the global scientific community an intense x-ray source more powerful than anything available today. It will deliver many closely spaced pulses. The result will be stunning high-resolution structure measurements that tell researchers about the phases and mesoscale properties of materials.

At Los Alamos this new capability is of foremost importance for national security responsibilities. With MaRIE, Laboratory scientists will have a revolutionary tool for assessing the nuclear stockpile. In addition, as a scientific user facility, MaRIE will provide researchers who study fundamental materials science the opportunity to make, measure, and model with precision and speed materials for the future. ■

MEASURING milestones



ChemCam on Mars

Since Curiosity landed on Mars in 2012, ChemCam has fired more than 60,000 shots at rocks and soil and revealed details about their composition, including a group of smooth pebbles that apparently were shaped by ancient water flows. The system relies on a technology primarily developed at Los Alamos called laser-induced breakdown spectroscopy (LIBS). LIBS has successfully been used on Earth to determine the composition of objects within extreme environments such as inside nuclear reactors and on the sea floor. Other applications for LIBS include cancer detection and environmental monitoring. The Mars Science Laboratory is the technology's first extraterrestrial use.



Trinity

All in one year—1945—Los Alamos made final measurements of the critical mass of uranium and plutonium—vital to the design of the first nuclear weapons—and demonstrated with the Trinity test in New Mexico that the Laboratory

had succeeded in its wartime mission to investigate the possibility of building and using nuclear weapons in World War II. The type of bomb tested in the New Mexico desert (Fatman) and another type of nuclear weapon (Little Boy) were dropped on Japan within a month of the Trinity test; Japan announced its surrender days later.



Stepping into the open

The door to post-war unclassified research began to swing open in 1951 when Los Alamos built a new physics building on South Mesa. This sturdy structure, SM-40, which to this day has reinforced concrete walls thick enough to withstand a Hiroshima-size nuclear explosion, housed a variable-energy cyclotron that enabled Los Alamos physicists to make new measurements, which they published in 68 scientific works between 1956 and 1966, marking the beginning of the Laboratory's distinguished publishing record.

Eyes in the sky

The Vela satellite project, one of the Laboratory's earliest nonproliferation activities, was a series of space-based nuclear detonation sensors used to verify the 1963 Limited Test Ban Treaty. A bonus result came in 1973 when Lab instrumentation detected cosmic gamma-ray bursts, the most powerful explosions in the universe. Los Alamos continues to monitor the skies with space- and ground-based instruments in support of national security and fundamental science.



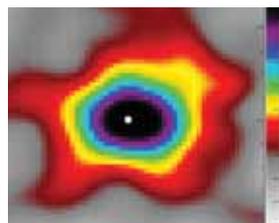
Los Alamos builds world's first enriched uranium nuclear reactor

The world's first nuclear reactor using enriched uranium, code-named "Water Boiler," achieved criticality in 1944. With this in-house neutron source and others like it, Los Alamos performed pioneering neutron physics research and research on the technology of reactors. Today, research reactors are widely used for materials development, radioisotope production, and education.

MEASURING milestones



Reaching for the sun Since 1957, when Los Alamos started the first experiments designed to test controlled thermonuclear reactions on a plasma, using a device called the Perhapsatron, the Laboratory has been driven to unleash fusion energy. Today, Los Alamos scientists stare straight into the core where nuclear reactions take place at California's National Ignition Facility (NIF), the world's largest laser. Laboratory researchers built and installed two major NIF diagnostics: the Gamma Reaction History instrument, which measures the time of peak neutron emission and the duration of the thermonuclear burn; and the Neutron Imaging System, which takes a picture of the neutron-emitting region caused by the deuterium-tritium fusion reactions. Research into high energy density plasmas also continues at the Laboratory's Trident Laser Facility and the University of Rochester's OMEGA laser.



In 2013, an international team of researchers, including scientists from Los Alamos, took the first image using **HAWC** (for High-Altitude Water Cherenkov Observatory). The facility, under construction in Mexico, is designed to detect the highest energy gamma rays ever observed from astrophysical sources. HAWC is based on the water Cherenkov detection technique pioneered at Los Alamos's Milagro observatory.

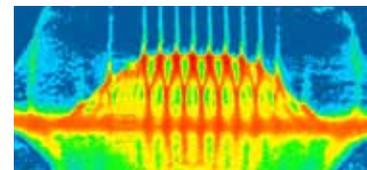
100 tesla

Los Alamos researchers set a new world record in 2012 for the strongest magnetic field ever delivered by a nondestructive magnet. The ability to create pulses of extremely high magnetic fields nondestructively gives researchers a tool with advanced capability for studying fundamental properties of materials—from metals and superconductors to semiconductors and insulators.



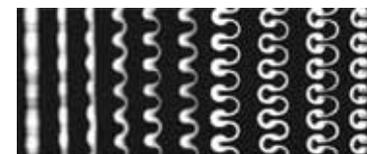
Subcritical experiments at Cygnus

With the cessation of underground nuclear explosive testing in 1992, Los Alamos developed new diagnostics needed by the weapons design community. The Cygnus radiographic capability, one major innovation, allowed high-resolution, multi-axis radiography of high-explosive-driven plutonium experiments for the first time. First used in 2004, Cygnus radiographic sources are still in use today, having successfully radiographed the Gemini series in early 2013 at the Nevada National Security Site.



Proton radiography

invented at Los Alamos National Laboratory, employs a high-energy proton beam to image the properties and behavior of materials under extreme conditions. The invention of proton radiography is the direct result of the synergy between the Laboratory's defense mission and basic science research and supports the Laboratory's national security science mission as well as provides for fundamental science discoveries.



Turbulent mixing

prevents inertial confinement fusion from igniting and producing energy. Turbulent mixing is too complex and chaotic to be simulated by existing computers, so Los Alamos scientists are developing a BHR (Besnard Harlow Rauenzahn) turbulence model to simplify simulations without losing the most important mixing forces.



MPDV garners R&D 100 Award

Multiplexed Photonic Doppler Velocimetry (MPDV) launched a new era in hydrodynamic experiments. The Laboratory can measure the shock physics properties of metal in unprecedented detail and resolution, gaining deeper insights as it reports on the condition of the nuclear arsenal and considers reusing older systems without nuclear testing. The technique also can be used for the vibrational analysis of auto and aircraft systems.

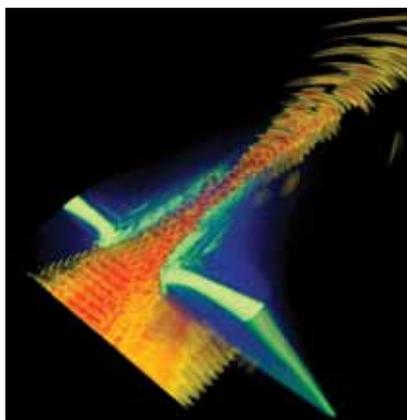
The evolution of Los Alamos measuring methods

Physics beyond the Standard Model

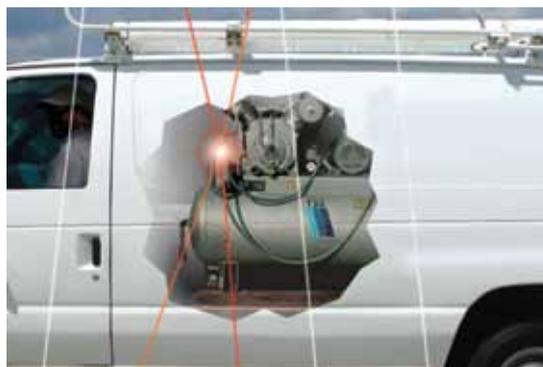
In 1995, Los Alamos's Liquid Scintillator Neutrino Detector (LSND) hinted at the existence of a new particle, thus defying elements of the Standard Model that seemed established. The unexpected results were intensively scrutinized—even criticized—yet ultimately duplicated. Research from MiniBooNE, another neutrino experiment, is consistent with LSND.

Ultrafast

Ultrafast optical and x-ray technologies are critical to Los Alamos National Laboratory capabilities ranging from condensed matter physics to high energy density physics. Understanding materials where the electron-electron interactions dominate is one of the greatest challenges in modern condensed matter physics. Ultrafast optical spectroscopy provides the unmatched capability to reveal competing quantum phenomena by separating them in time. High-energy laser beams, such as available at the Trident facility, provide the opportunity to study ultra-intense laser-matter interactions, dynamic material properties, and laser-plasma instabilities. Significant progress has been made on techniques for generating MeV monoenergetic ions, as well as on understanding nonlinear kinetic plasma waves and nonlinear behavior in fluids. With MaRIE, the future promise is an ability to coherently image dynamic events in high-Z materials in extreme conditions relevant to weapons physics.



Better border security



The technology to build the first full-scale operational scattering muon radiography system for sea container scanning was developed under a cooperative research and development agreement between Los Alamos and Decision Sciences International Corporation (DSIC). Building on the Laboratory's pioneering cosmic-ray muon scattering work, DSIC constructed and deployed the portal monitor at the Freeport Container Port in the Bahamas. Muon tomography uses ambient cosmic-ray muons, a type of subatomic particle, to detect and identify concealed nuclear threat materials based on their atomic number and density. Advanced reconstruction software generates a three-dimensional image indicating a threat object's precise location. Unlike other imaging and detection techniques, such as x-rays, muon tomography can also detect shielded threat materials. Other applications of cosmic-ray radiography include nuclear reactor imaging and treaty verification.

40s thru 50s

Secretly, Los Alamos scientists make nuclear physics measurements relevant to atomic weapons. The Laboratory branches out into fundamental science, taking the first measurement of the then-hypothetical neutrino and pursuing the possibility of civilian nuclear power and fusion.

60s thru 70s

Los Alamos further diversifies its research program by building the Los Alamos Meson Physics Facility in 1972, the world's most powerful medium-energy research accelerator. Renamed the Los Alamos Neutron Science Center, the national user facility is an invitation for scientists worldwide to come here. In 1977, the Weapons Neutron Research Facility opens, where researchers study radiation effects, obtain nuclear data for weapons design, and explore basic nuclear physics.

80s thru 90s

After President George H.W. Bush declares a halt in 1992 to detonating warheads underground, Los Alamos transitions to laboratory-based experiments, some in underground labs at the Nevada National Security Site, to investigate nuclear materials under the conditions leading up to an explosion. Scientists learn how to use data from past nuclear tests in combination with non-nuclear testing, computer models, and experimental models. Los Alamos develops the Dual-Axis Radiographic Hydrodynamic Test Facility, providing scientists with a view inside a mock nuclear warhead and a set of x-ray images. The Proton Radiography Facility is a new way to probe components of nuclear weapons.

00s thru 10s

Laser-based studies in high energy density physics and inertial confinement fusion heat up. To explore fundamental laws of physics, scientists bottle ultracold neutrons and watch their decay at a new Los Alamos facility. In South Dakota, Los Alamos scientists lead the development of MAJORANA DEMONSTRATOR, a neutrino detector experiment.

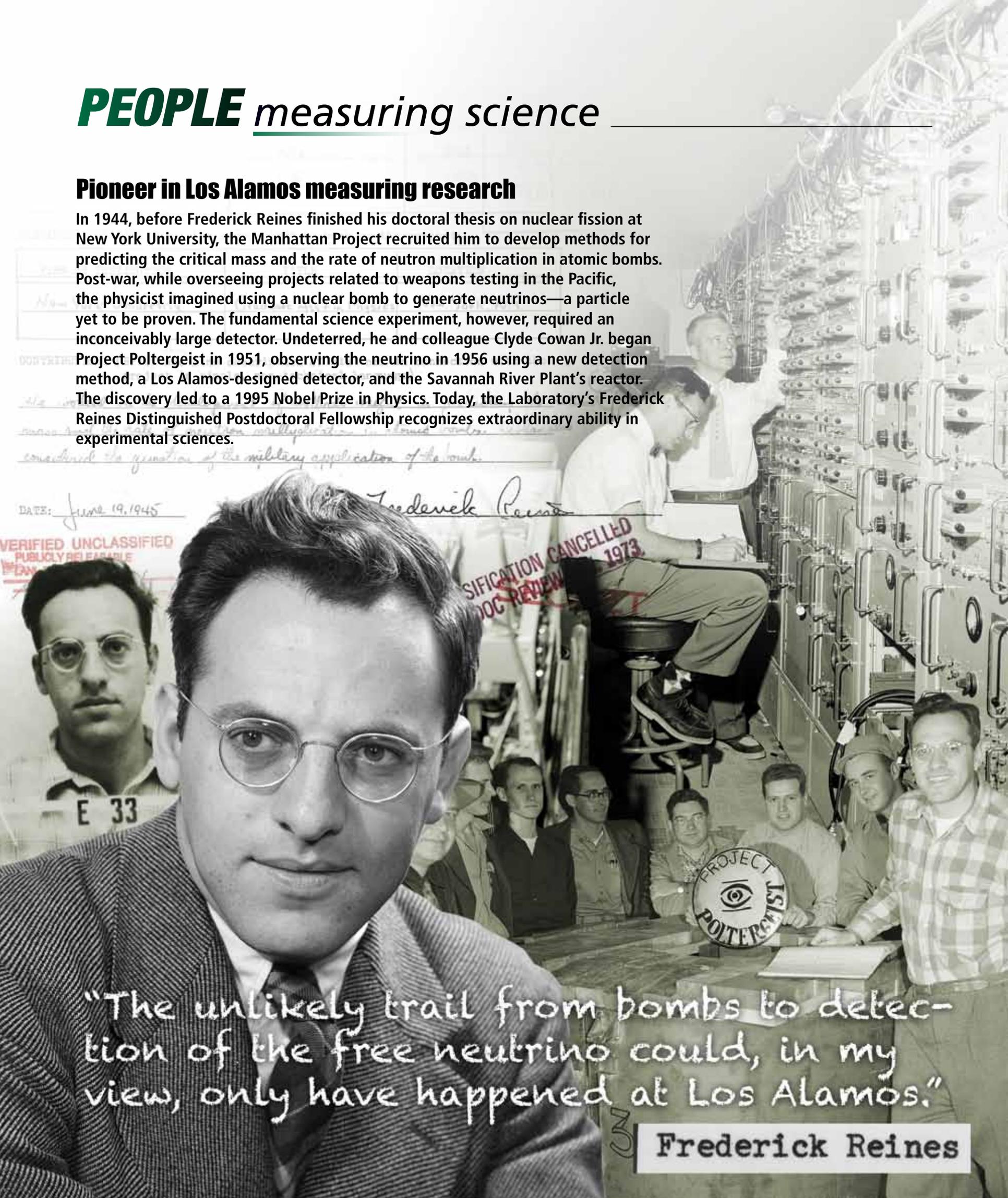
Today thru . . .

Los Alamos broadens its measuring tools, furthering studies in climate change, neuroscience, quantum information science, biosecurity, astrophysics, and cosmology.

PEOPLE *measuring science*

Pioneer in Los Alamos measuring research

In 1944, before Frederick Reines finished his doctoral thesis on nuclear fission at New York University, the Manhattan Project recruited him to develop methods for predicting the critical mass and the rate of neutron multiplication in atomic bombs. Post-war, while overseeing projects related to weapons testing in the Pacific, the physicist imagined using a nuclear bomb to generate neutrinos—a particle yet to be proven. The fundamental science experiment, however, required an inconceivably large detector. Undeterred, he and colleague Clyde Cowan Jr. began Project Poltergeist in 1951, observing the neutrino in 1956 using a new detection method, a Los Alamos-designed detector, and the Savannah River Plant's reactor. The discovery led to a 1995 Nobel Prize in Physics. Today, the Laboratory's Frederick Reines Distinguished Postdoctoral Fellowship recognizes extraordinary ability in experimental sciences.



"The unlikely trail from bombs to detection of the free neutrino could, in my view, only have happened at Los Alamos."

Frederick Reines

PEOPLE *measuring science*

Outstanding contributions



John Browne

In late 1993, after 20 years as the “flagship” of nuclear physics, LAMPF was identified for closeout by the DOE, and Director Sig Hecker appointed me as program director for the research programs at Technical Area 53 with the guidance to develop a new mission for the 800-MeV accelerator and associated facilities. In his initial “navigator” meetings in 1994 developing the Stockpile Stewardship program, Vic Reis said that each Lab needed a “Nordstrom as the anchor store,” and that Livermore got “photons” (NIF), Sandia got “electrons” (Z), and Los Alamos got “neutrons” (LANSCE), and everyone got “computing.” So we got the opportunity to transition LAMPF to LANSCE (changing the name to the Los Alamos Neutron Science Center) and broadening the mission to focus on materials science, radioisotopes, weapon physics, and nuclear physics. But it took a combination of Reis, Senators Domenici and Bingaman, along with the support of the DOE Office of Energy Research to give us adequate funding to build a new foundation for LANSCE that has resulted in a second 20 years of successful research at TA-53.



Carl Ekdahl

During the early 1990s, I led P-14 (the Fast Transient Plasma Measurements group) through its transition from underground testing to aboveground, non-nuclear experiments. P-14’s ability to make difficult measurements in tough environments provided the opportunity to participate in many exciting experiments. At the All-Russian Research Institute of Experimental Physics (VNIIEF), the Russian counterpart to Los Alamos, our job was to measure the millions of amperes of electrical current produced by an explosive generator. We used an exquisite technique we had perfected for experiments at Los Alamos, measuring the magnetically induced change in polarization of laser light in an optical fiber wrapped around the current conductor. A blend of Russian ingenuity and American expertise led to a successful measurement of the 47 million amperes that crushed an aluminum shell in the experiment. This was the first of many experiments at VNIIEF in collaboration with our former Cold War adversaries, now our colleagues.



Michelle Espy

I had the good fortune of joining a team that was applying physics methods to the noninvasive study of the human brain. It’s amazing that we don’t, to this day, understand how the brain really works—how it’s connected and what it’s doing. And so it’s been really fun to get to try to apply physics methods to new technologies to understand the brain. And at the same time my team and I have been able to apply these methods to a whole host of different kinds of problems too, including some work on detection of liquid explosives hidden inside carry-on luggage at the airport.



Nick King

In reflecting back on some 73 years of living and working at Los Alamos, I have memories of playing leapfrog with Fermi in Santa Clara Canyon as a child, hiking with Stan Ulam and Hans Bethe during high school and college, and performing a diverse range of experiments as a physicist. In the complex environment of nuclear underground testing, for example, I initiated the effort to isolate physical processes to better characterize nuclear weapons performance via ultrafast imaging techniques. That’s how ultrafast shuttered imaging came about at LANL. We measured time histories in nuclear testing with nanosecond snapshots and ultimately achieved a 0.1-ns imaging capability. With laser light, we also investigated applications for detecting mines, characterizing trapped antiprotons, and scanning neonatal brains for oxygen deficiencies. The programmatic flexibility to carry out this diverse range of experiments has been an exciting aspect of being an experimental physicist at LANL.



Toni Taylor

I came to the Lab to work on the “Bright Source,” an ultrafast, high-intensity laser system that our team developed to study matter interactions at ultrahigh intensities. My focus in that project, which has continued to the present, was on the dynamics that ensued following excitation with very short optical pulses. Taking advantage of the vast scientific expertise at LANL, my interests evolved with a focus on processes in functional materials to include not only investigations on the fundamental timescales of electronic and nuclear motion (10^{-14} to 10^{-11} sec), but also to include ultrascale spatial scales—the nanoscale. Understanding materials behavior in both ultrafast timescales and ultrascale spatial scales underpins the discovery of the scientific principles governing the design of nanoscale materials with controlled functionality leading to novel properties, a goal of LANL’s Materials Pillar, implemented at the Center for Integrated Nanotechnologies.

MODELING

Applying the scientific method to complex systems

CUTTING-EDGE TOOLS AND METHODS TO GUIDE AND INTERPRET EXPERIMENTS AND FURTHER FUNDAMENTAL UNDERSTANDING AND PREDICTIVE CAPABILITIES FOR COMPLEX SYSTEMS

Calculating the precise amount of nuclear material required to construct an explosive device was the first task of Los Alamos theoreticians, making 1943 the first time theory, modeling, and computational studies were applied to materials at the Laboratory. These fields of study and materials are again vitally linked in 2013, the Laboratory's 70th anniversary, as Los Alamos develops MaRIE, its proposed Matter-Radiation Interactions in Extremes experimental facility.

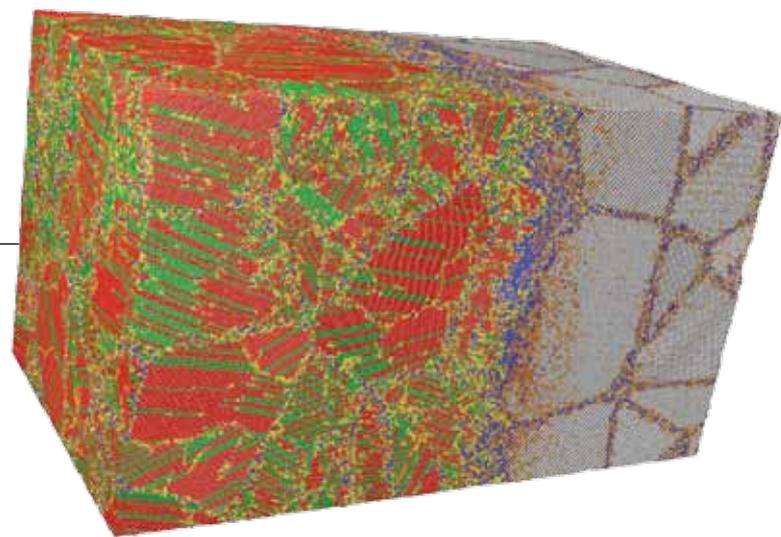
PAST

Project Y, which eventually became Los Alamos National Laboratory, relied extensively on computers to design the world's first atomic bombs. Several mechanical calculating machines were purchased when the Laboratory commenced operations in spring 1943. These devices, the most useful of which was the Marchant desktop calculator, were primarily used to perform calculations in support of the gun-assembled uranium weapon program (Little Boy). Relatively powerful IBM punched-card machines soon followed, enabling more-complex computing in support of the implosion-assembled plutonium weapon program (the Trinity device and Fat Man). Los Alamos's early computing program boasted several notable

scientists, among them Richard Feynman, who would win the 1965 Nobel Prize in Physics, and Nicholas Metropolis. Despite early computing technology's lack of reliability, the machines became nearly indispensable, especially as Feynman and Metropolis grew more adept at maintaining the equipment, thus enabling the scientific staff to model complex experiments. The data produced in these models helped scientists understand the physics of implosion. Likewise, computing enabled scientists to accurately predict other physical scientific phenomena, such as the weapon's explosive yield, pertaining to the Trinity test of July 16, 1945.

PRESENT

Throughout the Laboratory's history, computers have been specifically developed for the nuclear weapons program. In 2008, the Laboratory's Roadrunner machine was the world's fastest computer. Today, more-powerful computers enable more-detailed weapons simulations. More-detailed weapons simulations, supported by the Laboratory's experimental data, produce greater certainty in assessing the nuclear stockpile for safety and reliability. Greater certainty in assessing the nuclear stockpile ensures the nation will be able



From a thousand to a trillion atoms

By coupling the power of computers with molecular dynamics simulations, Los Alamos researchers gained understanding not possible through laboratory experiments, so noted a 1964 *Scientific American* article. Researchers have since extended the number of particles—and the timescale of their calculations—to explore previously inaccessible physical phenomena in complex polycrystalline materials. With MaRIE, the advent of exascale computing will allow large-scale and time-accelerated atomistic simulations approaching microns in size and milliseconds in time and electronic structure calculations on unit cells capturing the physics of several thousand atoms.

to maintain a credible nuclear deterrent well into the future.

Yet throughout the Laboratory's history, computers have also been utilized to advance diverse fields of scientific research. Biological explorations into the human genome, which continue today, can be traced all the way back to the 1950s, when Los Alamos scientists attempted to decode DNA sequences using one of the world's first electronic digital computers, MANIAC (mathematical analyzer, numerical integrator, and computer). Los Alamos computers have also been used for mineral exploration, basic science, and energy research. And into the future, Laboratory computers will produce ever more detailed and accurate models for understanding global climate change, the spread of pandemics, and the nature of our universe, as well as the state of the nuclear weapons stockpile.

FUTURE

With MaRIE, Los Alamos will develop a predictive capability for materials in extreme

environments. By integrating MaRIE experimental data with advanced theory, simulation, and information-theoretic tools—in a paradigm referred to as co-design—the Laboratory will provide an unparalleled capability to understand, predict, and control materials behavior under extreme conditions. Modeling and simulation will be enhanced by the increased computational capacity of extreme (exascale) computing.

The Laboratory focus on Information, Science, and Technology (IS&T) takes advantage of advances in theory, algorithms, and the exponential growth of high-performance computing to accelerate the integrative and predictive capability of the scientific method. MaRIE will enable prediction of material properties from knowledge of microstructural heterogeneities, and this theory, modeling, and computation capability will provide the Laboratory with unprecedented tools for use in nuclear weapons, nuclear energy, and basic materials science. ■

MODELING milestones

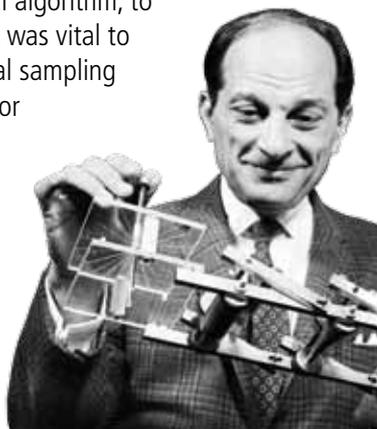


Advent of modern multifunctional computers

An operator tends to MANIAC's coding instruments. As with all computers of its early 1950's era, MANIAC, which was built at Los Alamos, was a one-of-a-kind machine that could not exchange programs with other computers.

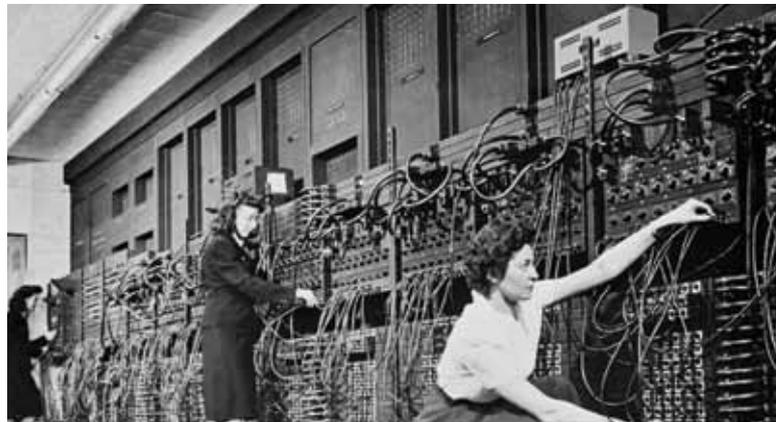
A method to their computational madness

In 1945, Stan Ulam (pictured) and John von Neumann developed the Monte Carlo method, a computational algorithm, to study the behavior of neutrons, which was vital to the Laboratory's mission. The statistical sampling technique proves to be a framework for studying a range of systems involving large numbers of particles. It's applicable to not only nuclear and high-energy physics activities, but also to studies involving substantial uncertainty in inputs, ranging from the physical sciences and engineering to business risk and computer graphics.



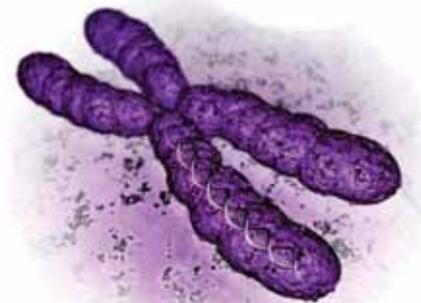
'The Los Alamos problem'

In 1945, the world's first large-scale electronic computer, ENIAC, was successfully used for solving the "Los Alamos problem," a calculation needed for the design of atomic weapons. High-speed computing and weapons design have been linked ever since.

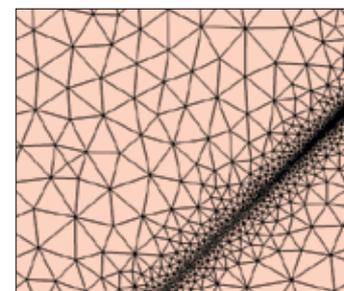


It's in the genes

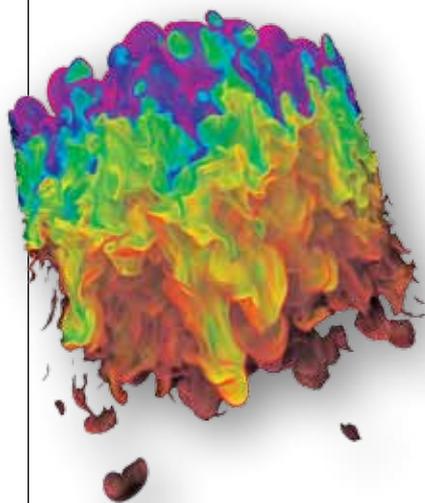
In 1995, Laboratory scientists completed the map of Chromosome 16, the genes of which are linked with leukemia, breast cancer, and prostate cancer. The Laboratory has a distinguished history in genetic research—an expansion of the Laboratory's studies into the physiological effects of radiation exposure—including a database for genetic sequence information, a gene library that produced and distributed DNA fragments for scientific use around the world, a center for human genome studies, and membership in the Department of Energy's Joint Genome Institute.



Order from chaos Los Alamos develops numerical simulation capabilities in order to accurately predict the behavior of complex physical systems ranging from manufactured parts to natural systems like oceans and Arctic ice. Numerical analysts first subdivide a complex model into a collection or grid of many simple blocks. They then solve the physical equations on the blocks and piece the solutions together to understand the big picture. Unconstrained by a rigid, regular structure, unstructured grids better represent complex domains, such as geology or coastlines, and also get to the solution faster for such models. Los Alamos is actively developing and using unstructured grid-based numerical methods that preserve or mimic important properties of underlying continuum models for a wide range of applications.



MODELING milestones

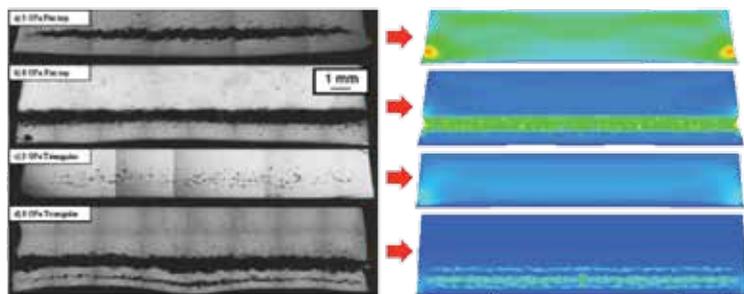


You say you want a 'nonlinear' revolution

A key Los Alamos discovery in the 1970s—one that predicted a universal behavior for certain chaotic systems—ignited a revolution in how complex systems are studied and understood. The Laboratory's Center for Nonlinear Studies was formed in 1980. Many of the Laboratory's energy and defense programs have involved complex nonlinear phenomena, making the development of analytical tools in this field important to several research areas.



In **1986**, the Laboratory established an AIDS database and Laboratory researchers analyzed sequences and published their data along with the work of others. Since then, the Laboratory has developed Hepatitis C Virus, Influenza Sequence, Oral Pathogen, and STD Sequence databases.



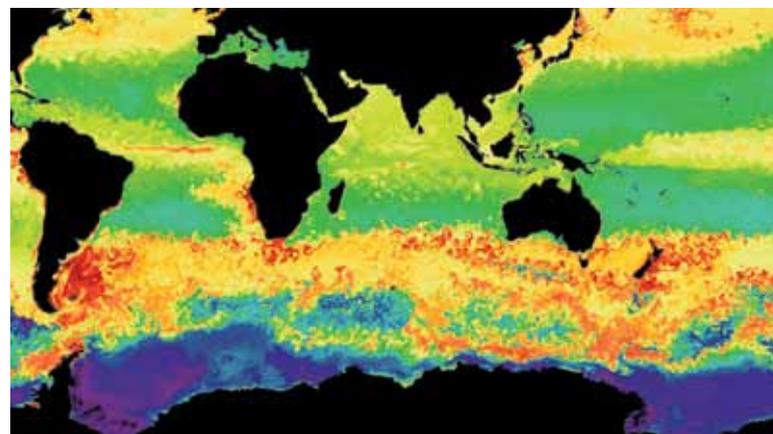
Through the study of dynamic events,

such as the collapse of shaped charge warheads and the interaction of the resulting high-velocity metal jet with targets of interest, Los Alamos scientists and engineers gain confidence in their simulation tools and can better assess what they need to know about the materials used in the designs. Early experimental work in the Department of Defense made it clear that combinations of certain explosives and metals worked better than others. Additionally, the processing history of the metal liners can drastically change the performance of the design. Recent numerical and material characterization advancements of the Joint Munitions Program have allowed designers to successfully capture this behavior and predict the changes in system performance due to proposed design changes.

Co-design for predicting and controlling materials properties



The past half-century has seen enormous advances in the ability to control homogeneous, bulk systems, such as a single crystal of silicon, leading researchers to the threshold of a paradigm shift: viewing materials properties as a consequence of intrinsic heterogeneities including defects and interfaces, which need to be characterized and manipulated. Through co-design, the integration of MaRIE experimental data with advanced theory, simulation, and information-theoretic tools, Laboratory researchers will have an unparalleled capability to understand, predict, and control materials behavior under extreme conditions.



Cracking the climate code

By numerically modeling the oceans and sea ice using high-performance computing capabilities, Los Alamos is developing advanced codes that address scientific issues related to climate change such as sea level rise, rapid changes in the Arctic, the role of ocean mesoscale eddies on the ocean's global circulation, and high latitude biogeochemical interactions.

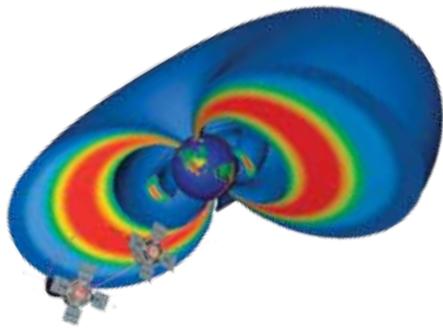
3d

In 2000, Los Alamos successfully demonstrated the first-ever three-dimensional simulation of a nuclear weapon explosion and visualization capability to analyze the results. This single simulation generated data comparable to the amount of data represented by the entire book collection of the Library of Congress. In the absence of nuclear testing, this capability maintains the reliability and safety of the nation's nuclear stockpile. With MaRIE, Laboratory researchers will have a deeper physical insight of the behavior of materials, providing confidence in our predictive capability.

The evolution of Los Alamos modeling science

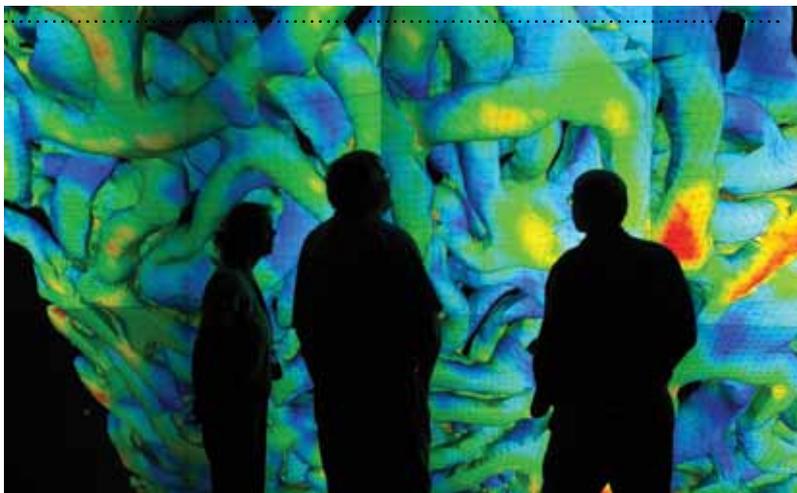
exaflop

To address the modern world's increasingly complex problems, Los Alamos scientists are partnering with other national laboratories and industry to develop supercomputers that can achieve exaflop speeds—that is, a quintillion (a million trillion) calculations per second. Put in perspective, that is equivalent to 50 million laptops all working together at the same time. Researchers also are developing the interacting components of a computational system as a whole. Through this computational co-design approach, exascale computers will be put to use to solve some of today's most pressing problems, including clean energy production, nuclear reactor lifetime extension, and nuclear stockpile aging.



A three-dimensional numerical simulation

of the Earth's magnetic field, representing 40,000 years, revealed a surprising reversal of the computer-generated field near the end of the simulation—a phenomena observed, but never before understood, in the geologic record.



A view that's outta this world!

Whether examining the inner workings of an atom or the outer reaches of the cosmos, scientists at Los Alamos use unprecedented computing and visualization methods that transform datasets from raw numbers to geometric and image-based representation to understand their data. These tools are used for tests in nuclear and particle physics and applied physics, involving collaborations between scientists from across the Laboratory and institutions around the world.

40s thru 50s

Early weapons experiments are simulated mathematically by people with arrays of desktop calculators and conventional punched-card accounting machines. Developed at Los Alamos, MANIAC is the first computer to store instructions within memory. With the need for more computing power, by the mid-1950s the Laboratory begins partnering with industry for its supercomputers.

60s thru 70s

The Limited Test Ban Treaty goes into effect, placing more emphasis on computer modeling and simulation. Cray Research Inc. begins its three-decades-long history with the Laboratory, serving as the backbone of Los Alamos computing with delivery of the Cray-1 for \$8.8 million. To handle the intense heat generated by the computer, Cray developed an innovative refrigeration system using Freon. From here on, one of the challenges of supercomputers is power consumption and heat dissipation.

80s thru 90s

The 1990s is the decade of high-performance computing, which includes massively parallel computers, gigabit networks, terabyte storage devices, and visualization tools, being applied to critical problems of global importance. The Accelerated Strategic Computing Initiative is created, a tri-laboratory program focused on the development of the computational capabilities to allow a smooth transition from nuclear test-based certification to science- and simulation-based certification.

00s thru 10s

Construction of the Nicholas C. Metropolis Center for Modeling and Simulation is completed. The 300,000-square-foot computing and office complex features a football field-size computing floor. The Laboratory's Roadrunner holds the international speed record for computation in 2008. Its unique architecture inspires new supercomputer designs around the world, pushing computer speed and capability to greater heights.

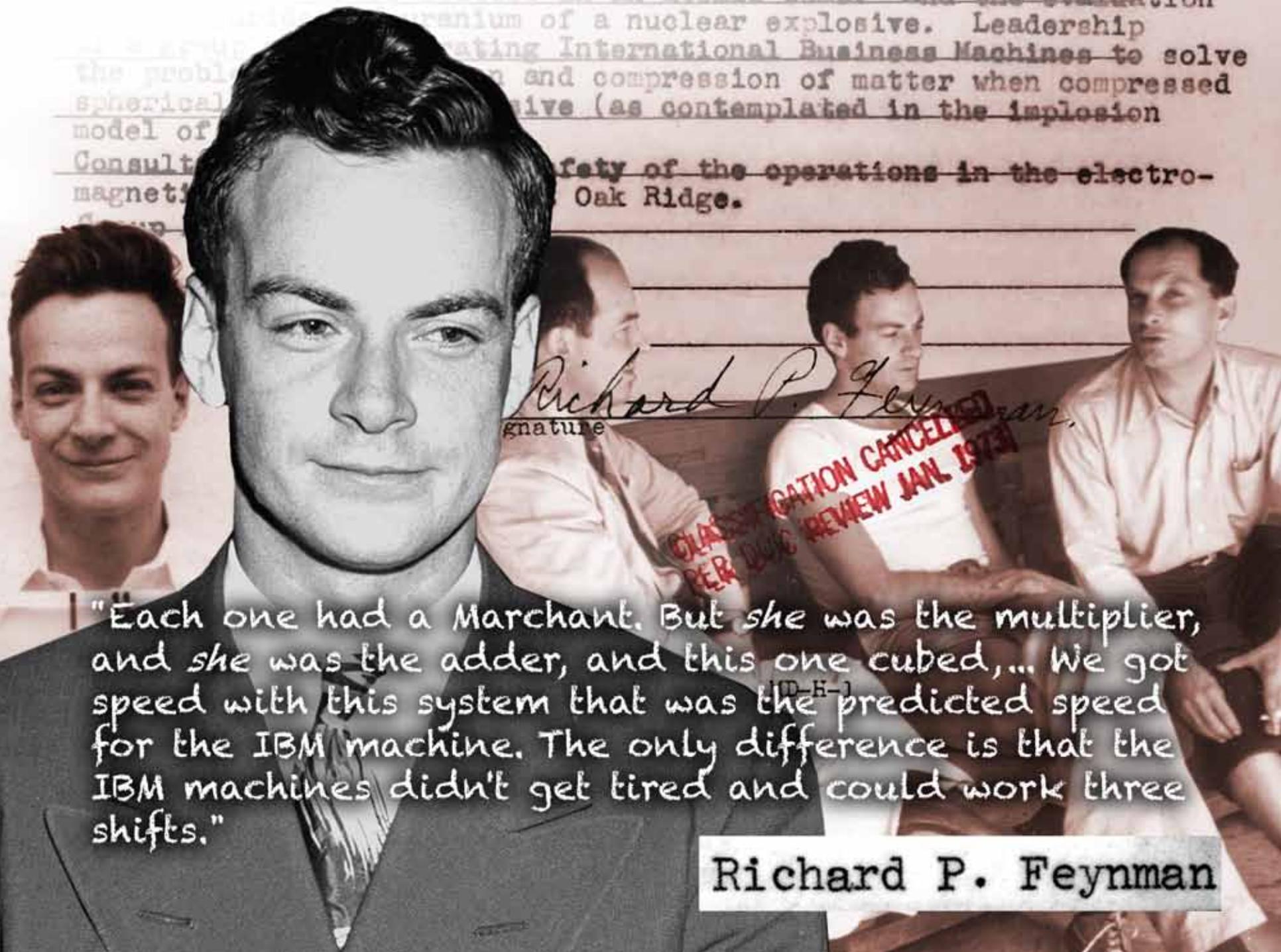
Today thru ...

The Laboratory has one of the largest supercomputing centers on the planet, with massive resources for both classified and unclassified scientific simulation, along with world-class computational physicists, computer scientists, and mathematicians. The result is a tight integration of theory, modeling, and computational science.

PEOPLE *modeling science*

Pioneer in Los Alamos modeling research

As a PhD physics student at Princeton University, Richard P. Feynman was tapped by the Manhattan Project to crunch the numbers for the design of an electromagnetic device that would separate uranium isotopes. In 1943 at Los Alamos, he became a group leader in the Theoretical Division, calculating the physics of implosion and predicting the explosive yield from various nuclear bomb designs. (The Bethe-Feynman formula for calculating the yield of a fission bomb remains classified to this day.) At that time, the mechanical workhorses of the Laboratory were Marchant desk calculators and IBM accounting machines. Feynman spent two years at Los Alamos, witnessing the Trinity test a month before his wife died of tuberculosis. He went on to become a Nobel Prize-winning quantum physicist. Today, the Laboratory's Richard P. Feynman Distinguished Postdoctoral Fellowship recognizes extraordinary ability in theory or computing.



"Each one had a Marchant. But she was the multiplier, and she was the adder, and this one cubed, ... We got speed with this system that was the predicted speed for the IBM machine. The only difference is that the IBM machines didn't get tired and could work three shifts."

Richard P. Feynman

PEOPLE *modeling science*

Outstanding contributions



Alan Bishop

The most striking memory of my “materials” years at Los Alamos is experiencing first-hand how traditional discipline boundaries, with which I was familiar when I arrived in 1979, dissolved under the need to understand and exploit real materials—and to discover and design new and functional ones. To meet the national imperatives of this century, Los Alamos must continue to be proactive in how we fulfill our national security science mission. The challenges we as a nation now face are of sufficient complexity that we must approach them in a deliberately interdisciplinary fashion, often at scale. Today, the Laboratory is increasingly bridging disciplines through what we call co-design, strategic teaming between experiment, simulation, and theory. Through co-design, we are again observing the long-term power of a great national laboratory—mission needs driving scientific frontiers, which in turn empower even more challenging missions, and again transform research frontiers.



Stirling Colgate

When Oppenheimer and E.O. Lawrence arrived at the Los Alamos Ranch School in 1942 to shut it down, us budding physics students instantly recognized them from our physics books and were sure a nuclear bomb would be built here. I entered the Merchant Marine during World War II, then studied physics at Cornell. My astrophysics career began after convincing the Russians during the Atmospheric Test Ban negotiations that we had to have what later became the Vela satellites to sort out space signals like supernovae from nuclear explosions, otherwise we might be dropping bombs on each other in short order. In 1976, [Los Alamos Laboratory Director] Harold Agnew hired me to start a theoretical astrophysics group, which produced talent for the weapons program. I was the only Ranch School student to return. At 88, I’m still at Los Alamos studying exploding stars, inertial fusion, and the magnetic fields of the universe.

As *Vistas* was going to press, Stirling Colgate passed away. His Los Alamos colleagues are saddened to hear of this loss.



Francis Harlow

In 1953, the 701, a large IBM computer, arrived and we started developing new techniques for fluid dynamics calculations. I think a lot of people thought it was just a rich laboratory hobby. Fun and games. But we had a feeling that a lot of things could be calculated for the first time in the world. My whole life has been built on gut feelings. I have never been able to write computer codes, but I have a lot of imagination. By 1959, people (at the Laboratory) recognized that there were some useful things here, and I was allowed to start T-3, the Fluid Dynamics group in the Theoretical Division. Back then we ran our own jobs. I’d set my alarm clock and race over to the lab at 2:30 a.m., running down the stairs trying not to drop a box of punched cards. Our ability to calculate very turbulent fluids was one of our best achievements. A lot of these calculations were very useful in interpreting a variety of experiments being performed at the Laboratory.



Turab Lookman

Looking at materials from the perspective of energetics—where a system wants to end up to minimize energy—has been a rewarding experience. Being able to predict materials behavior under dynamic conditions requires some a priori knowledge of energy landscape of possible configurations. Of particular interest was gaining an understanding of how collective behavior and self-organization emerge at the mesoscale. My colleagues and I developed a framework that married, for the first time, the coupling of elasticity to material functionality such as magnetism and charge polarization. This research provides a potential foundation for new methods of fabricating materials that might be technologically important for new-generation energy research, and also is important to fundamental materials physics research. Equally important, when I joined the MaRIE effort in 2008, it provided the basis for articulating the accompanying theory, modeling, and computation challenge at the mesoscale.



Karissa Sanbonmatsu

When I came to Los Alamos I was actually in nonlinear physics and plasma physics. But one of the great things about Los Alamos is they really encourage and foster interdisciplinary collaborations, and it’s a place where you can jump from field to field if you’re interested in other fields. And so I quickly switched to biophysics, which is where I got interested in these genetic switches and how the genes are turned on and off in your body, and also how these huge RNA molecules affect these switches. I think one of the things I love about science is the thrill of discovery. There’s nothing like the moment when you make that discovery because it’s something only you know. It doesn’t last very long because pretty soon everybody knows about it, but there’s that one key moment that’s really special.

The essential role of chemistry

in support of making, measuring, and modeling

Chemical science has played a vital role in making, measuring, and modeling at Los Alamos since the days of the Manhattan Project when chemists produced and chemically separated plutonium. As the Laboratory's mission has expanded, so has the role of the chemical sciences in contributing to achievements in this research. For example, the chemical sciences are central to the Laboratory's prowess in isotope production, chemical signature sensing, and high-explosives characterization. Today, the chemical sciences contribute to nearly every aspect of the Laboratory's mission, from nuclear deterrence to addressing global threats to bioscience and energy security. Read on to learn more about recent chemical science advances in support of making, measuring, and modeling.

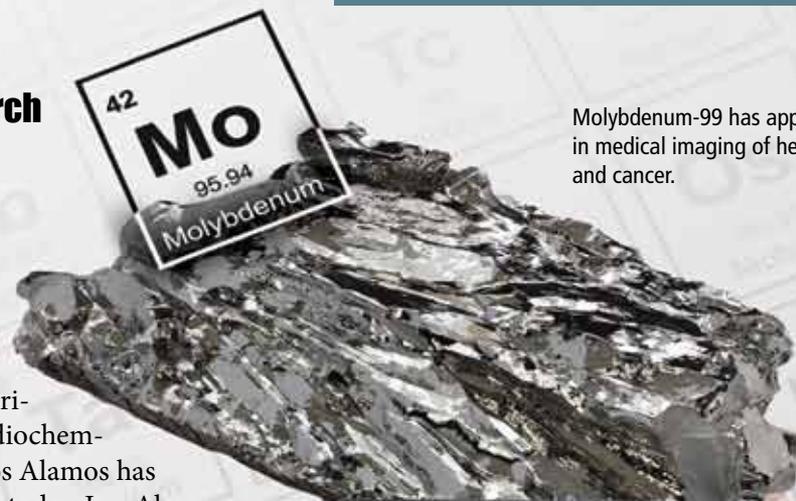
An organizational perspective

Although the Chemistry and Metallurgy Division endured for decades with only modest name changes, in the course of time it evolved, reflecting the importance of the two disciplines to the Laboratory's mission. Chemistry became its own division, and in 1982, Metallurgy became part of the Materials Science & Technology Division. However, underscoring the importance of this cross-disciplinary expertise, the Laboratory continues to maintain facilities for chemistry and metallurgy research.

MAKING

Nuclear chemistry expertise benefits medical research

Using the capabilities of the Los Alamos Neutron Science Center (LANSCE), the Laboratory is one of the few places in the world that distributes isotopes produced via high-energy accelerator. LANSCE provides the requisite beam energy to make strontium-82 routinely available to support cardiac imaging as well the research associated with proof-of-concept actinium-225 studies. Only a handful of other facilities on the planet are configured for the appropriate energy and have target irradiation capability. The Laboratory's radiochemistry expertise extends back to the Manhattan Project. Since 1974, Los Alamos has been making medical isotopes and production continues in full force today. Los Alamos recently demonstrated the production and separation of molybdenum-99 from uranium sulfate solution. The effort, with private industry, aims to create a nationally sourced supply of this critical isotope, employed in medical imaging of heart disease and cancer, without using highly enriched uranium. The Laboratory also synthesizes isotopes for national security, environmental studies, and a variety of industrial and R&D applications.



Molybdenum-99 has applications in medical imaging of heart disease and cancer.

MODELING

Modeling thermal explosions with radiography

Understanding what makes an explosive explode, when, and how it does is of great importance to groups as diverse as our defense forces, the mining industry, and fire and rescue organizations. Most conventional initiation mechanisms are well understood; however, it has been difficult (to say the least) to characterize the factors that make a heated explosive initiate. Los Alamos researchers made the first direct measurements of this special type of "thermal explosion" in 2008 and the science has continued to evolve. (continued next page) ▶





(MODELING cont.) The first observations were made at the Proton Radiography Facility at LANSCE, where thermal explosions were imaged in the first few microseconds after initiation to provide a real-time look at how an explosion unfolds and releases its energy. More recently, techniques involving a combination of tabletop dynamic radiography and LANSCE proton radiography have increased the insight into the mechanisms behind thermal explosions—specifically, the range of temperature over which ignition may occur and the subsequent power of the explosion. The significance of this work has been highly recognized within the defense community.

MEASURING

Optimal dynamic detection of explosives

Explosives are commonly present in violent threats, and understanding the nature of those explosives is critical to mitigating the threat. Explosive devices take many forms, from various improvised bombs to sophisticated devices used to disperse chemical, biological, or radiological compounds. A first step toward neutralizing these threats is identification of the nature of the device, preferably from a safe distance. A common goal is 50 meters. Unfortunately, many explosives have very low vapor pressures, making the detection and identification of explosives molecules in the air exceedingly difficult. One must then look for microscopic trace contamination that may have been left on an external surface—another challenging prospect. A technique that uses lasers to meet these challenges is under development at Los Alamos. It is called ODD-Ex (Optimal Dynamic Detection of Explosives) and uses a novel approach to solving this seemingly unsolvable problem.

ODD-Ex interrogates the target with a laser, exciting the molecules of interest, which then give off a signature that can be analyzed. The challenge is that the hundreds of possible molecules that might be used in explosives must be screened and background signals must be filtered out. ODD-Ex solves this problem by using femtosecond laser pulses that are shaped so that they excite only the molecules of interest. Signal detection and analysis is done with standard spectrometers. There is still work to be done to optimize this measurement technology, but ODD-Ex holds great promise as a next-generation explosives detection technique.

The technology is under development by a team led at Los Alamos in collaboration with colleagues at Princeton University. The collaboration between the two groups was spurred by the needs of the U.S. Department of Homeland Security for dramatically better next-generation explosives detection technologies. ■

Darleane Hoffman



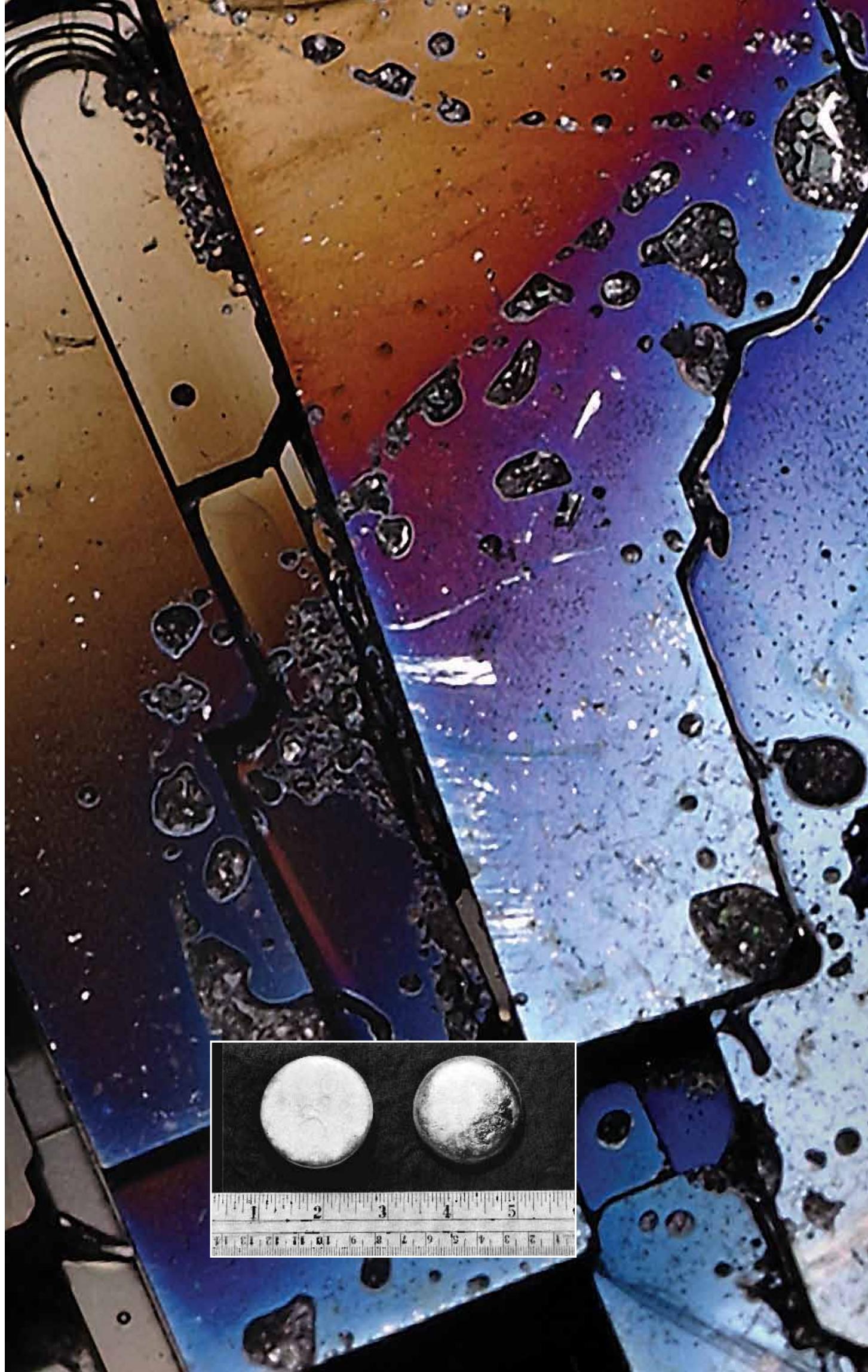
I was privileged to lead the Isotope and Nuclear Chemistry Division from 1979 to 1984—the first woman division leader at Los Alamos. As a chemist in the Radiochemistry group since 1953, I had studied nuclear fission, sought out new isotopes, researched radionuclide migration in the environment, and discovered the existence of plutonium-244 in nature. One of my most important scientific accomplishments at Los Alamos was conducted with co-investigator Jerry Wilhelmy at the Laboratory's Van De Graaff facility in liaison with Livermore colleagues. These difficult experiments involving tritium bombardments of essentially weightless rare fermium targets produced a new fermium isotope exhibiting a spectacular symmetric fission distribution, which opened a whole new regime for scientific exploration. In 1983, my colleagues nominated me for the Glenn T. Seaborg Award for Nuclear Chemistry for the production and characterization of heavy elements, both man-made and in nature. I was the first woman to receive this award! Next, I joined the University of California, Berkeley as a professor and Lawrence Berkeley National Laboratory as a researcher.

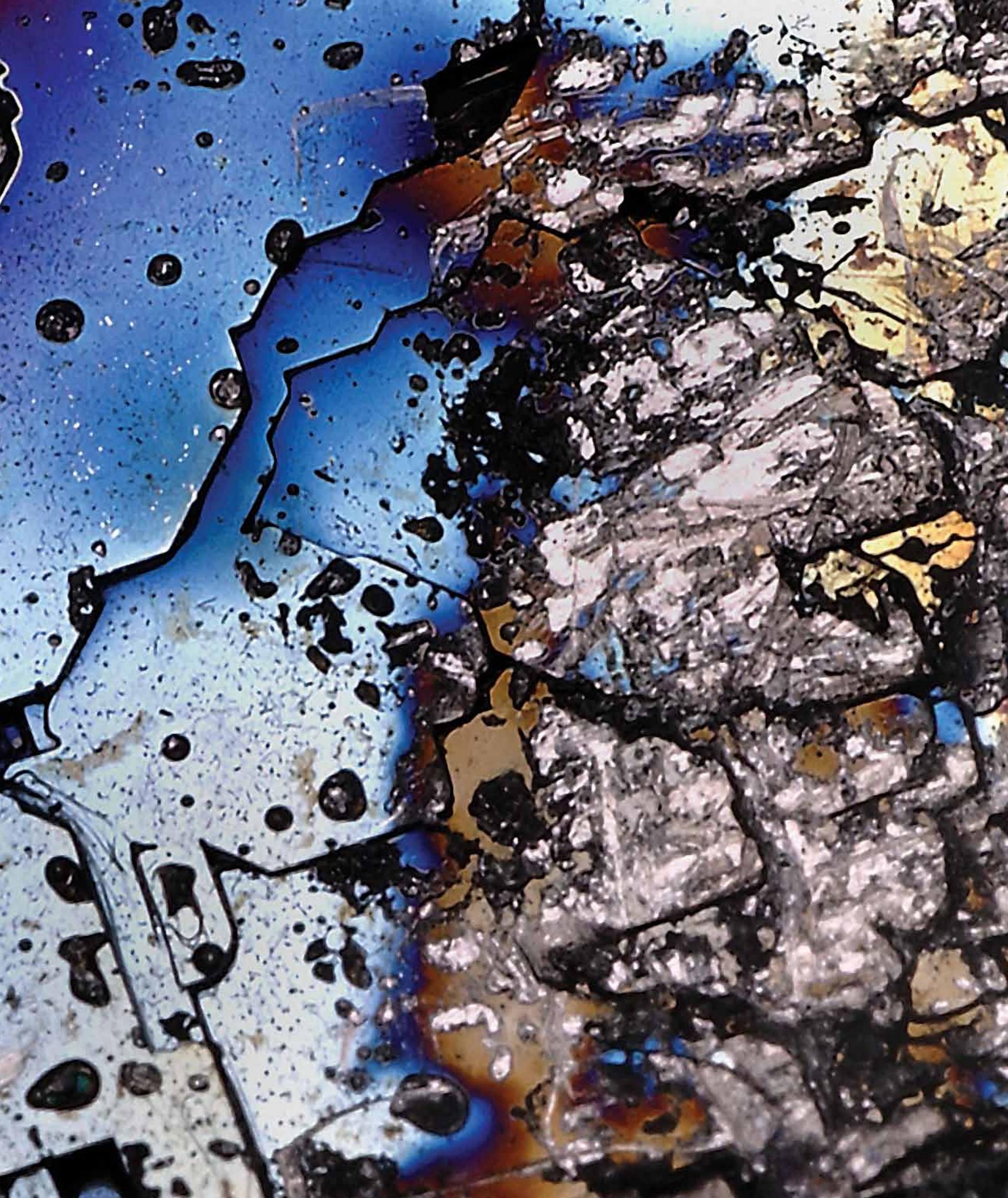
FOCUS

MAKING

In 2002, a renaissance in the interaction of plutonium metallurgy and condensed matter physics culminated in the discovery of unexpected superconductivity in a plutonium compound. This crystal is a cerium-based analogue of the plutonium-based superconductor.

(Inset) During the Manhattan Project, plutonium nitrate arrived in relatively impure form. Techniques and equipment were developed at Los Alamos for purification, preparation of plutonium tetrafluoride and other compounds, reduction to metal (pictured), and metal fabrication.



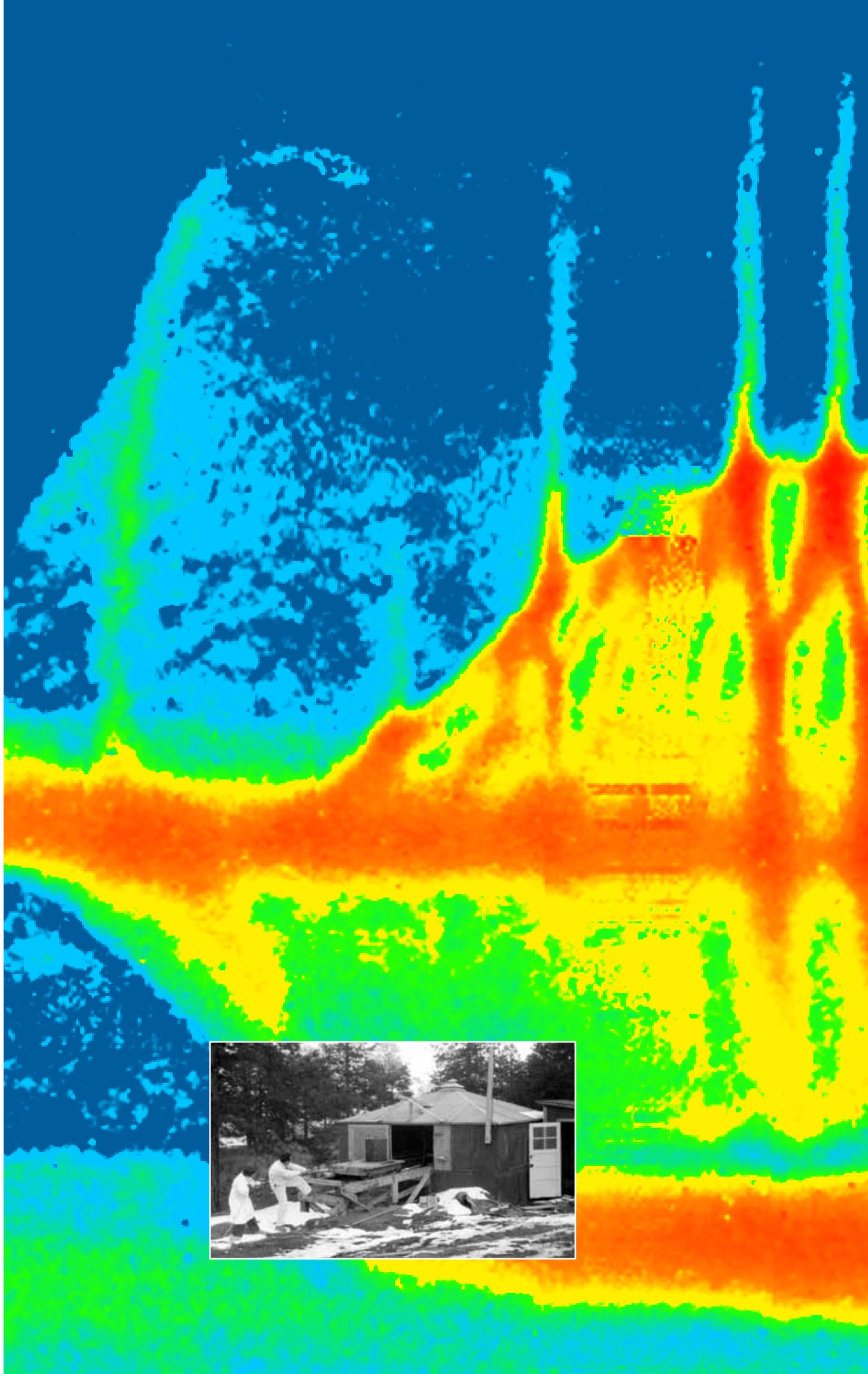


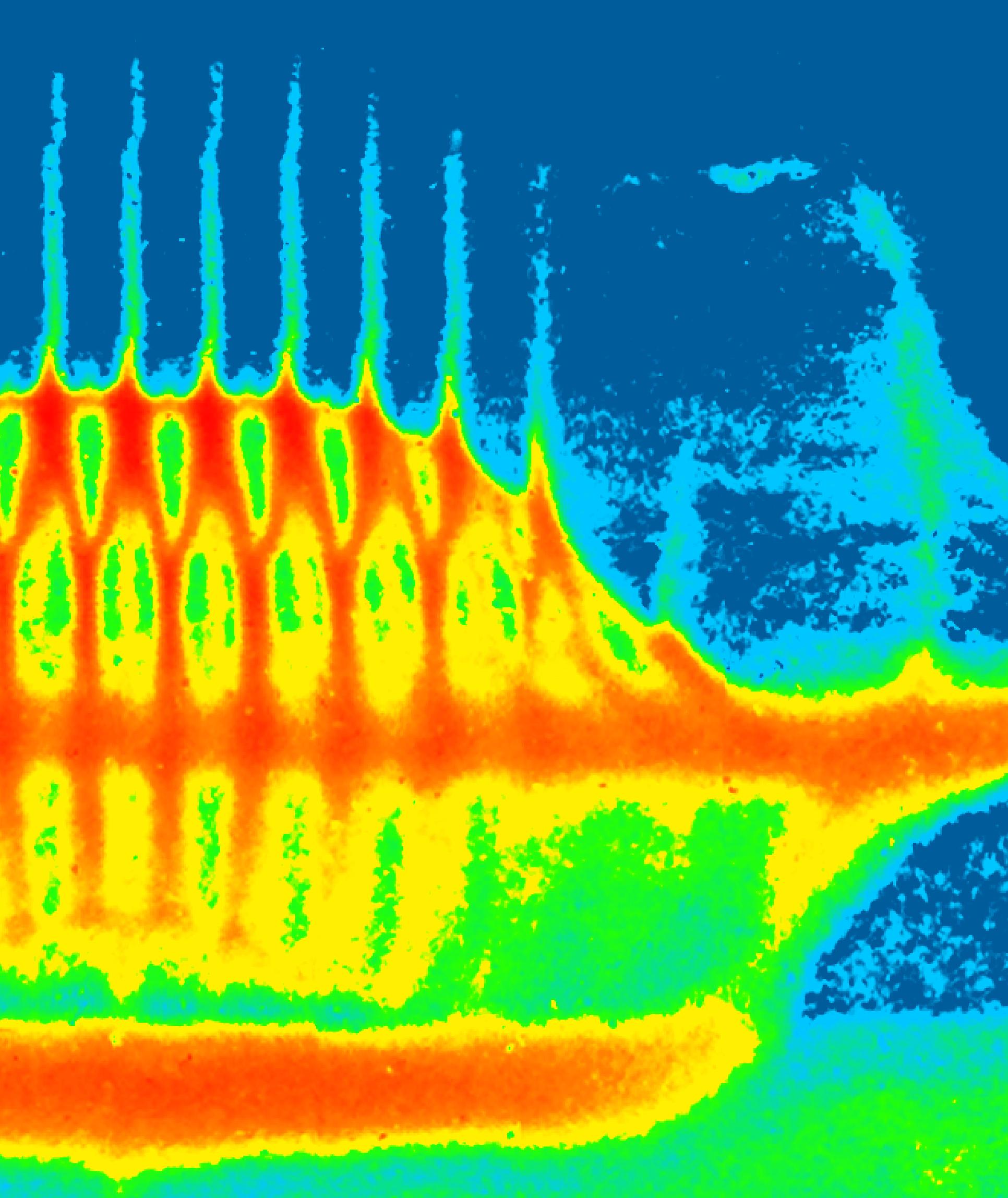
FOCUS

MEASURING

In this proton radiography image, protons penetrate a sample of explosively shocked tin, providing insight into the material's behavior under dynamic conditions.

(Inset) Two technicians carefully handle a kilocurie source of radiolanthanum for use in the Manhattan Project RaLa (radioactive lanthanum) experiments designed to study the hydrodynamics of implosion.



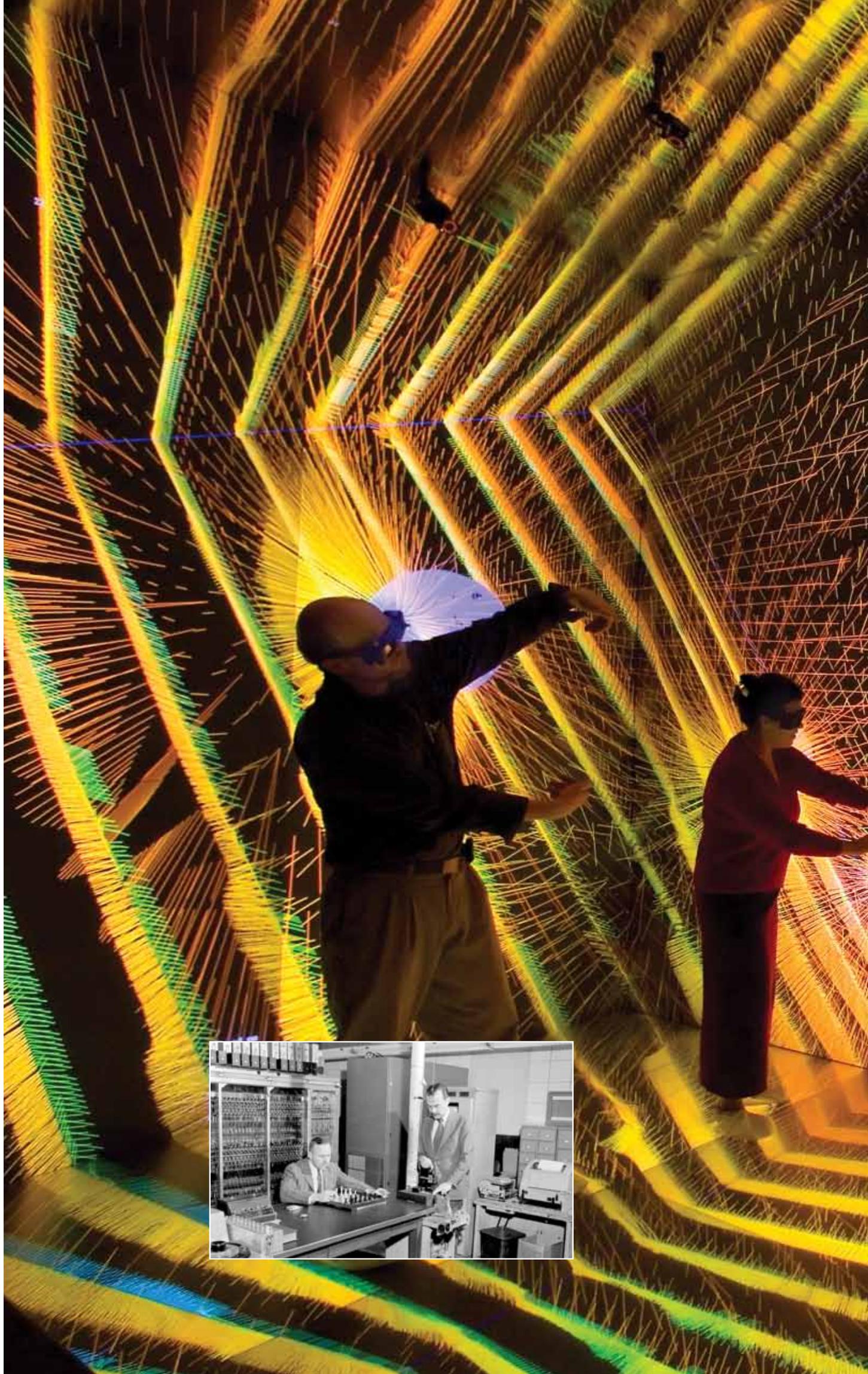


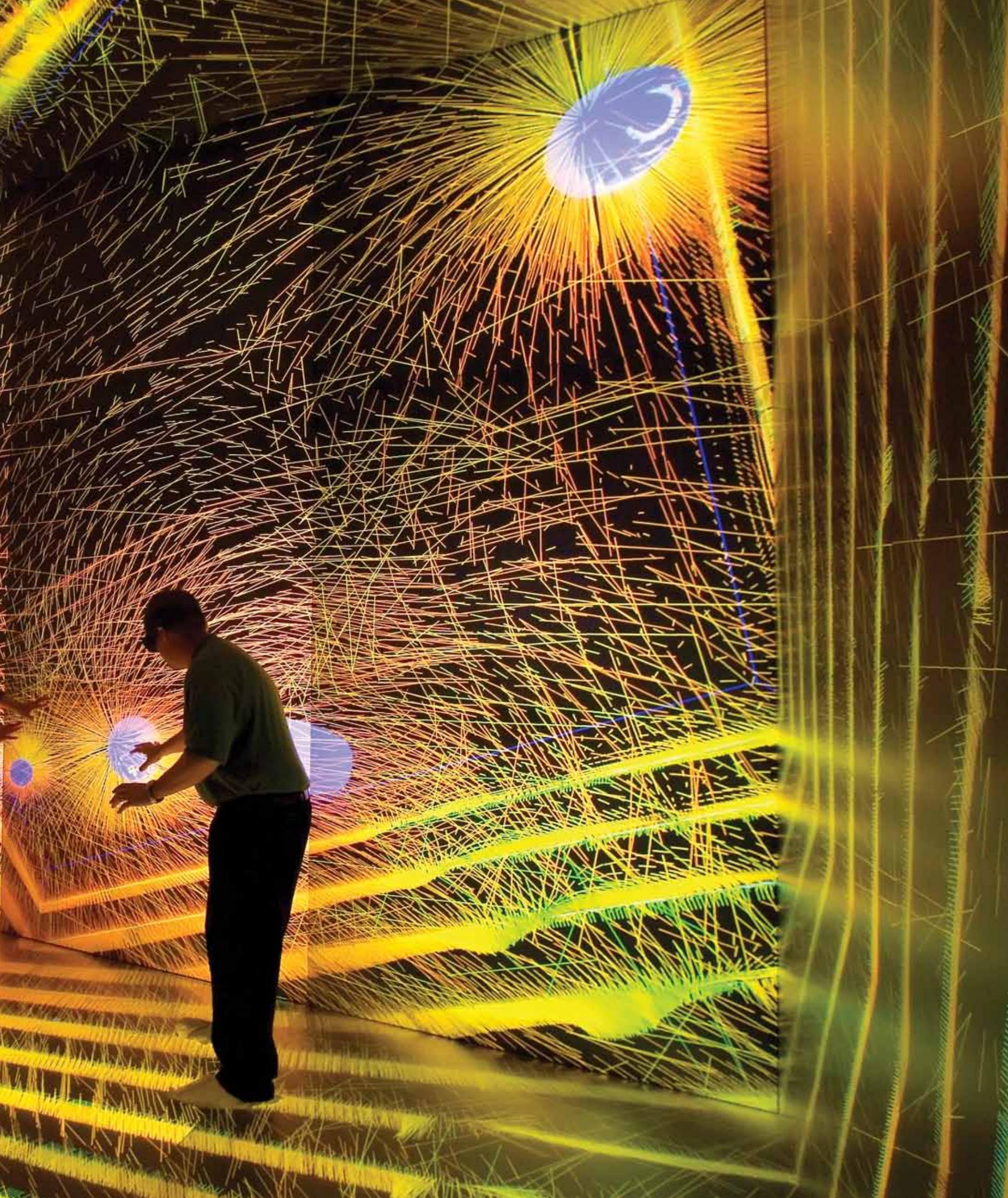
FOCUS

MODELING

Researchers investigate details of an astronomical simulation in the CAVE at the Los Alamos Strategic Computing Complex. CAVE stands for Cave Automatic Virtual Environment or immersive virtual reality environment.

(Inset) MANIAC (for mathematical analyzer, numerical integrator, and computer) was developed in Los Alamos during the early 1950s. Paul Stein (left) and Nicholas Metropolis test MANIAC's skill at chess.





From LAMPF to LANSCE . . .

STAYING AT THE FOREFRONT OF NUCLEAR PHYSICS LED THE LABORATORY TO ESTABLISH A SIGNATURE FACILITY

A 1962 memo from Louis Rosen to Physics Division Leader J. M. B. Kellogg contains the first official record of the Los Alamos Meson Physics Facility (LAMPF). Rosen, a nuclear physicist who had arrived at Los Alamos during the war years, measured nuclear cross sections using local facilities and contributed to the development of the hydrogen bomb. He realized that although the Los Alamos facilities had important work to do, they would not keep the Laboratory at the forefront of nuclear physics. To maintain the Laboratory's expertise in this critical discipline, Rosen conceived the world's first meson factory and the first national-scale user facility, LAMPF.

The project presented political as well as technical challenges. Putting aside his research activities, Rosen generated significant support in Washington, D.C., and energized the scientific community. To achieve the performance required of LAMPF, new accelerator technology had to be developed. Design and construction combined the Laboratory's making, measuring, and modeling expertise as theoretical physicists developed models for accelerator performance, experimental physicists tested and analyzed system components, and materials scientists fabricated parts.

Groundbreaking began in 1968. And, four years later, when LAMPF opened its doors, the user group had 830 members representing 228 institutions from across the world. The total cost of construction was \$56 million.

Progress continued. In 1977, the Weapons Neutron Research Facility, initially focused on weapons physics, first produced neutrons. The original concept, however, included a proton storage ring (PSR) to compress the proton pulses in time, and thereby achieve high neutron energy resolution. With the PSR's completion, the Los Alamos Neutron Scattering Center (now the Manual Lujan Jr. Neutron Scattering Center) became a locus for materials as well as nuclear studies; and in 1995 LAMPF became the Los Alamos Neutron Science Center (LANSCE), reflecting this broadening of research. (Please see John Browne's story on page 17.)

During this time, the realization of what was needed to certify nuclear weapons in the absence of nuclear testing became more and more real to the weapons program. LANSCE provided an ability to move into the real-time, direct measurement of material properties under dynamic conditions. A dedicated

facility for proton radiography, invented and demonstrated using the capabilities constructed by the LAMPF nuclear physics program, was constructed. Early proton radiography data contributed to decisions on the nuclear stockpile—a first for above-ground experiments. Neutron scattering also increasingly became a probe providing value in assessing weapons materials performance. All these efforts gave the broader weapons community a sense of the value provided by these newly developed diagnostics.

At the 2006 transition of the Laboratory contract from the University of California to Los Alamos National Security, LLC, the Experimental Physical Sciences Directorate was formed, uniting physics and materials in one organization. Soon thereafter, Director Michael Anastasio issued a Lab-wide call for ideas for a signature facility—one envisioned to play the defining role for the Laboratory future that LAMPF/LANSCE had for 30 years. From that emerged the concept now known as MaRIE (Matter-Radiation Interactions in Extremes). This proposed experimental facility has been developed on a solid foundation of science and technology created at LAMPF.

The evolution of signature facilities at Los Alamos



Fabricating a pillar on 5- μm diameter (about one-tenth the diameter of a human hair) in the Focused Ion Beam Laboratory.

... to MaRIE

MATTER-RADIATION INTERACTIONS IN EXTREMES WILL BE USED TO DISCOVER AND DESIGN THE ADVANCED MATERIALS NEEDED TO MEET 21ST CENTURY NATIONAL SECURITY AND ENERGY SECURITY CHALLENGES

Throughout its 70 years, Los Alamos National Laboratory has a proud history of its scientists stepping up to take on and solve the grand scientific and technical challenges of national security. Materials science has been a key pillar supporting the Laboratory's mission—from discoveries instrumental in ending World War II to ensuing advances in understanding nuclear materials, developing insensitive high explosives, and creating materials for fusion reactions, radiation casings, and neutron sources.

To meet new and emerging national security issues the Laboratory is stepping up to meet another grand challenge—transitioning from observing and validating to predicting and controlling a material's performance.

This challenge requires the best of experiment, modeling, simulation, and computational tools. MaRIE (Matter-Radiation Interactions in Extremes) is the Laboratory's proposed flagship experimental facility intended to meet the challenge.

The 2011 National Nuclear Security Administration (NNSA) call for future Defense Programs experimental facil-

ity ideas was an opportunity to identify and respond to decadal science, technical, and engineering challenges for stewardship of the nation's nuclear stockpile.

MaRIE 1.0, the NNSA-relevant elements of MaRIE as defined in the February 2012 proposal, is Los Alamos's top priority answer. Future opportunities are seen to enhance MaRIE, especially for non-NNSA sponsors. Don Cook, NNSA deputy administrator for Defense Programs, sent a letter to the directors of Los Alamos, Lawrence Livermore and Sandia national laboratories dated December 3, 2012, stating that MaRIE 1.0 was the highest ranked proposal.

The nation's future stewards will need to make decisions regarding materials to qualify and certify the stockpile of the future. MaRIE 1.0 is designed to support key NNSA goals to understand the condition of the nuclear stockpile and to extend the life of U.S. nuclear warheads. When combined with the emerging computational capability to simulate materials at ultrahigh resolution, MaRIE 1.0 will fill the gap in understanding of micro- and mesoscale materials phenomena and how they affect weapon performance.

(continued on next page) ►

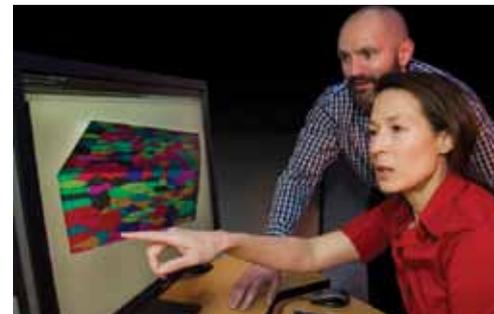
(MaRIE cont.)

MaRIE 1.0 brings together the following:

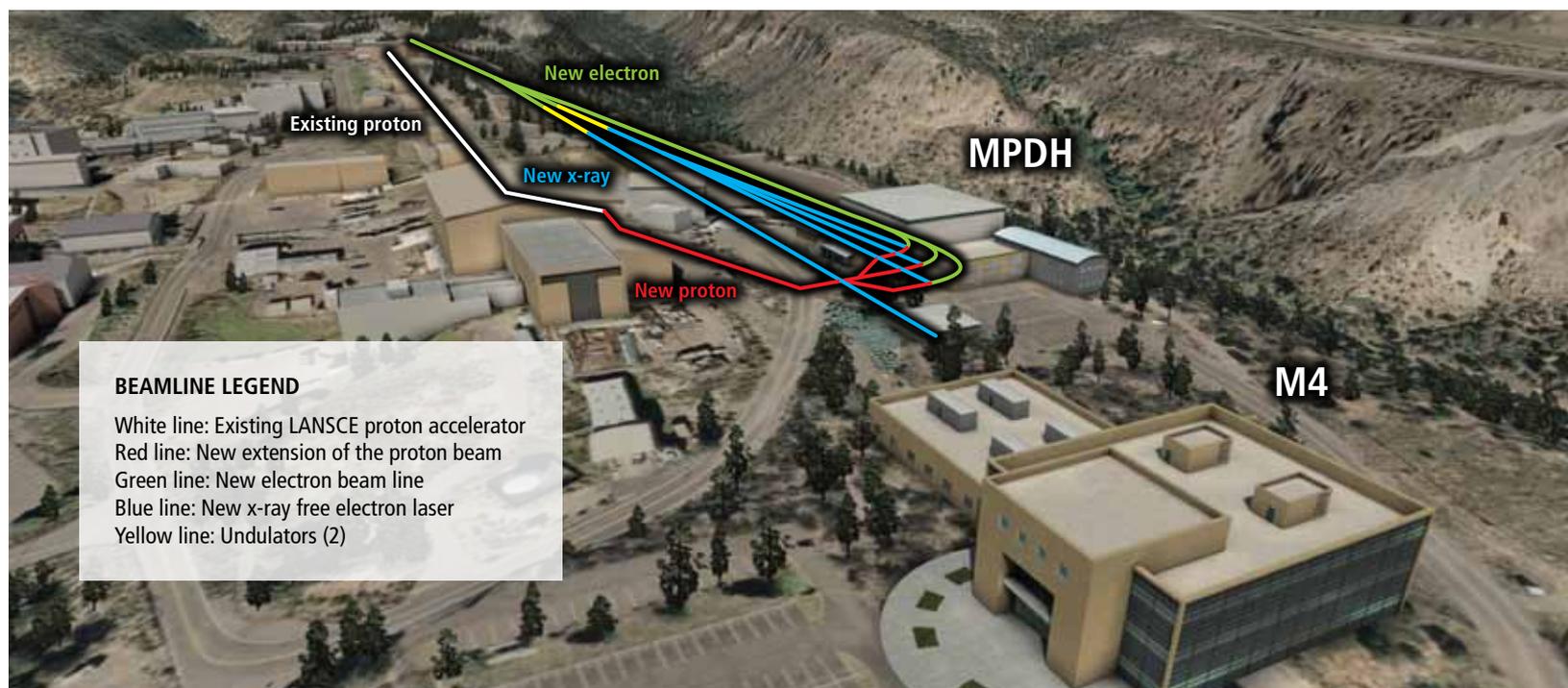
- The world's first very hard (42-keV) x-ray free-electron laser (XFEL), a high-peak brightness, low-emittance light source, which will create a one-of-a-kind focusing capability and allow for unique observations in dynamic extremes;
- A Multi-Probe Diagnostic Hall (MPDH) in which materials under extreme dynamic loading are simultaneously illuminated with hard, coherent, brilliant x-ray photons and radiographed with protons and/or electrons;
- A Making, Measuring, and Modeling Materials Facility (M4) in which samples are synthesized, characterized, and probed during fabrication and in dynamic experiments to understand phenomena at the mesoscale; and,
- Collocation of computation, theory, and experimental expertise with access to data visualization tools to provide an integrated ability to inform design and characterization of materials properties.

Working with the NNSA customer, Los Alamos plans to begin constructing MaRIE 1.0 in fiscal year (FY) 2020, with capabilities available to NNSA and the scientific community starting in FY27. In advance of facility construction between now and FY20, the Laboratory will conduct research and development to mitigate risk and reduce uncertainty in the areas of accelerator science, x-ray optics, and detectors, and to co-design aspects of experimental and modeling concepts. This all will be done with the backdrop of developing the scientific techniques that meet the nuclear weapons program challenges of the future while applying them to today's nuclear weapons program problems.

MaRIE 1.0 is the first step in attaining Los Alamos National Laboratory's future signature facility MaRIE. It will revolutionize materials in extremes, addressing the grand challenge of observation to control of functionality, while contributing to the qualification and the certification of performance of the future stockpile. MaRIE, as the next-generation signature facility for Los Alamos, will enable the Laboratory to attract the best and the brightest scientists across a broad range of disciplines. ■



MaRIE science is underway at Los Alamos National Laboratory. **Making:** Deniece Korzekwa and Seth Imhoff inspect a graphite mold used to cast plutonium "pucks" with specific microstructures. **Modeling:** Irene Beyerlein and Jason Mayeur examine interfaces in a simulation of deformed nanomaterials. **Measuring:** Frank Merrill replaces the proton-to-light converting scintillator in preparation for a dynamic experiment at LANSCE's Proton Radiography Facility.



As shown in this conceptual illustration, MaRIE 1.0 builds on Los Alamos Neutron Science Center's powerful 800-MeV proton linear accelerator, with new proton and electron beamlines, the world's first very hard x-ray free-electron laser, a Multi-Probe Diagnostic Hall (MPDH), and a Making, Measuring, and Modeling Materials Facility (M4).

Revolutionizing materials in extremes

MaRIE will couple theory, experiment, and simulation through real-time feedback to achieve transformational material advances in extreme environments.

PROCESS

Making, Measuring, and Modeling Materials Facility (M4)

THEORY

SIMULATION

DATA

CHARACTERIZATION

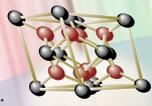
PROCESS FEEDBACK

PERFORMANCE FEEDBACK

MESOSCALE

1nm

Molecular dynamics
Atomic structure



Computing per bit

1fsec

Single crystal
Red blood cell

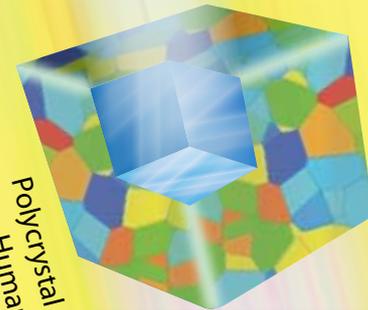


Shockwave by atom

1psec

1µm

Polycrystal
Human hair



Laser pulse

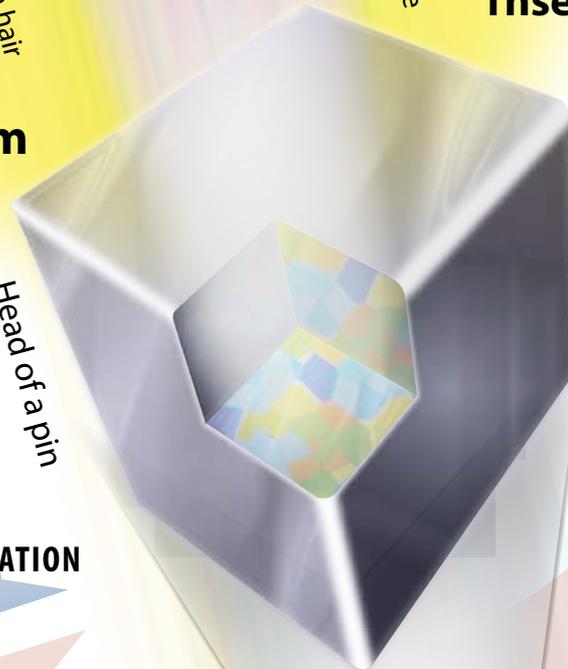
ultrafast

1nsec

ultrasmall

1 mm

Head of a pin
Flea



THEORY

DATA

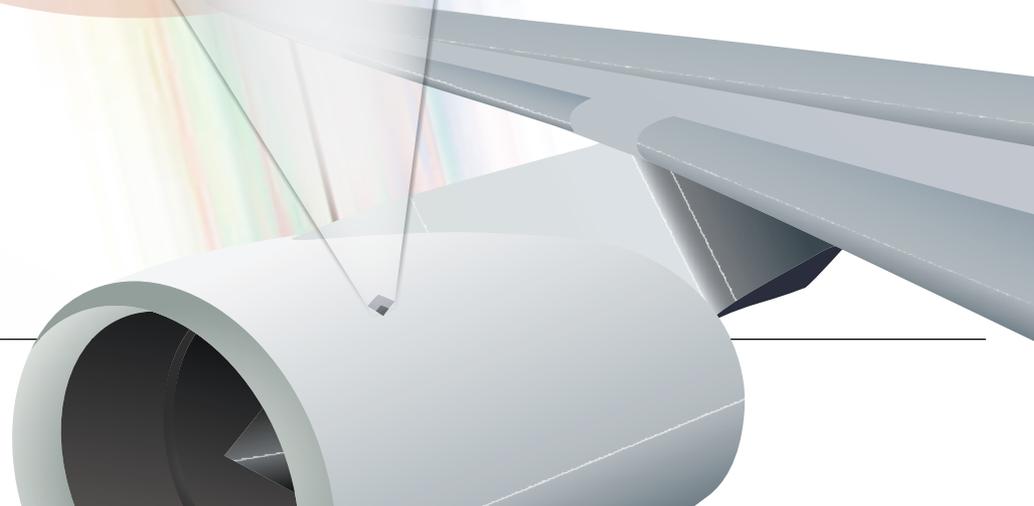
SIMULATION

EXPERIMENTATION

PERFORMANCE

Multi-Probe Diagnostic Hall (MPDH)

MaRIE will probe the mesoscale, the length scale between a few nanometers and many microns. The mesoscale is the spatial scale where the heterogeneous physics of nucleation, growth, and coalescence takes place. Heterogeneities can occur as a result of spall damage, creation of void and gas bubbles due to fission or irradiation, phase transformations, plasticity, or twinning. High-fidelity predictions of materials at the mesoscale under dynamic conditions require large-scale computation to capture the relevant physics.





 **Los Alamos**
NATIONAL LABORATORY

 **NNSA**
National Nuclear Security Administration