LOS ALAMOS NATIONAL LABORATORY ◆ SPRING 2025

NATIONAL ★ SECURITY SCIENCE

THE PHYSICS ISSUE

Physics for national security: Los Alamos physicists keep America safe

One byte at a time: Computational physicists get to work

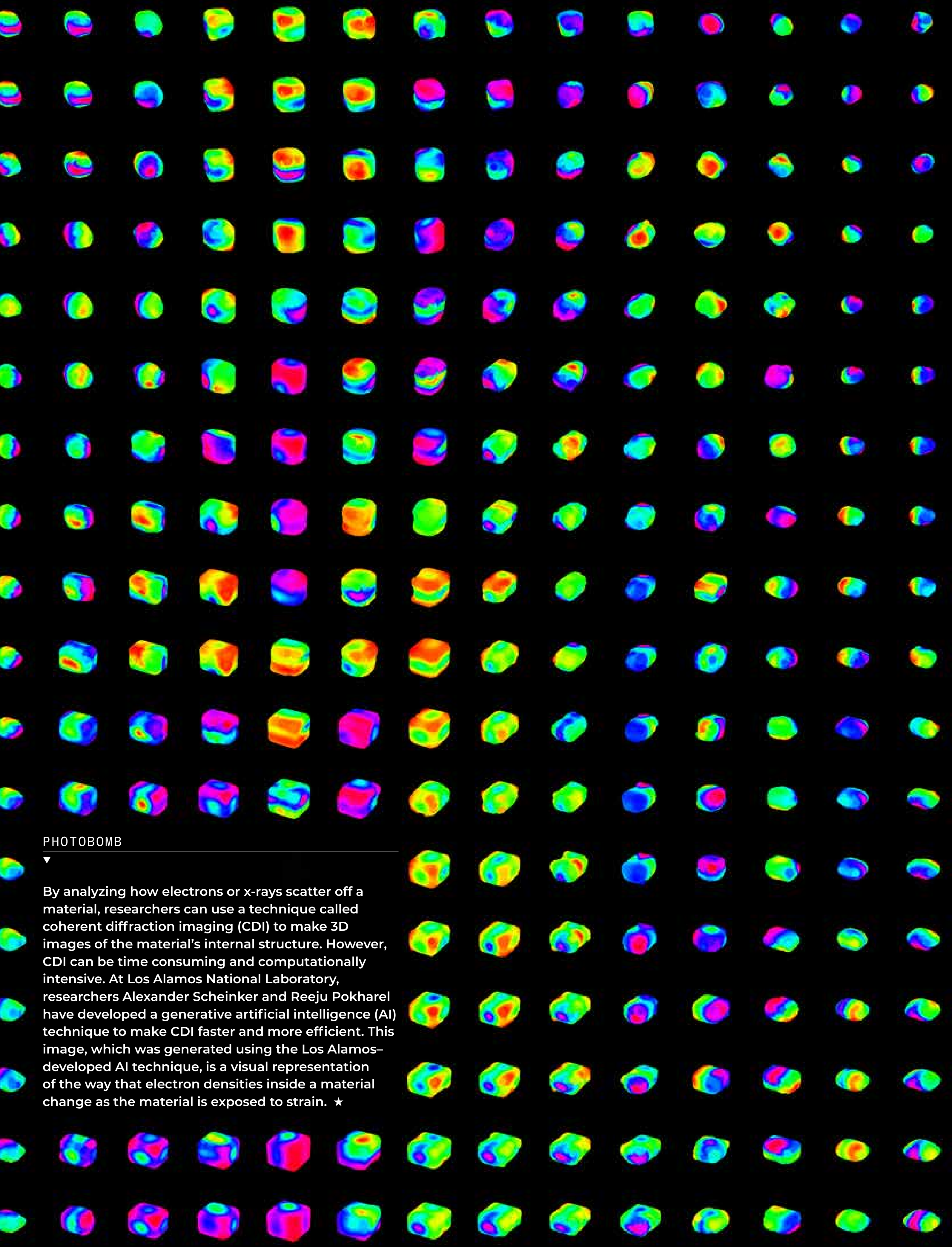
The power of plasma: High-energy-density physics unlocks mysteries

Advancing accelerators: New and improved facilities support the nuclear weapons stockpile

Remembering Los Alamos Director Charlie McMillan

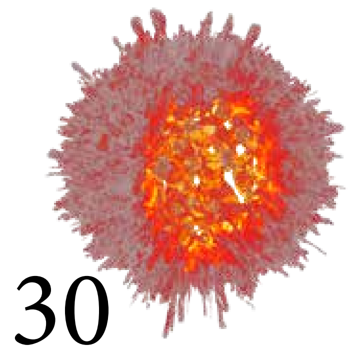
+PLUS:

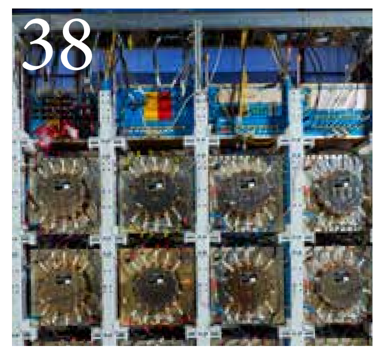
A new documentary about betrayal, treason, lies, and spies	The physics of a fictional universe	60 years in the sky for the B-52 Stratofortress



PHOTOBOMB

By analyzing how electrons or x-rays scatter off a material, researchers can use a technique called coherent diffraction imaging (CDI) to make 3D images of the material's internal structure. However, CDI can be time consuming and computationally intensive. At Los Alamos National Laboratory, researchers Alexander Scheinker and Reeju Pokharel have developed a generative artificial intelligence (AI) technique to make CDI faster and more efficient. This image, which was generated using the Los Alamos–developed AI technique, is a visual representation of the way that electron densities inside a material change as the material is exposed to strain. ★





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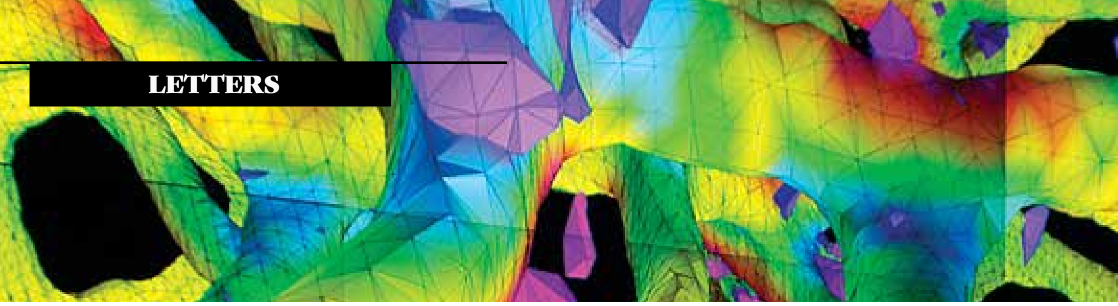
FEATURES

About the cover:
From his cabin in Angel Fire, New Mexico, former Los Alamos Director Charlie McMillan used a special camera and telescope to capture the cover image of the Rosette Nebula, a star-formation region located about 5,000 light years from Earth. Learn how scientists create conditions like those found in stars on p. 30. Learn about McMillan's life and career on p 50. ★

Photos: McMillan family



THE PHYSICS ISSUE

Innovative science helps ensure national security.

BY CHARLIE NAKHLEH
ASSOCIATE LABORATORY DIRECTOR FOR WEAPONS PHYSICS

Solving national and global security challenges requires world-class physics, which means bringing world-class experimental facilities, theory, and computational capabilities to bear on tough problems. Los Alamos National Laboratory has been an established leader in this type of national security work for more than 80 years.

Our primary mission here at Los Alamos is to develop and maintain the nation's nuclear deterrent, and our ability to execute this mission depends on our understanding of both fundamental physics and the ability to accurately predict the performance of intricate physical systems. Physics is the foundational discipline for understanding the design and operation of nuclear explosive devices. In the course of doing our work, we draw upon many fields of pure and applied physics, including nuclear physics, plasma physics, thermodynamics and statistical physics, hydrodynamics, and many aspects of materials science. Our goal is to ensure that the nation's nuclear stockpile remains safe, secure, and effective in the absence of full-scale nuclear explosive tests.

This issue of *National Security Science* magazine will introduce you to some of the Laboratory's passionate and dedicated physicists, the work they do, and some of the complex scientific infrastructure that makes such work possible. Using state-of-the-art scientific facilities and the Lab's extensive high-performance computing capabilities, Los Alamos scientists develop and apply innovative theory, computational models, and multiphysics simulation codes. We also conduct applied physics experiments to generate data that places our scientific understanding on a firm foundation.

Much of that data is used to model and simulate aspects of weapon aging and performance, which helps with weapons assessment and design. Learn more on page 22, and get to know some of the many physicists at the Lab on page 16 as they explain their contributions to national security. Plus, you can explore an innovative Los Alamos program that helps train scientists working in weapons physics. Read about the Theoretical Institute for Thermonuclear and Nuclear Studies on page 21.

You will also learn about a scientific instrument that has played a large role in experimental research to support stockpile stewardship. I'm talking about the accelerator, of which there are many types. These devices accelerate subatomic particles, such as protons and electrons, up to near-light speeds. We then put those particles to work in a number of fascinating ways. You can read about how we do that, and the work that is underway to upgrade two of Los Alamos' flagship accelerator facilities, on page 38.

This issue also explores how artificial intelligence (AI) is enhancing everything the Lab's physicists do. Learn how AI is contributing to everything from fusion research (p. 30) to computational physics (p. 22).

Finally, make sure to read the profile of former Los Alamos Director Charlie McMillan, an accomplished physicist, an outstanding leader, and a passionate advocate for the Laboratory and our work. Charlie died recently in a tragic car crash, and we all feel his loss keenly. Even if you did not know him personally, I hope that learning about him and his legacy will inspire you to live your life with the integrity, energy, and commitment he demonstrated each day. I did know him, and I count myself the luckier for that. ★

MASTHEAD

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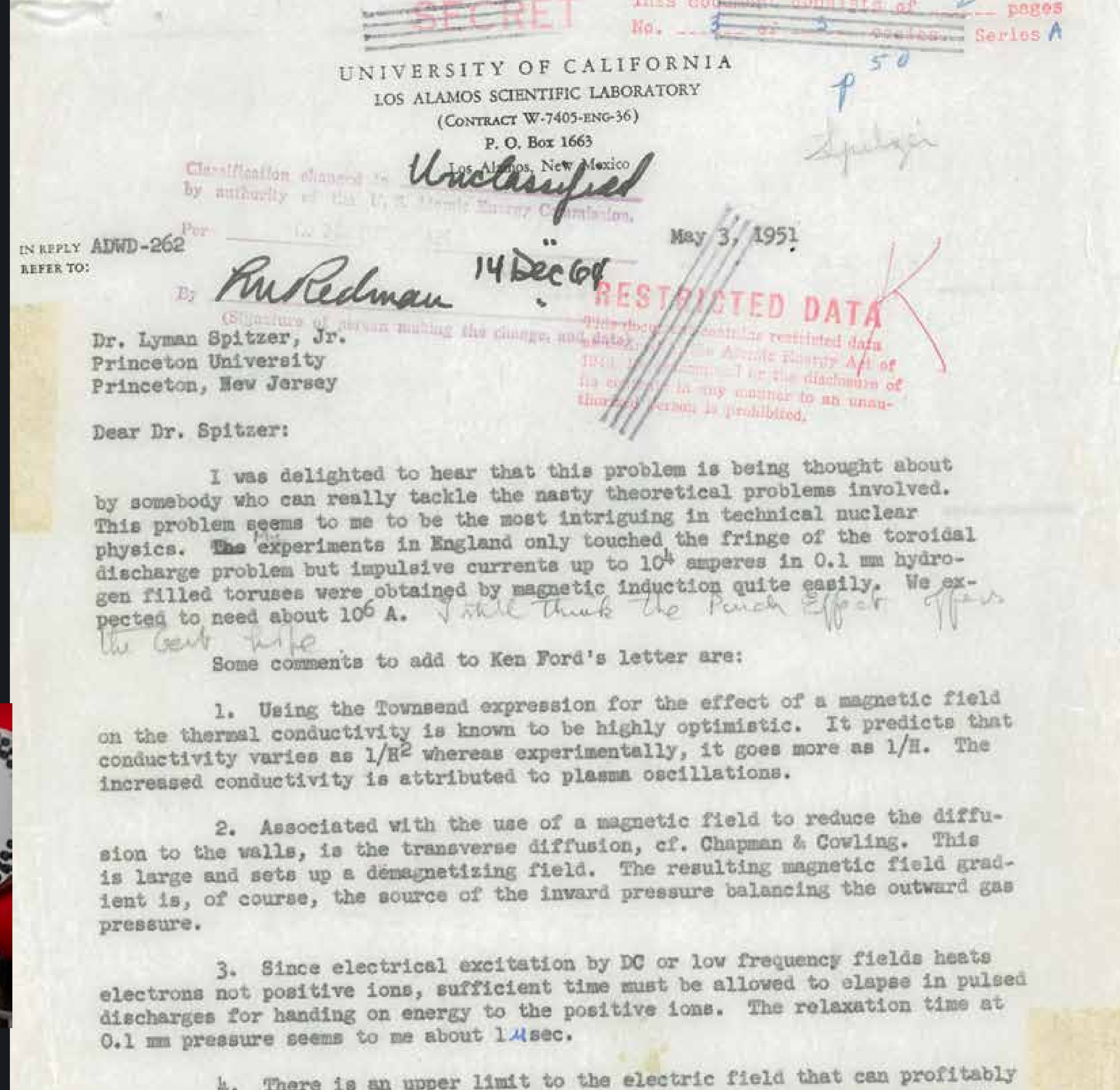
NSS STAFF SPOTLIGHT

Photographer Ignacio Perez served in the U.S. Navy for 11 years prior to joining the Laboratory in February 2024. "As a mass communication specialist 1st class, I worked with scientists, engineers, and service members to create videos and photos that helped explain new technologies and advancements," he says. "My current work here at Los Alamos is similar." Perez took many of the photographs in this issue of *National Security Science*, including the portrait of scientist and author Ian Tregillis on p. 66. "It was amazing to meet someone who is so humble and grateful to work at Los Alamos," Perez says. "And also, science fiction is my favorite genre of writing." ★



SECRET

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Los Alamos, New Mexico

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IN REPLY REFER TO: ADWD-262

May 3, 1951

RESTRICTED DATA
This document contains restricted data as defined in the Atomic Energy Act of 1946. Its transmittal or the disclosure of its contents in any manner to an unauthorized person is prohibited.

Dr. Lyman Spitzer, Jr.
Princeton University
Princeton, New Jersey

Dear Dr. Spitzer:

I was delighted to hear that this problem is being thought about by somebody who can really tackle the nasty theoretical problems involved. This problem seems to me to be the most intriguing in technical nuclear physics. The experiments in England only touched the fringe of the toroidal discharge problem but impulsive currents up to 10^4 amperes in 0.1 mm hydrogen filled toruses were obtained by magnetic induction quite easily. We expected to need about 10^6 A.

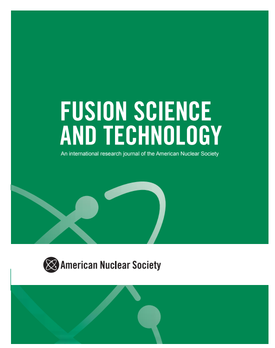
Some comments to add to Ken Ford's letter are:

1. Using the Townsend expression for the effect of a magnetic field on the thermal conductivity is known to be highly optimistic. It predicts that conductivity varies as $1/H^2$ whereas experimentally, it goes more as $1/H$. The increased conductivity is attributed to plasma oscillations.

2. Associated with the use of a magnetic field to reduce the diffusion to the walls, is the transverse diffusion, cf. Chapman & Cowling. This is large and sets up a demagnetizing field. The resulting magnetic field gradient is, of course, the source of the inward pressure balancing the outward gas pressure.

3. Since electrical excitation by DC or low frequency fields heats electrons not positive ions, sufficient time must be allowed to elapse in pulsed discharges for handing on energy to the positive ions. The relaxation time at 0.1 mm pressure seems to me about 1 μsec.

4. There is an upper limit to the electric field that can profitably



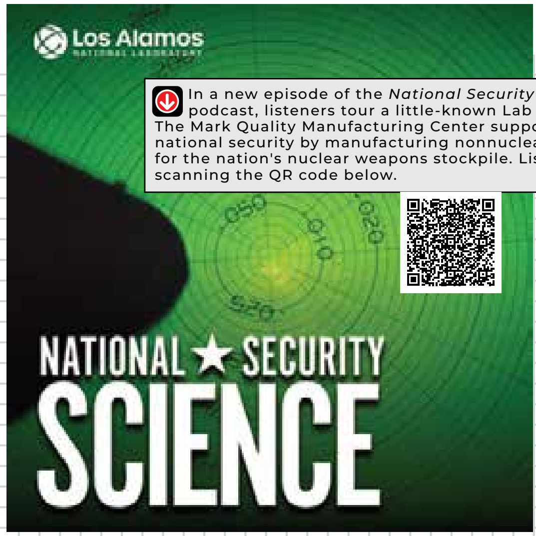
■ The October 2024 edition of *Fusion Science and Technology*, a journal published by the American Nuclear Society, commemorates early research on fusion conducted at Los Alamos National Laboratory in support of the eventual hydrogen bomb program. In their introduction, Mark Chadwick (associate Laboratory director for Simulation, Computation, and Theory) and B. Cameron Reed (emeritus professor at Alma College) provide an overview of the topics covered, including the historical origins of the thermonuclear program, what was known about fusion reactions at the outbreak of World War II, and the remarkable breakthroughs associated with fusion work, including the prospect of deuterium-tritium reactions conducted during the war.

Among the supporting documents in the edition is this 1951 letter from Los Alamos physicist James Tuck to Princeton University physicist Lyman Spitzer. Tuck discusses the physics of stellarators, which are the magnetic confinement fusion devices invented by Spitzer in the early 1950s.

To read the ANS edition, scan the QR code. For more on fusion at Los Alamos, see p. 30.

THE INTERSECTION

Science and culture converge in northern New Mexico—and beyond.



In a new episode of the *National Security Science* podcast, listeners tour a little-known Lab facility. The Mark Quality Manufacturing Center supports national security by manufacturing nonnuclear parts for the nation's nuclear weapons stockpile. Listen by scanning the QR code below.

SCIENCE

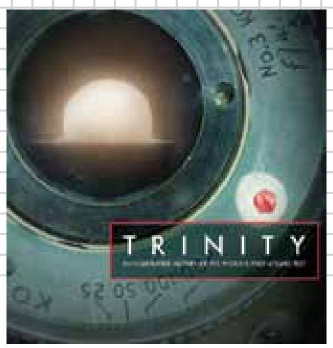
In certain areas of the Lab, employees have received dozens of email alerts about a lurking bobcat. “Be aware of your surroundings,” the emails say. “Use caution when entering and exiting buildings and vehicles.” Well, there are so many alerts because, it turns out, there are multiple bobcats. Tristan Davis, of the Lab’s Space Instrument Realization group, captured footage of two of them near his building. “We noticed that the bobcats were sitting on top of one of our storage containers,” Davis says. “Our team was surprised that the bobcats found a way to hop the fence and enter the secured area.”

CULTURE

On January 7, the National Nuclear Security Administration (NNSA) announced the completion of the last production unit of the B61-12 Life Extension Program (LEP). The milestone marks a significant achievement for the nation's nuclear deterrence efforts by extending the bomb’s service life by 20 years. Los Alamos and Sandia National Laboratories are the design agencies for the project, with Los Alamos also being responsible for producing detonators and other classified components.

In October 2024, delegates from the Japanese government visited Los Alamos National Laboratory and then toured the Trinity test site with National Security Research Center historian Nic Lewis. “The tour was a remarkable moment of exchange and understanding over the deep historical meanings of the Trinity site,” Lewis says. “The delegates were enthusiastic and incisive with their questions, which ranged from the logistical challenges of the Trinity test to the feelings of Los Alamos scientists as they grappled with inaugurating the atomic age. I believe we learned a lot from one another. It was an incredible opportunity to be a part of this event that reinforced where we are as allies, eight decades later.”

In November, Dick Groves visited some of the Los Alamos National Laboratory sites where his grandfather—General Leslie Groves—worked during the Manhattan Project, leading the effort to develop the world’s first atomic bomb. The day after his tour at the Lab, Dick traveled to Jemez Springs, retracing the route his grandfather took with Oppenheimer when scouting the area for the ideal secret site. “It was great to imagine Groves and Oppenheimer on that long-ago November day,” Dick said.



The Lab’s National Security Research Center is publishing a pictorial history of the Trinity test, showcasing more than 800 photos from its collections. *Trinity: An Illustrated History of the World’s First Atomic Test* will be available later this year to commemorate the 80th anniversary of the test.

Scan the QR code to view the trailer for the NSRC’s latest documentary.

BETRAYAL, TREASON, LIES, AND SPIES

A new documentary tells the story of World War II espionage at Los Alamos.

BY JILL GIBSON

On August 29, 1949, the Soviet Union shocked the world by detonating Joe-1, a device similar to the Fat Man atomic bomb that the United States developed and released over Nagasaki, Japan, four years earlier. Despite the secrecy and security enshrouding the Los Alamos wartime creation, counterintelligence efforts confirmed that three spies—physicists Klaus Fuchs and Theodore Hall and Army machinist David Greenglass—enabled the Soviet success. Decades later, in 2019, declassified materials revealed the contributions of a fourth spy, Army technician Oscar Seborer.

Fuchs, Hall, Greenglass, and Seborer are the subjects of a forthcoming documentary by the National Security Research Center (NSRC) at Los Alamos National Laboratory—formerly Project Y of the Manhattan Project, where all four men were employed.

Secrets in the Shadows: The Project Y Spies features never-before-shared historic materials from the NSRC collections, interviews with subject matter experts, and new insights on the relevance of this history for the Lab’s mission today.

NSRC Director Brye Steeves says the documentary reflects the NSRC’s role in both preserving and disseminating history in support of national security. “Understanding past successes and failures related to espionage informs the evolution of our country’s counterintelligence work,” she explains. “Be it understanding mitigation and discovery of the era or gaining insight into the human psychology of motivation and betrayal, the history of espionage helps address the complexities of this facet of national security.”

Over the decades, many authors and filmmakers have attempted to tell the story of World War II–era espionage, but, according to Senior Lab Historian Alan Carr, Los Alamos is uniquely positioned to share this information. In producing the hour-long video, Carr and Lab filmmaker Dave Tietmeyer recorded interviews with numerous experts to provide a compelling and historically accurate documentary.

“Everyone loves a spy story, but these spy stories really happened and had deadly consequences,” Carr says. “The archival film clips and interview segments put the spies’ actions in context, showing the consequences and explaining the importance of combating espionage today.”

Steeves says the documentary doesn’t disappoint. “These are fascinating anecdotes of motivation, narcissism, and betrayal—all preserved in the collections of the NSRC.” ★

Reis, pictured here in front of the Laboratory's National Security Sciences Building, spoke at Los Alamos during the Lab's 70th anniversary celebration in 2013.

In 2020, Reis sat down with *National Security Science* magazine to talk about the creation of stockpile stewardship—specifically, how he was able to bridge the gap between scientists and policymakers. Scan the QR code to read the article.

HAPPY BIRTHDAY, VICTOR REIS!

The "architect of stockpile stewardship" turned 90 in February.

BY JILL GIBSON & WHITNEY SPIVEY

On February 11, 2025, former assistant secretary for Defense Programs at the Department of Energy, Victor Reis, celebrated his 90th birthday. In addition to commemorating this milestone birthday, many across the nuclear security enterprise recognized more than three decades of Reis' biggest contribution: science-based stockpile stewardship.

The United States stopped testing nuclear weapons in 1992. In August 1993, Reis assumed responsibility for developing a new way for the United States to maintain its aging nuclear stockpile. Reis was instrumental in creating a science-based stockpile stewardship program, which uses dynamic experiments, computing simulations, and historical test data to evaluate the health and extend the lifetimes of America's nuclear weapons.

During an interview for the forthcoming Los Alamos National Laboratory documentary *Clouds, Craters, and Codes*, Reis reflected on the beginning of stockpile stewardship.

"The Cold War's over," Reis said, "but we've still got nuclear weapons, and the Russians still have nuclear weapons, as do the Chinese. I used to joke that the president really has two things that only he has to deal with. One is the nuclear button, and the second is the Marine Band."

It turned out that the "nuclear button" was a bit more complicated than the United States Marine Band, but Reis had an idea. "How do we challenge the laboratories to maintain the weapons without testing?" he asked. "That's got to be a really difficult scientific challenge. I said, the Cold War's over, but we're going to need those laboratories. The most important thing you can do is keep those laboratories engaged."

Before long, the science-based Stockpile Stewardship Program was born. "If you set it up as a science program, I knew the laboratories would come in and figure out what that program really meant," said Reis, who became known as "the architect of stockpile stewardship."

Siegfried Hecker, retired Los Alamos National Laboratory director, also commented on the beginnings of stockpile stewardship when interviewed for *Clouds, Craters, and Codes*. Hecker described the decisions behind Reis' plan. "As part of Vic's overall game plan for science-based stockpile stewardship, we all agreed that it would take a huge increase in computing. We actually had the nuclear weapons and computer codes people get together and lay out what we needed to do to create the sort of modeling and simulation needed in the absence of nuclear testing to help us keep confidence in the stockpile."

Another aspect of Reis' plan was developing world-class experimental facilities. Hecker explained, "Vic also realized that each of the laboratories ought to have a Nordstroms—like in the mall, an anchor facility. And so for Lawrence Livermore, it was lasers and the National Ignition Facility. For Los Alamos, it was DARHT." (For more on the National Ignition Facility, see p. 30; for more on the Dual-Axis Radiographic Hydrodynamic Test facility, see p. 38.)

In the end, the government embraced Reis' ideas for stockpile stewardship, and his vision has shaped how the complex has operated for more than three decades. According to Associate Laboratory Director for Weapons Physics Charlie Nakhleh, "Stockpile stewardship has succeeded beyond the wildest expectations of even the most ardent advocates in those days." ★

SPARKING COLLABORATION

A new partnership with the University of Michigan will bolster high-performance computing and AI work.

BY JILL GIBSON

Los Alamos National Laboratory and the University of Michigan are partnering to create a national research center and high-performance computing facility to support joint research in science, energy, and national security.

The collaboration, which is called Michigan SPARC (Strategic Partnership for Accelerated Research and Collaboration), will "combine the capabilities and intellectual DNA of two great public institutions to make revolutionary advances in supercomputing and AI for the nation's benefit," says Charlie Nakhleh, associate Laboratory director for Weapons Physics.

This partnership builds on a five-year, $15 million research contract that the Lab awarded the university in early 2024. The funds are supporting research on developing advanced computing technologies, including artificial intelligence (AI) and sophisticated modeling techniques, to address complex challenges such as unlocking fusion's potential as a clean-energy source. SPARC, officially announced in December 2024, continues and builds on the earlier-established research contract.

"Los Alamos drives a wide range of vital national security programs that utilize high-performance computing, AI, and other capabilities like advanced materials and manufacturing to provide leading-edge solutions to some of the world's most challenging problems," Laboratory Director Thom Mason says. "This partnership will provide critical new resources to support our data-intensive work."

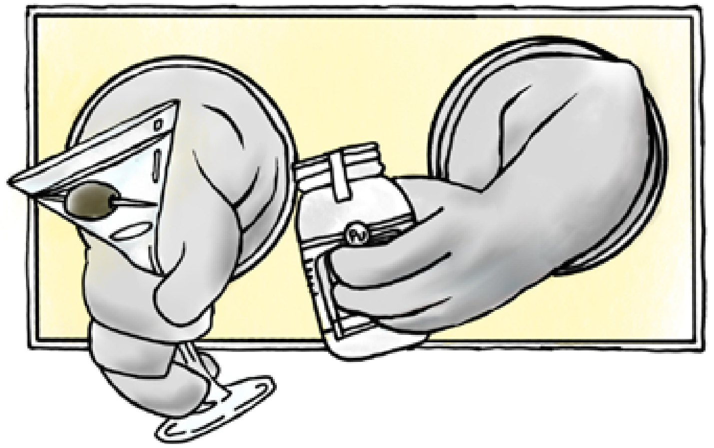
The partnership will include creating a facility for federal, classified research and a separate facility for unclassified research, which will be used by faculty, staff, and students, with potential opportunities for use by other universities. Both will be located in Washtenaw County, Michigan. Lab leadership anticipates the partnership could create up to 200 new jobs and numerous new research and networking opportunities.

To kick off the collaboration, two Los Alamos scientists—physicists Daniel Israel and Joshua Dolence—accepted joint appointments and relocated to Michigan. "I'm excited about the opportunity to help build a powerful new vehicle for mission-driven innovation, leveraging fresh perspectives and the incredible energy and talent at the University of Michigan," Dolence says.

Israel agrees, noting how much he enjoys working with college students. "Helping students learn about national challenges in science and then seeing them contribute to solving them is extremely rewarding," he says.

Dolence says he looks forward to the continued expansion and growth of the partnership. "This gives us a unique opportunity to build lasting and deep collaborations," he says, "and we're excited to grow the scope and diversity of this interaction." ★

Los Alamos scientists Israel and Dolence are leading collaborations at the University of Michigan.



PROBING PLUTONIUM

Los Alamos scientists conduct groundbreaking research on a complex element.

BY JILL GIBSON

In 2023 and 2024, scientists at Los Alamos National Laboratory conducted two novel experiments, Martini and Moonshine. Despite their names, the experiments have nothing to do with alcohol. Instead, both are focused on finding new ways to analyze plutonium, a radioactive element that plays a key role in nuclear weapons. By using existing facilities in new ways and reestablishing a dormant testing capability, scientists say they are uncovering valuable information about how plutonium behaves.

The National Nuclear Security Administration, which oversees the Laboratory, honored Martini with a Defense Programs Award of Excellence and a citation for exceptional achievement, recognizing the test as one of the three most important national security science technical achievements of 2023. Martini demonstrated the Lab's ability to execute a complex experiment that required extensive collaboration between multiple national laboratories in an extremely short time period—only four months.

Martini was conducted at Sandia National Laboratories' Annular Core Research Reactor (ACRR). The ACRR allowed researchers to subject plutonium samples to high neutron irradiation, providing insights into how the material behaves under different conditions.

"Plutonium still has surprises, and it's important to conduct these experiments to understand its material properties better," says Karen Paige, Weapon Survivability program manager. "Martini and its follow-on experiments allow us to assess the nation's nuclear stockpile and provide information that will contribute to future weapons designs."

Paige says the team will build on what they have learned from Martini by testing plutonium at the Transient Reactor Test facility at Idaho National Laboratory. Transient testing involves the application of controlled, short-term bursts of intense neutron flux, which will provide additional information about plutonium's material properties. "Different neutron sources with different characteristics extend our knowledge of plutonium's properties," she says. "These new approaches offer important insights, and I'm excited to work on the forefront of these discoveries."

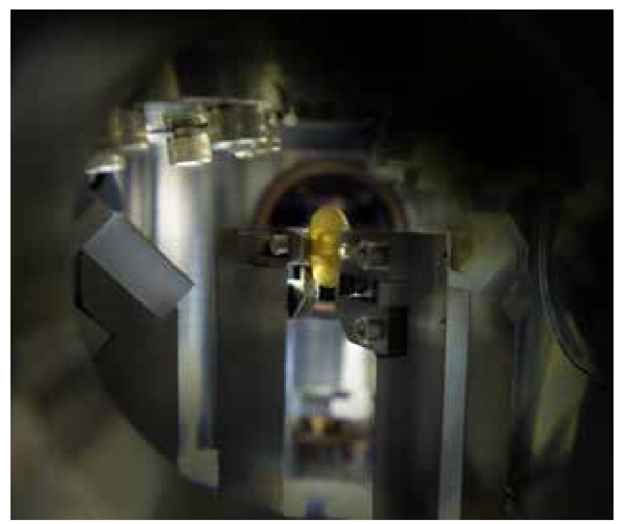
Los Alamos is also conducting a groundbreaking series of plutonium experiments at its Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility. (Learn more about DARHT and other accelerators on p. 38.) The goal of the series is to answer physics questions about plutonium and how it behaves under certain conditions.

The first experiment in the series, Moonshine, took place in May 2024 and used the DARHT accelerator's electron beam to change the thermodynamic state and phase of a plutonium sample. Physicist Rendell Carver suggested using DARHT for this experiment series because its beam "provides a unique combination of energy density, penetration, and time scale," he explains. Moonshine marked the first time plutonium had ever been used in a DARHT experiment. The amount of plutonium used in the Moonshine series tests was small—about the size of a quarter, only a tiny fraction of that contained in a nuclear weapon.

Carver notes that being able to predict plutonium's behavior is a crucial component of assessing the reliability, performance, and safety of the nation's nuclear weapons, which all contain plutonium that is decades old.

Scientists are only beginning to scratch the surface when it comes to understanding the data from Martini, Moonshine, and follow-up experiments. "These are some of the most innovative experiments on plutonium I have seen in decades," says Los Alamos Deputy Director for Weapons Bob Webster. "They are critical to expanding our understanding." ★

■ Sandia National Laboratories' ACRR allows researchers to subject various test objects to a neutron irradiation environment. Photo: SNL



■ An inert sample sits in a containment system during run-up operations for the Moonshine experiment.

QUOTED

"The completion of the last production unit marks the results of years of collaborating among a diverse team of experts from various technical fields across the Laboratory. I'm extremely proud of the dedication and hard work of everyone who contributed to this outcome."

—Deputy Laboratory Director for Weapons Bob Webster, on the last production unit of the B61-12, which was announced on January 7. Learn more on p. 4.

QUOTED

“Serving at Los Alamos National Laboratory on the most important mission for the nation has been a great honor. The work we do here is not just technical—it is a responsibility, a commitment to ensuring our nation’s security through scientific and engineering excellence. I have been privileged to stand alongside some of the most brilliant minds in the field, and what we have accomplished together is a testament to the dedication and ingenuity of this community. As I transition to the next chapter, my confidence in the future of LANL and our contribution to the nuclear weapons mission remains unwavering. The mission continues, and it is in capable hands.”

—Former Associate Laboratory Director for Weapons Engineering and Chief Engineer James Owen, who recently left Los Alamos to be the president of Fuse Federal, a subsidiary of Fuse, a nuclear fusion company.

THE MIGHTY MUON

Scientists harness cosmic particles to safeguard nuclear material.

BY JAKE BARTMAN

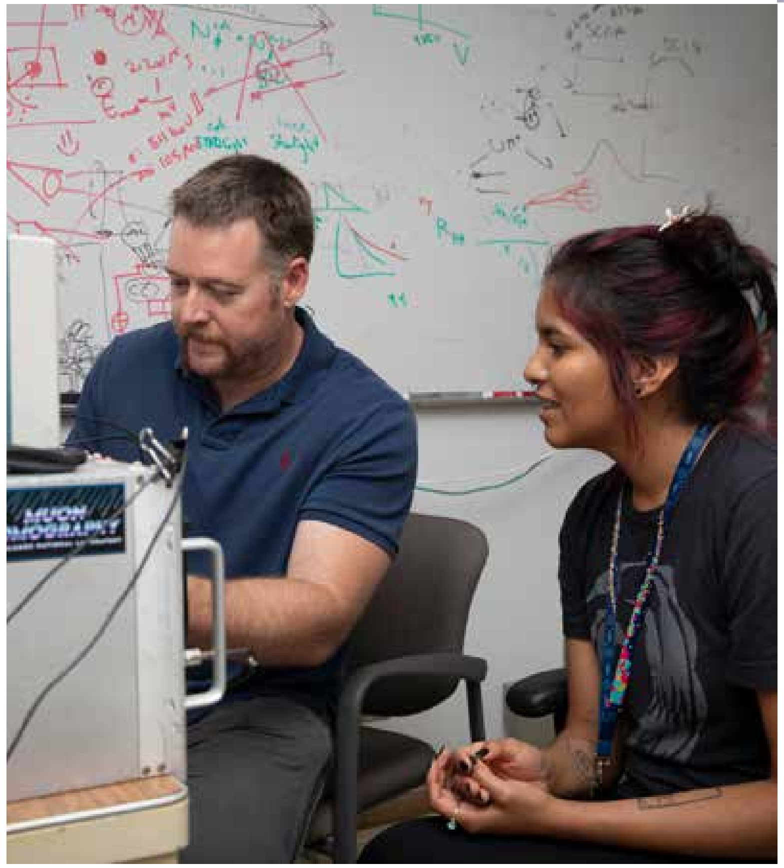
The Earth’s atmosphere is continually bombarded with particles (such as protons) from outer space. When these particles collide with the atmosphere, they produce other particles, including a type of subatomic particle called a muon, that rain down on the planet.

By using a detector to register how many muons are absorbed by an object, it is possible to infer the object’s density and structure. Physicist Luis Alvarez famously used muography, as this technique is called, in the 1960s to look for hidden rooms in the pyramids at Giza, Egypt. (Muons are capable of passing through hundreds of feet of solid rock.)

In the early 2000s, Chris Morris, a physicist at Los Alamos National Laboratory, developed a more sophisticated muography technique called muon scattering tomography, in which muons arriving at the Earth’s surface from the atmosphere travel through a detector, through an object, and then through a second detector. These paired detectors can track how muons change course when they interact with an object’s atoms—data that can be used to make a 3D model of the object’s structure.

Muon scattering tomography is especially useful for imaging materials with a high atomic number, such as uranium or plutonium, and for looking inside objects that are too dense to be penetrated by x-rays or gamma rays (which are used in other kinds of imaging). In 2006, Los Alamos licensed its muon scattering tomography technique to Decision Sciences International, which developed a detector system that is now used in the Bahamas, Singapore, and on the U.S.-Mexico border to search for drugs and other illicit substances hidden inside cargo.

■ Durham (left) works with student Victoria Nofchissey.



■ At Los Alamos, Durham stands beside a muon scattering tomography detector developed by Decision Sciences International. This summer, researchers will attempt to use the detector to image the contents of spent nuclear fuel casks.

More recently, researchers at Los Alamos have been exploring the use of muon scattering tomography to help ensure that radioactive waste created by nuclear reactors isn’t diverted for nefarious purposes. After uranium is irradiated inside a nuclear reactor, the spent fuel—which contains plutonium produced as a byproduct—is submerged in a pool of water for around a decade before being sealed inside a cask and dispositioned for long-term storage. To prevent any radioactivity or nuclear material from escaping, the casks, which are large (weighing up to 250,000 pounds when full) and heavily shielded with steel and lead, are welded shut.

However, after a cask has been sealed, verifying the contents can be difficult for International Atomic Energy Agency safeguards inspectors, who are sometimes called upon to ensure that none of the material inside a cask has been stolen or diverted. “There isn’t any good way to look inside these containers,” says Matt Durham, a researcher at Los Alamos. “You can’t image them with neutrons or gamma rays because of all the shielding. The only way to see inside a container is to open it up again.”

With colleagues from the University of New Mexico and the Colorado School of Mines, in the summer of 2025, Durham and other Laboratory researchers will bring a state-of-the-art detector developed by Decision Sciences to Idaho National Laboratory, where they will attempt to use muons to image the contents of spent-fuel casks. Previous research and modeling have demonstrated the experiment’s feasibility. “We have much larger detectors now, so we can look at the casks from multiple sides,” Durham says. “That will give us a huge amount of data relative to what we were able to capture before.”

If all goes well, the experiment could support the development of tools that safeguards inspectors could use to verify spent-fuel casks’ contents. The research could also open the door to other applications of muon scattering tomography.

For example, muon scattering tomography could conceivably be used to verify the contents of small modular reactors (a kind of advanced nuclear power reactor that researchers around the world are working to develop). Like spent-fuel casks, these reactors are heavily shielded, which could make verifying their fuel content challenging. Someday, muons—a few of which have likely passed through you as you’ve read this article—might help ensure that these reactors don’t pose proliferation risks, supporting nuclear security into the future. ★

■ Surrounded by team members, Reines (third from the right) holds a Project Poltergeist poster.

PROJECT POLTERGEIST

Frederick Reines won a Nobel Prize for detecting the neutrino.

BY IAN LAIRD

From 1943 to 1945, some of the world's most brilliant scientists descended on Los Alamos, New Mexico, in support of the Manhattan Project—the U.S. government's top-secret effort to create the world's first atomic weapons. Eighteen of these scientists were or would become Nobel Laureates. But only one would be honored for work actually performed at what is today Los Alamos National Laboratory.

That one was Frederick Reines, who remained at the Lab following the end of World War II. Around 1947, Reines started to explore ideas that would culminate in his detection of the neutrino—and a Nobel Prize in physics.

The neutrino is a neutral (non-charged) particle with a mass of less than one electronvolt. For comparison, an electron has a mass of 511,000 electronvolts. To give a different perspective, a neutrino is about 10 billion, billion, billion times smaller than a grain of sand.

In addition to being incredibly small, neutrinos are incredibly abundant. Every object emits neutrinos, but because of their neutrality and low mass, neutrinos very rarely interact with other particles. At any given moment, tens of trillions of neutrinos are passing through your body.

Austrian physicist Wolfgang Pauli first hypothesized in 1930 that such particles existed. In 1932, Nobel laureate and future Manhattan Project scientist Enrico Fermi coined the term neutrino ("little neutron" in Fermi's native Italian). But it would be more than two decades before anyone had experimental proof the neutrino existed.

In the late 1940s, Reines took an interest in nuclear weapon effects and studied blast waves and radiation pollution. Reines suspected that a nuclear detonation might emit large quantities of neutrinos, but together with Los Alamos physicist Clyde Cowan decided the rapid timescale of a detonation would make detection too difficult. The pair then turned to nuclear reactors, believing a more controlled environment and longer timescale would make detection easier.

Reines and Cowan hypothesized that a neutrino might interact with a proton to produce a neutron and a positron. The positron would in turn interact with any nearby electron, annihilating both itself and the electron and producing two detectable gamma rays. The probability of such an interaction is extremely low (one in one trillion trillion), so a large neutrino generator and a large source of protons would be necessary.

■ Project Poltergeist experiments used a liquid scintillation detector to detect the neutrino. Reines (left) helps lower Wright Langham into the detector's chamber.

Because the Lab didn't have a nuclear reactor to facilitate their experiment—dubbed Project Poltergeist—the two Los Alamos researchers traveled to Hanford, Washington, in 1953 and then to the Savannah River Site in South Carolina in 1955.

At Savannah River, two 200-liter tanks filled with water were placed near the reactor. Because of the weak bonds between hydrogen and oxygen in water molecules, the hydrogen atoms functionally serve as free protons. Neutrinos would interact with the hydrogen atoms, setting off the hypothesized chain of reactions that would produce gamma rays. The water tanks were surrounded by liquid scintillator material, which responds to gamma rays by giving off a flash of light.

In the end, after collecting months of data, Reines and Cowan had evidence of three neutrino interactions per hour. To ensure the resulting gamma rays weren't being produced by some other reaction, Reines and Cowan switched off the reactor and saw the rate of detected events decrease significantly, an indication that the interactions were driven by the reactor's beta decay and proof that the ghost particle existed. In 1956, they published their findings in *Science* magazine.

Reines would leave Los Alamos shortly after this discovery, and although he would dedicate much of his remaining career to neutrino research, it was Project Poltergeist that ultimately won him the Nobel Prize in 1995. He and Cowan shared credit for the discovery, but Reines alone received the Nobel Prize (the award isn't bestowed posthumously, and Cowan had died in 1974). This accomplishment marked the first, and so far only, time that Nobel Prize–winning work was performed by a Los Alamos National Laboratory scientist.

Despite efforts to study neutrinos in the decades since Reines and Cowan's discovery, the "little neutrons" remain fairly mysterious. Scientists hope they could one day provide insights into the early universe, stars, and dark matter. ★

EXPLOSIVE EVIDENCE

Understanding the characteristics of underground explosions aids nuclear nonproliferation efforts.

BY AVERY ARENA

How can the United States know if a nuclear weapon is detonated underground by another country or group? Networks of sensors—seismic, infrasound, gas, and others—around the world provide clues. To develop a better idea of how an underground nuclear explosion could show up on such sensors, scientists at Los Alamos National Laboratory—in collaboration with teams from Lawrence Livermore, Pacific Northwest, and Sandia national laboratories and the Nevada National Security Sites (NNSS)—are conducting Physics Experiment 1 (PE1).

PE1 comprises seven distinct experiments at NNSS—none of which use special nuclear material. Arguably the most significant of the experiments conducted so far, PE1-A, occurred on October 18, 2023. During this experiment, 16.3 metric tons of chemical high explosives were detonated inside an underground chamber. Two additional experiments are scheduled for 2026 and 2027 and preparations for both are underway.

In each experiment, the size and configuration of the chamber is expected to affect the information recorded by sensors. The team is using accelerometers, seismometers, infrasound sensors, electromagnetic sensors, and chemical and radiotracer samplers to collect measurements. Already, the data from PE1-A is being used to validate predictive models and detection algorithms, and scientists are making changes to what they thought they knew about the propagation of electromagnetic waves and carbon monoxide gas through the NNSS lithologies.

"The Laboratory's nuclear nonproliferation work has perhaps never been so relevant and necessary as it is now," says Dave Coblentz, deputy division leader for Earth and Environmental Sciences. "PE1 is an innovative and timely scientific endeavor that considerably bolsters our understanding of underground chemical and nuclear explosions at a time when it's not out of the question that our adversaries might detonate a nuclear device below the Earth's surface." ★

■ PE1 experiments are taking place inside P Tunnel at NNSS.
Photo: NNSS

■ Henry (left) is a B-52 pilot and one of Los Alamos National Laboratory's two Air Force fellows. Photo: Joshua Henry

SIXTY YEARS IN THE SKY

After decades of service, the B-52 continues to deter the United States' adversaries.

BY JAKE BARTMAN

Hallmark cards and B-52 pilots agree on one thing: Age is just a number.

The B-52 Stratofortress—one of the United States' two nuclear-capable bombers—has been in service since the early 1960s. Although the B-52 "stratosaurus" (as some have jokingly referred to the aircraft) has served longer than any other bomber in American history, the B-52 isn't ready to retire yet. In fact, the B-52 will soon receive upgrades that enable it to achieve its mission for decades to come.

"It's a 60-year-old aircraft, but it's definitely not going anywhere," says Major Joshua "Reacher" Henry. Henry is a B-52 pilot who, as one of Los Alamos National Laboratory's two Air Force fellows, is at Los Alamos this year to share his experience as a pilot and to learn about the nuclear weapons enterprise from the Laboratory's perspective. "Modernization efforts are going to keep the bomber relevant well into the 2050s."

The Air Force's heavy bomber fleet consists of three kinds of aircraft: the B-1 Lancer, the B-2 Spirit, and the B-52. In the next two decades, the B-1 and B-2 will be retired and replaced by the B-21 Raider. But the B-52—which can carry the broadest range of conventional and nuclear bombs and missiles—is slated to remain in service past 2050. To keep the B-52 in the air for another 25 years or longer, the Air Force plans to overhaul the bomber with new engines, modern radar and defensive systems, and more. The first B-52 upgrades will happen in 2026.

Henry describes the B-52 as a "stick-and-rudder" aircraft that requires skill to handle but is "a blast" to fly. He notes that the B-52's dual capability (its capacity to carry and deploy both conventional and nuclear weapons) makes it an enduring part of the nation's nuclear deterrent. For one thing, the B-52's closed bomb bays mean that adversaries can't know for certain whether, and in what quantities, a bomber is carrying conventional or nuclear weapons on any given mission. "We rely on the B-52 every day to deter our adversaries," Henry says.

The United States' 46 nuclear-capable B-52s also play an important role in the nation's deterrence strategy because they are recallable, Henry says. Bombers can be deployed in a crisis to signal the nation's readiness to defend its interests, but unlike missiles launched from submarines or silos, they can be called back to base if tensions ease.

Henry has flown B-52 sorties, or missions, in Europe, Asia, Africa, South America, the Middle East, the Pacific Ocean, and elsewhere. He also flew the B-52 as a part of Operation Inherent Resolve (the United States' campaign against the Islamic State). One notable sortie involved joining forces with allies from Japan and the Republic of Korea over the Pacific Ocean. The sortie, which was a freedom-of-navigation mission intended to safeguard the neutrality of international waters, did not escape the attention of the People's Republic of China, which dispatched fighter jets to intercept the aircraft.

"When you're in the Pacific or the Middle East, you're not there just to execute your sortie and go home," Henry says. "Instead, you're taking the opportunity to integrate with allies and partners and to reinforce the extended deterrence umbrella for the United States. And when you're intercepted by adversaries, it shows that you're getting under their skin."

At Los Alamos, Henry is learning about diverse aspects of the Laboratory's nuclear security mission, including stockpile stewardship (which ensures—without nuclear testing—the safety, security, and reliability of the nation's nuclear deterrent). He is also studying the weapons development process, with a view to understanding how the Air Force could more efficiently modernize and sustain the nuclear weapons in its custody.

"As a bomber pilot, you know that there is a whole enterprise behind the deployment of nuclear weapons," Henry says. "But being here as a part of the fellowship, we're really getting to see the enterprise at work. If we didn't have institutions like Los Alamos, we wouldn't have the weapons that provide deterrence."

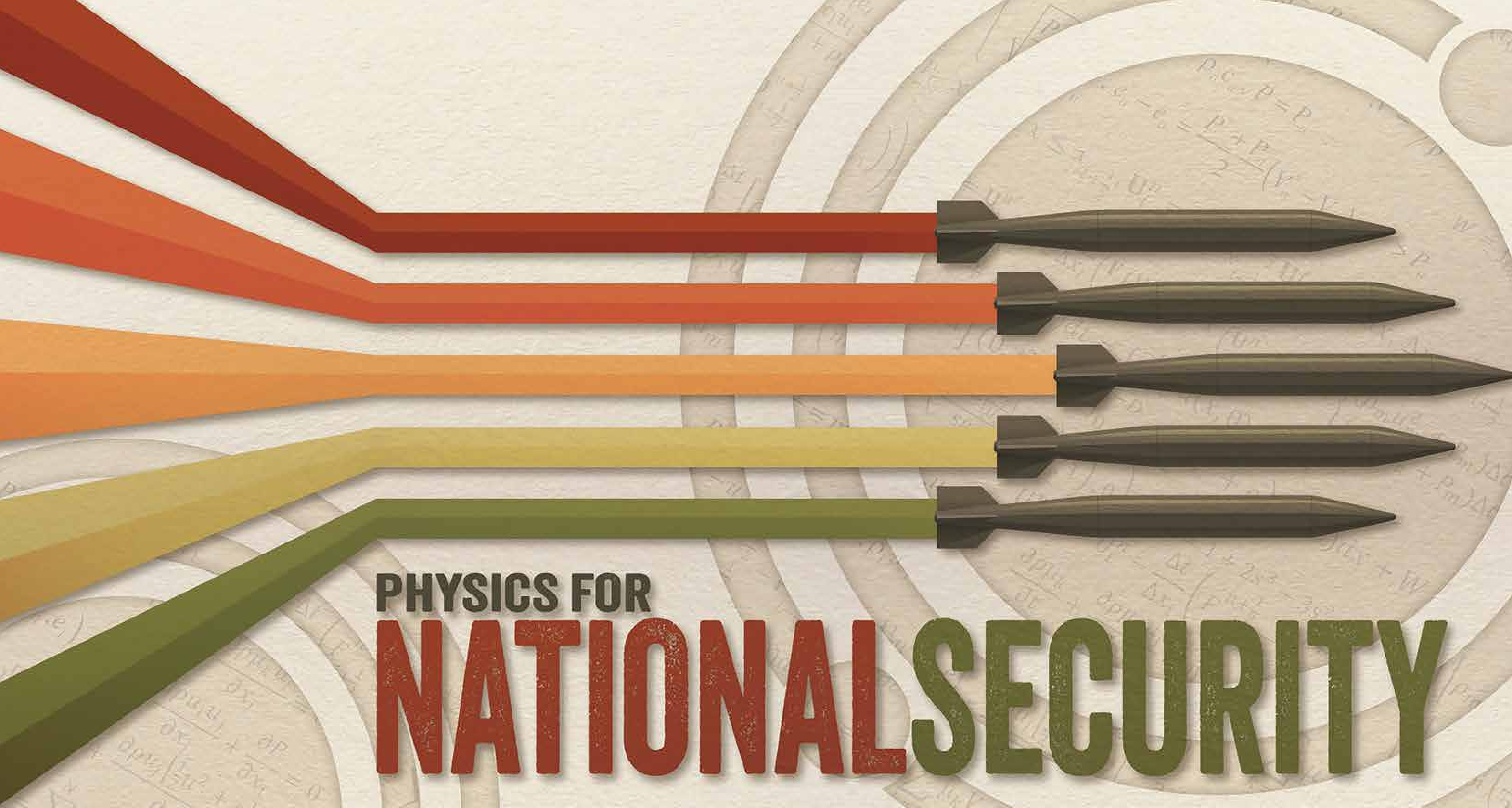
Henry says that although the B-52 has had a long life, the coming upgrades will ensure that the bomber remains a key part of the nation's nuclear forces well into the future. "The B-52 is an old jet, but it's got sharp teeth," Henry says. "It still provides a powerful deterrent effect for our adversaries." ★

■ A B-52 flown by Henry is photographed from above shortly after an air refueling in the Middle East. Photo: Joshua Henry

QUOTED

"From securing our weapons systems, to meeting Cold War-era waste commitments, to fostering innovation and technology breakthroughs, DOE protects what America has built and represents the very best of what it can achieve."

—Secretary of Energy Chris Wright, in his February 5 welcome remarks to Department of Energy employees (Los Alamos National Laboratory is part of DOE). Wright visited Los Alamos on February 24 and is pictured here at the Manhattan Project home of J. Robert Oppenheimer.



PHYSICS FOR NATIONAL SECURITY

Los Alamos physicists play a role in keeping America safe.

BY JILL GIBSON

"I have one of the coolest jobs in the world," says physicist Rachel Smullen. "I do some of the most interesting and impactful things. Some days, the work that I do goes to the president's desk."

The president of the United States, that is.

That's because Smullen works at Los Alamos National Laboratory—one of three laboratories in the country responsible for the design and maintenance of America's nuclear weapons. Because nuclear reactions happen so quickly, at such small scales, a combination of physicists, engineers, and some of the fastest supercomputers in the world are necessary to understand how these weapons work, age, and behave in a range of conditions.

Smullen is 1 of about 300 Los Alamos scientists—modern-day Oppenheimers, if you will—working in the branch of the Laboratory that "develops and applies cutting-edge theory, computational models, large-scale weapon simulation codes, and the design and execution of innovative and pioneering experiments," says Charlie Nakhleh, associate Laboratory director for Weapons Physics. The staff also works on nuclear counterterrorism, nuclear nonproliferation, nuclear forensics, and emergency response. "This is big science," Nakhleh says.

Physicist Beth Lindquist says that although her career is difficult to explain to the general public—particularly given security considerations—it's extremely compelling. "In the weapons physics community by its very nature, we are doing cutting-edge work that very few places in the world are able and allowed to do," she says. "You're leading the charge in the field. That's a unique aspect to working here."

A complex process

Work in weapons physics often begins with a request from the military, who is the custodian and potential user of America's nuclear weapons. "When we design a weapon, we begin by looking at the requirements and considering what might meet the military's requests," Smullen explains. "We ask ourselves, 'How can we approach the design and engineering to fit these requirements?'"


Rachel Smullen

> **"The type of people drawn to studying physics are the type of people who are always wondering why. Our brains never shut off."**
>
> —Rachel Smullen

These types of questions result in a theory, or an explanation of how a system works, or could work, based on observations, experiments, or existing scientific principles. "Physics theory is my strength," says Baolian Cheng, a computational physicist who has worked at Los Alamos for more than 30 years. "I am always working in abstract space. I start with theory and then ask myself, 'How can we observe it? What is the evidence? How can you prove it?'"

Next, physicists build a computer model that translates the theory into a mathematical framework. Then they write computer codes that implement the model to create simulations—representations of the outcome of the process or behavior. (See page 22 or more about models, codes, and simulations.) "All throughout the process, we run simulations," Smullen says. "Every time we make a design change, we run a new simulation. We are always asking whether the design can be certified as safe, secure, and effective."

"My job involves using computer models to create simulations of current weapons designs and concepts for the future," says physicist Jessica Thrussell. "We model experiments to check that our codes are simulating reality as best as they can, and we make improvements to how we run the codes."

Thrussell says she finds this process extremely gratifying. "I get to see results from my work, and what I'm doing is relevant—it has real-world impact and national importance."

Weapons designers move from theory to model to simulation, drawing on experimental data along the way. Los Alamos physicists also conduct experiments to test their theories, validate their models, and gather data. "I think one of the highlights is when you work on an experiment, and there are many different people contributing to it, and you get to make a measurement at the end that is useful," physicist Candace Joggerst says.


Ryan Jadrich

A desire to learn and collaborate

A uniting characteristic of the physicists at Los Alamos National Laboratory is curiosity. These scientists are driven by the desire to gain knowledge, answer questions, and push the boundaries of the unknown. "I have a passion for answering questions," says Ryan Jadrich, a physicist who works in post-detonation nuclear forensics. "Basically, I work on how to reverse-engineer nuclear detonations to determine what happened. I see my work as solving puzzles using inverse design methods of systematically going backward. I will keep digging deeper to get answers," he says.

Smullen says she appreciates the fact that there is always something new to learn at Los Alamos. "The type of people drawn to studying physics are the type of people who are always wondering why. Our brains never shut off." She describes her work as ideal for someone passionate and creative. "I feel excited that every year people come to me with new ideas and projects," she says. "The work constantly evolves. There is no rut to get stuck in. It's all fresh snow."

Smullen and her colleagues say they welcome challenges. "The complexity of the problems are multidimensional and multivariable phenomena are complicated," Cheng says. After three decades at the Lab, she is still full of energy and enthusiasm. "My work is never boring. My work is my hobby," she says.

For Thrussell, part of the appeal of Los Alamos is not getting pigeonholed into one area. "Most of us have several different projects and work on many different types of problems throughout our career and appreciate continued learning."

Lindquist, who works in nuclear threat assessment and global security, calls her work fast-paced and dynamic. "There's a collaborative environment in weapons physics and global security and that really appeals to me," she says.

Scientists often cite Los Alamos' collaborative culture as one of the key benefits of their work. Eli Feinberg started at the Lab as a staff member doing software development and is now earning a doctorate in applied physics at the University of Michigan while working at the Lab. "What really has me continuing to work with the Lab is the people there," he says. "I think about my coworkers and how much I've learned from them and the high regard I have for them." He adds, "If I won the lottery, I would still want to do this work. I think it's really fulfilling."

The high caliber of the staff is another benefit that the Lab's physicists often mention. "The people who are successful here are the ones that aren't intimidated that they're not the expert in the room, but they're excited that they get to sit in the room with so many experts," Joggerst says. "We like to argue—turn over different aspects of things, chew on them and consider them from different perspectives. You need a variety of technical backgrounds in an organization because no one can be an expert in everything, but we are each an expert in something."

Cheng agrees. "I work with so many amazing people," she says. "It is a collaborative culture, and I have always felt respected and have had great mentors and colleagues."

A drive for deterrence

Another commonality at the Lab is a commitment to nuclear deterrence and national security. "People recognize the need for unbiased technical expertise behind our nation's nuclear deterrent," Feinberg says, noting that when talking to people outside of the Lab he likes to emphasize the fact that his work helps provide a way to conduct crucial research without nuclear testing. "That is one of the things that makes me passionate about my work."

Thrussell seconds that sentiment. "My colleagues and I all want to have a strong deterrent to ensure nuclear weapons are never used. That's the motivation behind our work."

Smullen says the national security mission is both motivating and challenging. "In today's changing geopolitical situation, our jobs are transitioning as the Department of Defense asks for new things. We have to adapt to new technologies and develop flexibility in a world where our adversaries' capabilities are expanding. The U.S. stockpile needs to adapt to that."


Charlie Nakhleh

Baolian Cheng

This focus on the Lab's national security mission always takes center stage when Smullen talks to graduate students and prospective employees. "We need people who are dedicated to the mission; we need global security; we need smart, ethical people working on these problems."

Nakhleh says prospective Lab employees need to understand the significance and stakes of their work. "Nuclear deterrence is a cornerstone of global stability," says Nakhleh. "Today's and tomorrow's nuclear deterrence is an integral part of the mission, employing advanced science and technology to safeguard the future of the country and the world."

A struggle with stereotypes

Despite the significance of these Los Alamos physicists' work, there are some things many of them struggle with—explaining what they do to casual acquaintances and combating unflattering stereotypes.

"We can't really describe our work for security reasons," Joggerst says. "When someone on an airplane asks me what I do, I say 'I'm technically a designer, but most of what I do is modeling.' I don't explain what I design or that I mean computer modeling, not fashion," she adds with a laugh.

Jessica Thrussell

Candace Joggerst

> "In the weapons physics community by its very nature, we are doing cutting-edge work that very few places in the world are able and allowed to do."
>
> —Beth Lindquist

Smullen notes, "When I say I'm a physicist, some people's eyes glaze over. My mother said she never expected me to pursue a career related to national security. She once asked me what I do in my free time to be creative. I explained that my work is extremely creative."

Then there are the stereotypes. Long ago, many movies and television shows depicted physicists as nerdy men wearing pocket protectors and carrying slide rules. Today, that stereotype is a bit more modern, but it persists.

Thrussell says people often ask her if she has seen *The Big Bang Theory*, a television comedy about a group of geeky physicists with a socially awkward main character named Sheldon. "I'm often asked if I work with a bunch of Sheldons or if I am a Sheldon. I reply, 'What do you think? You're talking to me,'" she says. "While that physicist stereotype exists for a reason, and there are some people at Los Alamos who fit the stereotype, I think the public would be surprised by the diversity of the personalities of the people who work here."

Lindquist says the diversity of the staff plays an important role in achieving the Lab's national security mission. "In terms of the work we do and the mission, it's really great to have a bunch of people from different backgrounds because people bring different perspectives." She also debunks any resemblance to *The Big Bang Theory* stereotypes. "I don't find myself or my colleagues to be anything like the physicists portrayed in the show."

Feinberg, on the other hand, says he doesn't mind public perceptions of physicists as geeky. "I try to be my own person and do what's important and interesting to me. You'll always find people who connect with that. At Los Alamos, it's easy to find a core of people who are interested in science and accept you for the nerd that you might be." ★

LEARNING THE BUSINESS

The TITANS course prepares Los Alamos scientists for careers at a nuclear weapons laboratory.

BY IAN LAIRD

No one goes to school to learn how to make a nuclear weapon. That's largely because nuclear weapons science is incredibly complex and highly classified.

But at an institution like Los Alamos National Laboratory—one of three national laboratories responsible for designing and maintaining the nation's nuclear weapons—a subset of employees must have the knowledge to execute the Lab's national security mission.

That's why, in 1996, Los Alamos established the Theoretical Institute for Thermonuclear and Nuclear Studies (TITANS). Often referred to as a graduate program in nuclear weapons, TITANS is a three-year course in which 10 to 15 students from the Lab's Theoretical Design and Computational Physics divisions spend up to 20 hours a week advancing their knowledge and familiarity with the science and tools necessary for maintaining the nation's nuclear weapons.

Physicists Joyce Guzik, Roy Baty, and Eric Nelson preside over TITANS as deans and explain that the first part of the program involves helping students assess what they know and don't know.

"A goal of TITANS is to get people on a more level footing," Guzik says. "We have people who come in as engineers, materials scientists, chemists, and many kinds of physicists. Some are very specialized with a narrow focus, and others have broad educations."

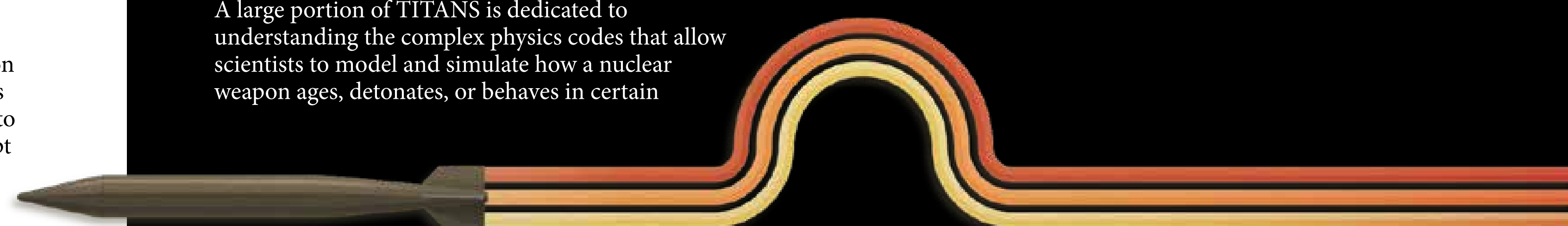
Baty agrees. "Nobody comes in with a background that crosses all the disciplines of weapons physics," he says. But at Los Alamos, TITANS students have access to information, tools, and senior employees, all of which help complete the big picture.

A large portion of TITANS is dedicated to understanding the complex physics codes that allow scientists to model and simulate how a nuclear weapon ages, detonates, or behaves in certain conditions. Guzik explains that students should understand how changing input variables can change the resulting simulations. "We want them to realize that just from thinking, you can almost figure out the answer before starting the simulation," she says. "Once you get an answer, how do you know it is right? How do you analyze it? How do you compare it with a back of the envelope calculation? So often, we run the simulation and assume it is right, but it may not be."

In the final year of TITANS, students focus on applying what they've learned. Students select a current or potential future problem facing a weapons system, and they then have a year to write a thesis paper on the topic. At the end of the year, the students defend their ideas in front of a panel that passes or fails them.

Baty stresses the importance of graduates believing in the value of their work. "It is about confidence," he says. "The whole point is we're trying *not* to ever use nuclear weapons—but they have to work. And in order to know they work, you have to trust the people. The people are the ultimate thing that has to be credible." ★

Clockwise from top left, Guzik, Baty, and Nelson are the TITANS deans. They note the importance of TITANS in educating and fostering the next generation of Los Alamos weapons experts.



ONE BYTE AT A TIME

Codes, models, and simulations inform computational physicists' work.

By Jill Gibson

■ A simulation of a fusion ignition experiment fills the movie-theater-sized screen of Los Alamos National Laboratory's Powerwall Theater.

Jimmy Fung, the Integrated Physics Codes director at Los Alamos National Laboratory, explains computational physics over a cup of coffee. "Consider everything that is happening to a physical system," he says. "In fact, consider this physical system." He gestures to the mug of steaming dark roast in his left hand. "Right now, acting on this cup, there are forces, effects and interactions, and the responses of materials. I can use computational physics to predict what will happen when certain variables change, such as the heat, the type of material the cup is made up of, the different chemical compounds within the coffee in the cup."

Computational physics is a branch of physics that uses computation (calculation of mathematical formulas) to solve complex mathematical equations that describe the fundamental physical principles, laws, and equations that govern the behavior of systems or phenomena.

"All we're doing is using math to solve science problems," says Computational Physics division leader Scott Doebling, who also leads the Laboratory's Advanced Simulation and Computing (ASC) program.

Much of the computational physics work at Los Alamos focuses on the performance and aging of nuclear weapons. Los Alamos is responsible for the design and maintenance of four of the seven types of nuclear weapons in the current stockpile, all of which are decades old. Computational physics allows scientists to predict or analyze how weapons components age and how a weapon could perform if ever detonated—without actually detonating a weapon.

"Los Alamos National Laboratory depends on computational physics to ensure that America's nuclear deterrent is safe, secure, and effective," Doebling says. "In many ways, computational physics is the heartbeat of the Lab."

MODELS AND CODES

A computational physicist studying Fung's coffee would develop relevant physics theories about the coffee and the cup and then build a model to forecast the outcome of certain changes to the cup of coffee. A model is a mathematical representation of a physical system or phenomenon, often described by equations or rules derived from the underlying physics. A model provides the framework or theoretical foundation for understanding a system's behavior.

Next, the physicist would create computer codes—scripts written in programming languages (such as C++ and Fortran) that implement the model. A computer code is a set of directions that a computer can follow to perform specific computational tasks. Fung says to develop codes, computational physicists need expertise in mathematics, physics, computer science, and software engineering. Scientists create codes and adapt existing codes to solve problems, make predictions, or simulate physical phenomena. Codes convert the theoretical framework of the model into numerical steps.

"The code itself is the set of instructions that you give to the computing hardware in order to generate that representation of reality," Charlie Nakhleh, associate Lab director for Weapons Physics, says. "Our codes are remarkably complicated things that encapsulate, depend upon, and tie together multiple different models."

Codes allow scientists to automate and scale up complex calculations that involve multiple variables. They interact with hardware and software to perform computations—making calculations, solving equations, or processing data.

"Codes are built by taking mathematical equations and discretizing them—transforming continuous equations into discrete forms—separate parts where variables have set values at specific points or intervals," Fung says. This key technique makes it possible for computers to solve equations.

Nakhleh says what goes on inside a human brain is not so different from what happens inside a computer. "The only way the human brain has ever been able to understand the world in which it lives and operates is to break it down into pieces, right? Complex reality is too much for anybody. So, what you do is you break it down into pieces, you understand the pieces, you analyze the problem, and then you tie it back together. And that's what a computer code does in terms of its simulation. It breaks this representation of reality down into a bunch of pieces, factors out these pieces into different parts of the computer code, and then ties them all back together to generate a simulation of what its view of reality is."

Codes change as they are adapted and rewritten, and some are discarded in favor of newer codes. Fung estimates that over the years the Lab has created more than 100 codes. "New software practices and new computer languages emerge that lead scientists to write new codes or rewrite old ones to take advantage of those new practices," Fung says. "Codes merge or split off, sometimes due to technological and scientific advances, and sometimes due to mission, organizational, or cultural changes."

Some of the most-used codes can be grouped by the method or approach they use. For example, Eulerian codes are based on observing a system at fixed points; Lagrangian codes track individual particles or elements as they move; Arbitrary Lagrangian-Eulerian (ALE) codes combine aspects of both Eulerian and Lagrangian methods; and Monte Carlo codes use random sampling to solve problems. The first Monte Carlo code was developed at Los Alamos in the 1940s to predict how radiation particles move through and interact with other materials. A variation of that code remains in use today.

SIMULATIONS

Nuclear weapons are more complicated (and much more energetic) than Fung's cup of coffee, but both can be studied using simulations. Simulations are the results of applying a model to generate digital representations that replicate, analyze, or predict the behavior of systems where multiple physical phenomena interact simultaneously. Simulations can be any type of visualization, animation, graph, dataset, or other representation that offers insights into a system. Although these results are often expressed strictly numerically, many can be translated into graphics and shared using large 2D and 3D displays. Simulations can take days, weeks, or even months to run.

■ The CAVE's walls, floors, and ceilings are projection screens. Inside this virtual reality environment, viewers can study a simulation from all angles.

> "ALL WE'RE DOING IS USING MATH TO SOLVE SCIENCE PROBLEMS."
> —SCOTT DOEBLING

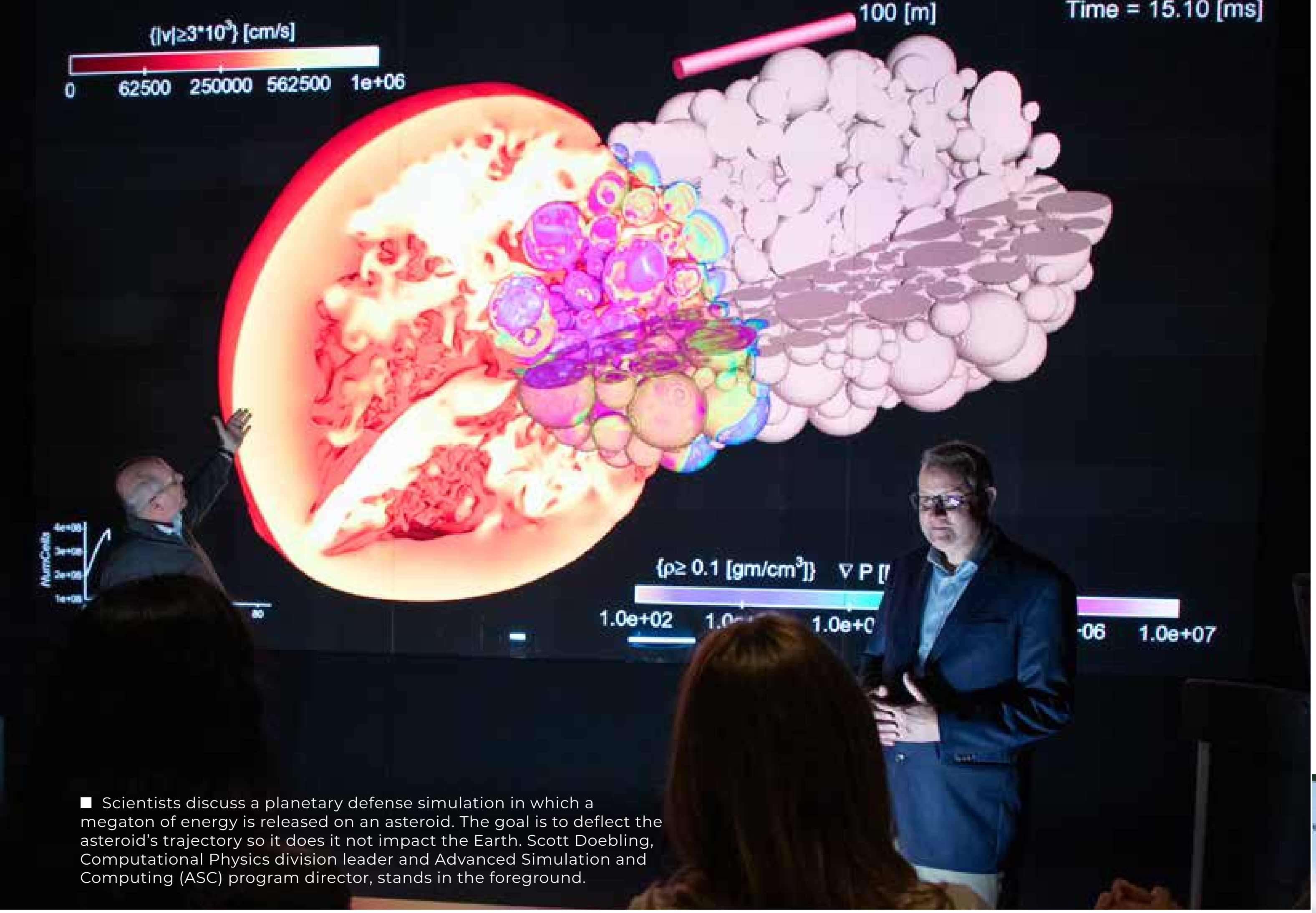
Running a simulation requires a supercomputer, a computer designed to handle large datasets at extreme speeds. At Los Alamos, teams of humans and teams of computers work together to solve problems. "It's the computational physicist's job to understand how physics and computation come together and then deliver these simulation capabilities," Fung says.

Los Alamos scientists can explore 3D visualizations of simulations using the Powerwall Theater and the La Cueva Grande SuperCAVE (Cave Automatic Virtual Environment). The Powerwall is a movie-theater-size screen connected to the Lab's high-performance computers. In a movie-theater-size room, it displays stereo 3D images of color-coded simulations. Using the Powerwall, scientists can view animated processes, zoom in and out, and rotate graphics.

"People want to get together and discuss what they are working on," says Dave Modl, a visualization engineer who supports the facility. He notes that training, meetings, and VIP visits often make use of the Powerwall.

Bob Greene, a computational physicist, works with his colleagues to prepare the visualizations. "The Powerwall brings scientists together in one room and literally allows them to get the big picture using complex 3D visualizations that illustrate the phenomena they are studying," he says.

While the Powerwall is designed to serve large groups of people, the CAVE was created for only a few users at a time. Scientists can step into this 3D display and stand inside their simulations. "One at a time, they can interact with the display wearing tracking glasses and see the perspective as they move in space," Modl says.



■ Scientists discuss a planetary defense simulation in which a megaton of energy is released on an asteroid. The goal is to deflect the asteroid's trajectory so it does it not impact the Earth. Scott Doebling, Computational Physics division leader and Advanced Simulation and Computing (ASC) program director, stands in the foreground.

Both Modl and Greene say they stay busy providing support and expertise for these facilities. "The Powerwall and the CAVE offer computational physicists an important way to view their simulations and explore their data in high resolution," Greene notes.

THE IMPORTANCE OF DATA

Data is the information that scientists feed into the computer. When it comes to nuclear weapons, data comes from two sources: the more than 1,000 full-scale nuclear tests America conducted before the 1992 testing moratorium and the experiments scientists now conduct across the nuclear security enterprise (many of them at Los Alamos). Data allows scientists to validate models and codes to ensure the resulting simulations are correct.

"If you can generate a simulation that matches the historical test database, then you're going to have a very high degree of confidence that you've got an adequate representation of reality," Nakhleh says.

Validation also comes from current experiments, conducted at facilities including Los Alamos' Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, Lawrence Livermore National Laboratory's National Ignition Facility (NIF), and Sandia National Laboratories' Z Pulsed Power Facility.

Bob Webster, Los Alamos deputy director for Weapons, says such data is essential for validating the Lab's computer models and codes. "We use experiments at NIF or Z or DARHT to continue to validate the models and codes that we have," he says. "We can take those models and codes that we validated and put them together in a deductive sense in these giant high-performance computing environments and evaluate the logical consequence of the theories that we've proved out in these other regimes."

Doebling says the ongoing experiments give researchers more confidence in their ability to create computer simulations that predict weapons behavior in many areas and study everything, including thermodynamics, fluid dynamics, mechanical properties, and the way materials age. Those simulations feed back into experiments. "We use simulation to design experiments. We use those experiments to give us data to determine whether we are getting the right answers," Doebling says. "We have lots of experiments to help tell us where our models and codes are right and where they are not."

Verifying and validating is essential, according to Doebling. "You have to ask yourself, 'Is my answer right?' That's always been a challenge when doing math, but doing large-scale computing just kicks that up because there are so many ways you can get things wrong. We are looking at things like aging of materials where the phenomena are complicated. We need more data from more experiments to ensure we are getting things right."

THE EVOLUTION OF COMPUTATIONAL PHYSICS

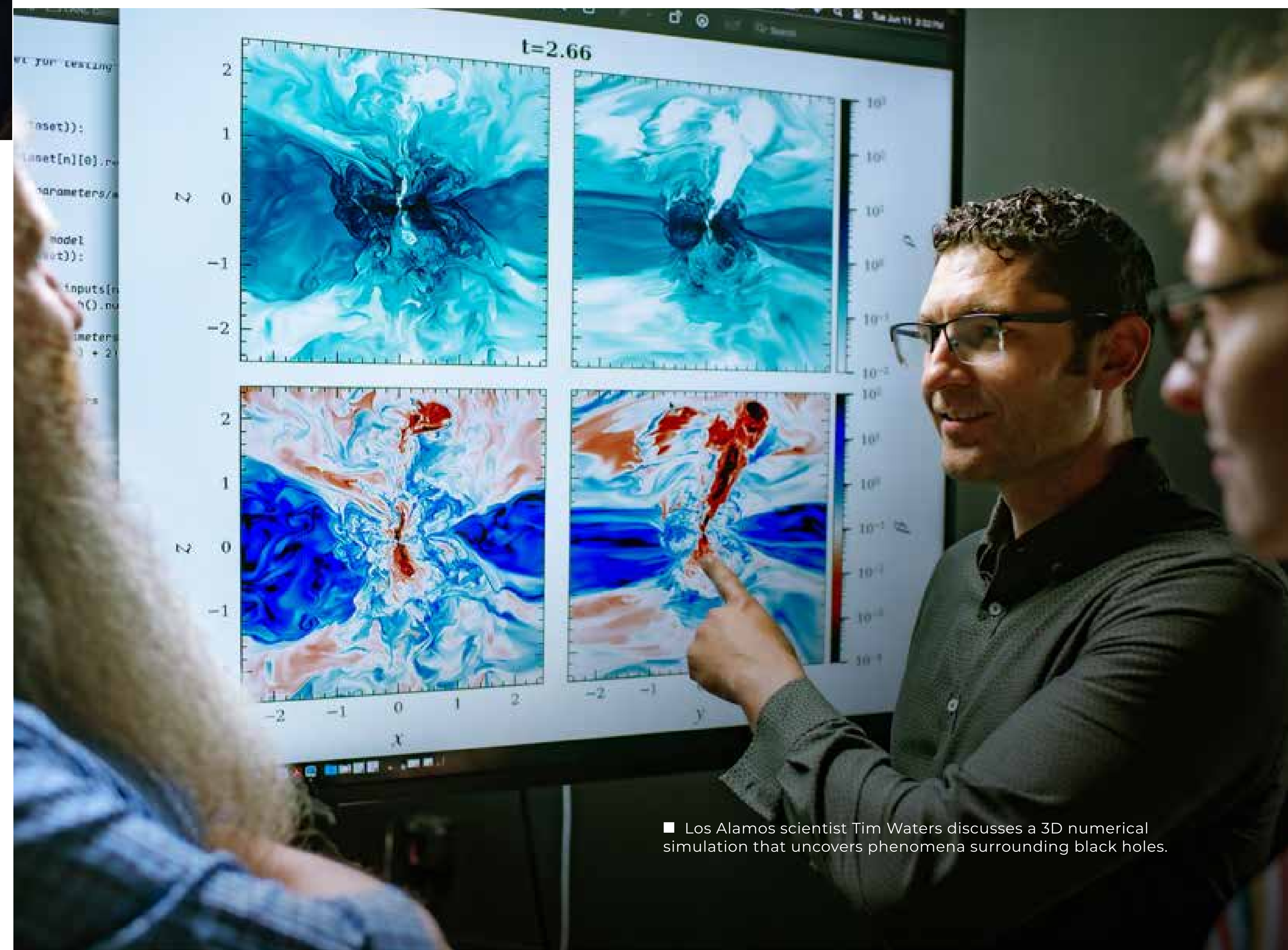
Computational physics was born at Los Alamos during the Manhattan Project. "In 1943, physicists needed to do a job," Doebling says. "They needed to invent the technology to win the war." That meant developing new ways to perform calculations used to understand and predict the complex physics of nuclear reactions.

During World War II, these calculations were initially performed by people, often the wives of male physicists and members of the Women's Army Corps, who were called computers. Scientists then augmented the abilities of human computers with IBM accounting machines. "These were some of the largest and most sophisticated simulations ever conducted at that time," explains Lab historian Nic Lewis. "Los Alamos pushed the limits of what was computationally possible in the mid-1940s."

"LOS ALAMOS PUSHED THE LIMITS OF WHAT WAS COMPUTATIONALLY POSSIBLE IN THE MID-1940S."

—NIC LEWIS

In the decades that followed, as the Cold War escalated and nuclear weapons became more complicated, more complex calculations were needed. "Lab scientists had to invent many of the technologies and methods needed," Lewis says. "As a consequence, Los Alamos became a key driver in the evolution of electronic computers and the advancement of mathematical models that would become ubiquitous over subsequent decades."



■ Los Alamos scientist Tim Waters discusses a 3D numerical simulation that uncovers phenomena surrounding black holes.

"IN MANY WAYS, COMPUTATIONAL PHYSICS IS THE HEARTBEAT OF THE LAB."

—SCOTT DOEBLING

In 1992, the United States declared a moratorium on full-scale nuclear testing. Because researchers were no longer detonating nuclear weapons to see if they worked, scientists developed computational methods to predict weapons behavior using data from previous full-scale tests. Over the years, researchers added nonnuclear and subcritical experiments that did not generate self-sustaining nuclear reactions.

"To guarantee the reliability of the U.S. nuclear deterrent, vastly improved computational capabilities were clearly needed," Lewis says. "Much as it did during World War II, Los Alamos spearheaded rapid advancements in computer hardware and simulation software to meet the needs of its national security mission."

■ Laboratory scientists and staff go behind the scenes to view the massive pipes that make up the cooling system of the Lab's Strategic Computing Center. Efficient cooling is crucial for supercomputers' performance.

■ Complex 3D visualizations allow computational physicists to study and discuss their work.

These advances provided (and continue to provide) scientists with the ability to modify weapons to meet military requirements, explore possible new designs, and assess the nuclear stockpile. "Taking care of the weapons—the deterrent of the present and the future—drives us," Doebling says.

THE FUTURE OF COMPUTATIONAL PHYSICS

The floor of the Strategic Computing Complex at Los Alamos (where the supercomputers sit) is 43,500 square feet, about the size of a football field. Lab leaders say they anticipate that a larger facility will be needed someday. "We will always need newer, better computers to run bigger problems faster," says High Performance Computing Director Jim Lujan.

Doebling notes that each new supercomputer requires more power and cooling than the last. "As we look toward the future, we have to have the power and the facilities to handle the computers," Doebling says. "We have to plan 10 to 15 years in the future for the next computing systems."

That planning requires responding to ongoing changes in the computing industry. "Computers are changing, and Los Alamos is having to adapt to industry changes in computing," says Fung, noting that computer languages, algorithms, computer components, and approaches to physics are always changing, requiring continuous adaptations at the Lab.

"We are designing better algorithms, which represents the way we implement the math in the computer programs," Doebling says. "We are also tailoring software to hardware and hardware to software to make them work faster as a system." This approach, called codesign, makes the calculations faster, more reliable, and more repeatable, he says.

And then of course, there is artificial intelligence (AI)—but Doebling is optimistic about the impacts of this new technology. "AI is just another name for a set of mathematical techniques used to analyze data," he says. "That's what we do in computational physics, we use math to analyze data and to predict the way things will happen, and much of AI is just a different take on things we already know how to do. But other capabilities of AI lead us to think about things we never thought would be possible, things that could revolutionize computational physics and even our overall mission."

Doebling predicts that AI will accelerate workflows by automating processes and will lead to the development of improved models and the verification and validation of the predictions that result. "We need to harness the power of AI while maintaining our expertise on the physics," he says.

THE MISSION IS THE BOSS

"The mission is the boss," is a statement Doebling often makes. He says that means every new development in high-performance computing and computational physics at Los Alamos is driven by the Lab's national security mission. "We want to enable a future for the nuclear security mission that's not only vibrant and secure but also agile and efficient in the face of ever-evolving challenges," he says.

Fung seconds that goal. "The changing geopolitical situation may have implications for military requests, which may impact weapons design and simulation," he says. "Weapons designers and computational physicists must work together very closely, particularly as mission applications and design practices evolve."

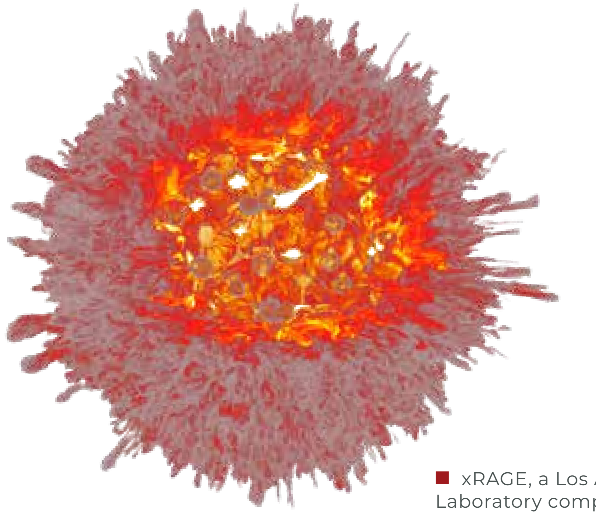
That's why both Fung and Doebling stress the importance of ensuring that the Lab maintains cutting-edge technology and hires technical experts who are willing to push the boundaries to get the answers they need.

"Computational physics plays a key role in ensuring our nuclear deterrent is safe, secure, and effective," Fung says. "That's incredible and adds to the satisfaction of working here." ★

THE POWER OF plasma

High-energy-density physics unlocks mysteries that start with the stars.

By Jill Gibson



xRAGE, a Los Alamos National Laboratory computer code, generated this simulation of an implosion during thermonuclear fusion burn.

Look up on a clear night, and you will see blazing spheres of plasma powered by the fusion of atoms in their cores. That's right, you're looking at stars—a celestial demonstration of high-energy-density (HED) physics at work.

For Los Alamos National Laboratory scientist Sasikumar Palaniyappan, sometimes a typical workday involves making a star on Earth. Well, sort of. As an HED physicist, Palaniyappan's work involves creating burning plasmas, concentrated balls of extremely hot, ionized gas generating light and heat—similar to the cores of those stars twinkling in the night sky. "It's so cool. It's an exciting physics platform," Palaniyappan says.

Inside a burning plasma, high temperatures and pressures break apart atoms, causing their electrons and ions to move around chaotically. When the free-moving electrons and ions collide in these conditions, they bind together, or fuse. If the reactions produce enough heat to trigger ongoing reactions, the burning plasma becomes self-sustaining. That means it continues burning without any additional fuel. "A self-sustaining burning plasma is our goal," Palaniyappan says. "For me, this is more than work; it's fun."

Creating burning plasmas is one of the keys to harnessing clean, affordable, and unlimited fusion energy. Researchers have been pursuing fusion energy for nearly 80 years. Recent breakthroughs suggest that commercial fusion energy is getting closer to becoming a reality, particularly due to successful experiments conducted by Lawrence Livermore and Los Alamos national laboratories.

Although Palaniyappan and his coworkers say they are ecstatic about the progress toward fusion energy, creating an alternative energy source is not the primary focus of their work. The conditions required to create fusion (and stars) also exist during the detonation of a thermonuclear weapon, in which a fission reaction triggers a fusion reaction to create kilotons or even megatons of explosive power.

"This extreme state occurs in astrophysical phenomena, such as stars, and during nuclear weapons detonations," says Los Alamos HED physicist Forrest Doss. "It doesn't exist anywhere else. Everything is hot and flowing; there are no solids; everything is glowing, and the energy balance is different than anything we experience during day-to-day life," he says.

In the past, the United States conducted nuclear weapons tests, proving that scientists can create fusion. The data from those tests helped scientists build the seven types of thermonuclear weapons in the U.S. stockpile today. But, in 1992, the nation declared a moratorium on full-scale nuclear testing. The United States now relies on nonnuclear and subcritical experiments coupled with advanced computer modeling and simulations to evaluate the health and extend the lifetimes of America's aging nuclear weapons, which are decades old. This approach is called stockpile stewardship, and HED physics is part of its success.

"There are serious questions about how nuclear weapons will perform in detonation conditions," says Los Alamos physicist Joseph Smidt, the co-director of the Los Alamos Inertial Confinement Fusion (ICF) program. "If you don't actually detonate a weapon, you have to ask yourself how you are going to obtain information on material properties, physics, and science at these extreme temperatures, densities, and pressures. That's why creating similar conditions in the laboratory is essential for national security."

Maintaining the truck

Smidt compares the weapons in the U.S. nuclear stockpile to an old truck parked in the garage—a truck that will need to run flawlessly if there is an emergency. "These weapons have not been tested in decades. It's a little bit like saying, here's this truck that you used to drive all the time, and you know it worked back then because you drove it all the time. We don't want you to drive it again, but we want you to guarantee that 20 or 30 or 40 years later, if you ever had to drive it, it would start and run smoothly, safely, and correctly."

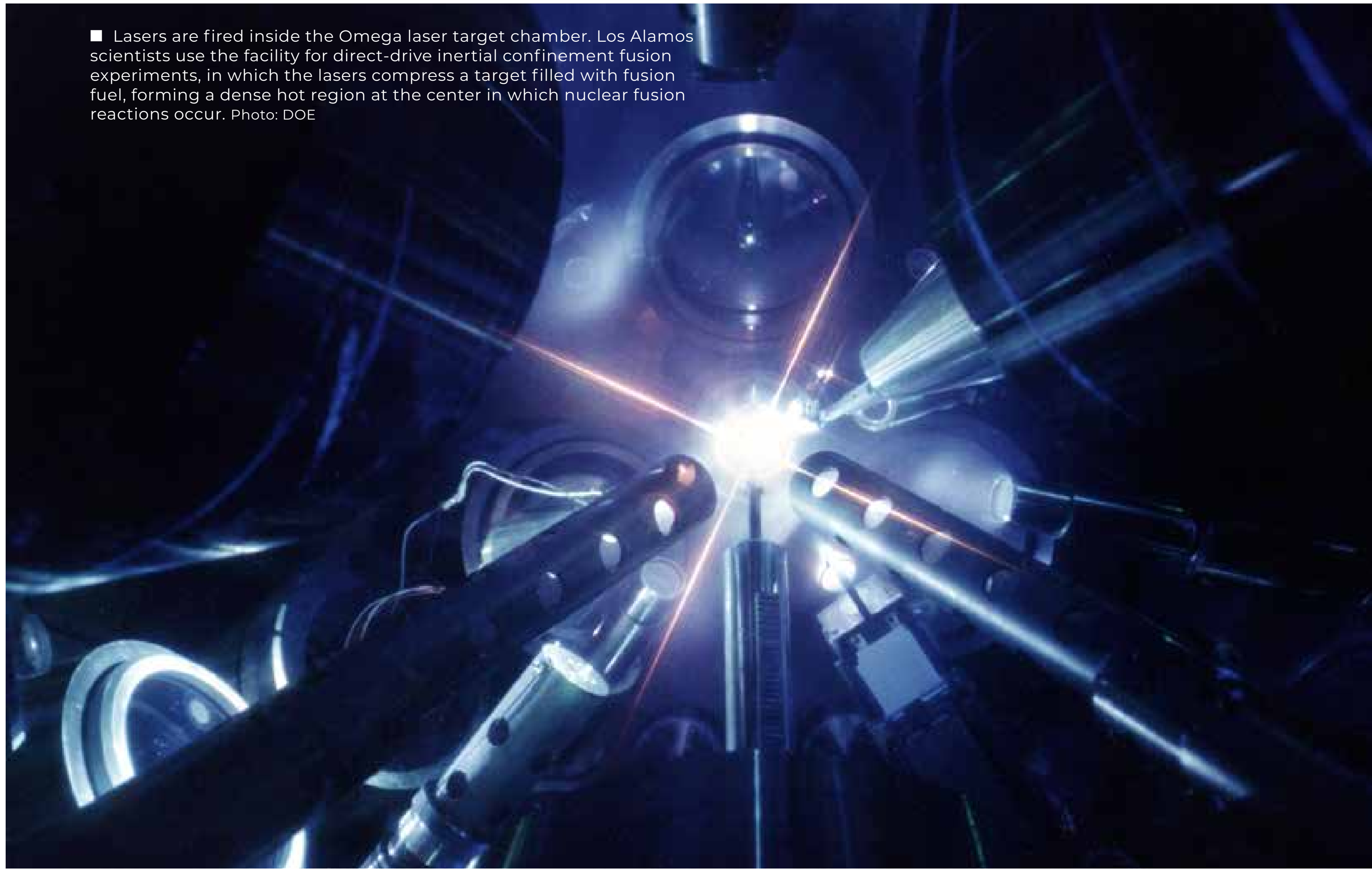
> "There are mysteries in implosions, and now we have a state-of-the-art tool to investigate those mysteries."
>
> —Brian Haines

Will the truck start? "Well, as you know, parts rust; things get old; the longer you go without driving it, the more uncertain you'll start getting about whether this truck is going to start," Smidt says. "How do you guarantee that it's going to work?"

Smidt notes that while you can't start the truck, you can conduct tests to see if individual parts are working correctly to help you understand its overall condition. HED physics experiments allow scientists to perform those sorts of tests on nuclear weapons.

In the past three years, Los Alamos scientists, working with their colleagues from throughout the nuclear enterprise, have made significant progress on HED research. These advances, combined with other recent breakthroughs, are opening windows into understanding weapons performance, aging, materials, and more.

"The research answers questions related to weapons physics and how well our computer codes and design efforts work. We can look at various material properties, processes that take place during a detonation, and energy and material



Lasers are fired inside the Omega laser target chamber. Los Alamos scientists use the facility for direct-drive inertial confinement fusion experiments, in which the lasers compress a target filled with fusion fuel, forming a dense hot region at the center in which nuclear fusion reactions occur. Photo: DOE interactions," Smidt says. "These are all things that are very important." In other words, they are things the scientists must study to ensure that if they need that truck to start up, the engine will purr, and the truck will operate safely and reliably.

Creating the conditions

Los Alamos scientists primarily create the conditions needed for this research at three facilities: Lawrence Livermore National Laboratory's National Ignition Facility (NIF) in Livermore, California; Sandia National Laboratories' Z Machine in Albuquerque, New Mexico; and the University of Rochester's Omega Laser Facility in Rochester, New York. These facilities achieve fusion conditions by rapidly compressing and heating a small quantity of fusion fuel. The process, called inertial confinement fusion, or ICF, gets its name from the word 'inertia,' because the goal is to compress fuel particles, so they are held together by their own inertia. NIF and Omega do this using lasers; Z uses pulsed power and magnetic fields.

Los Alamos physicists frequently travel to NIF, Z, and Omega to carry out experiments. Scientists also run diagnostics on other labs' experiments and collaborate with researchers from other institutions. "There's no way to study fusion and these extreme conditions outside of these HED facilities," Doss says. "Fusion only happens when things are so hot and so dense."

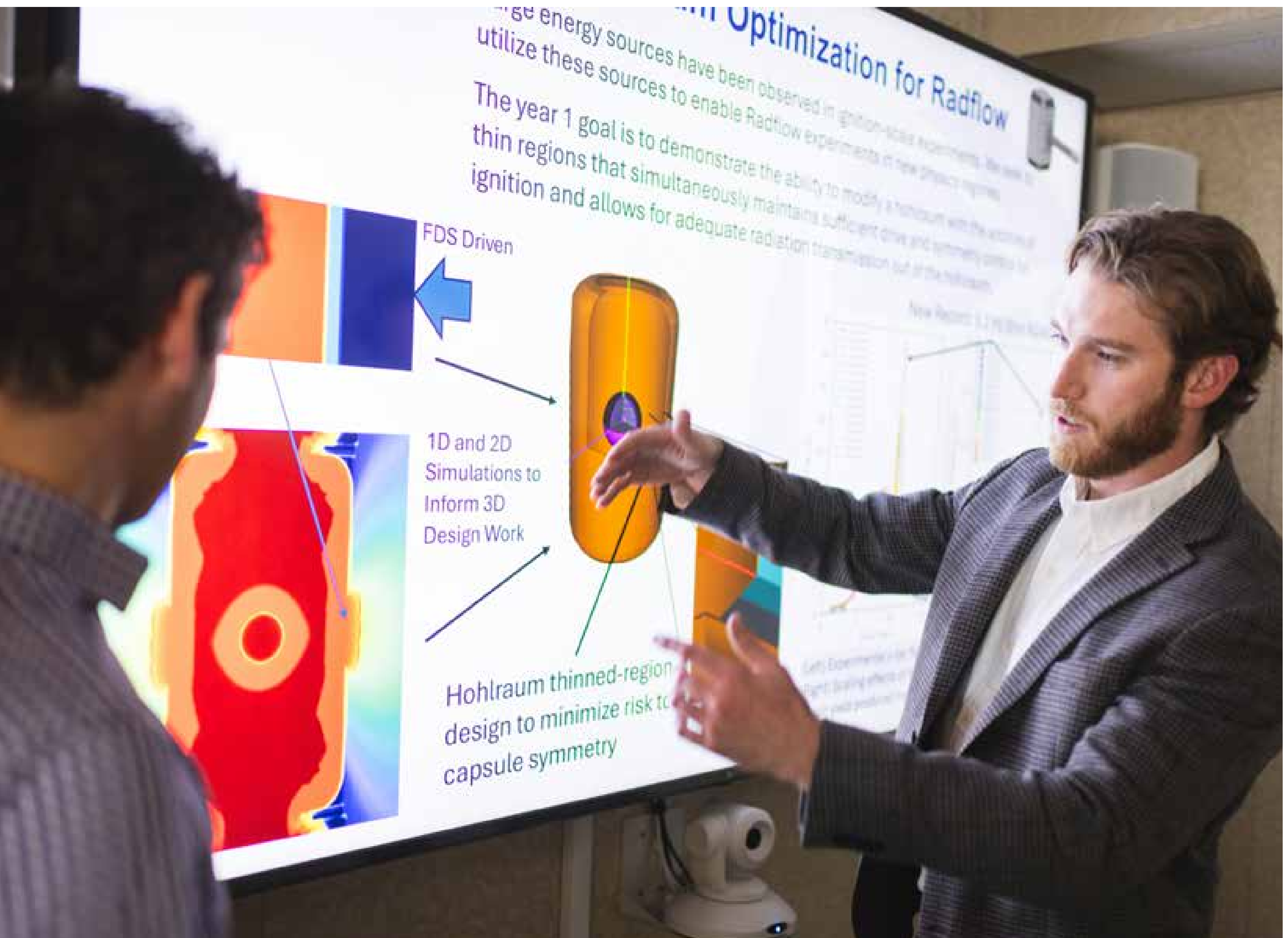
Whether he is designing an experiment to conduct at NIF, Z, or Omega, Doss says he always starts by identifying "a bit of physics we want to test, such as a term in the equations that make up the computer codes, or a particular interaction, effect, reaction, or process."

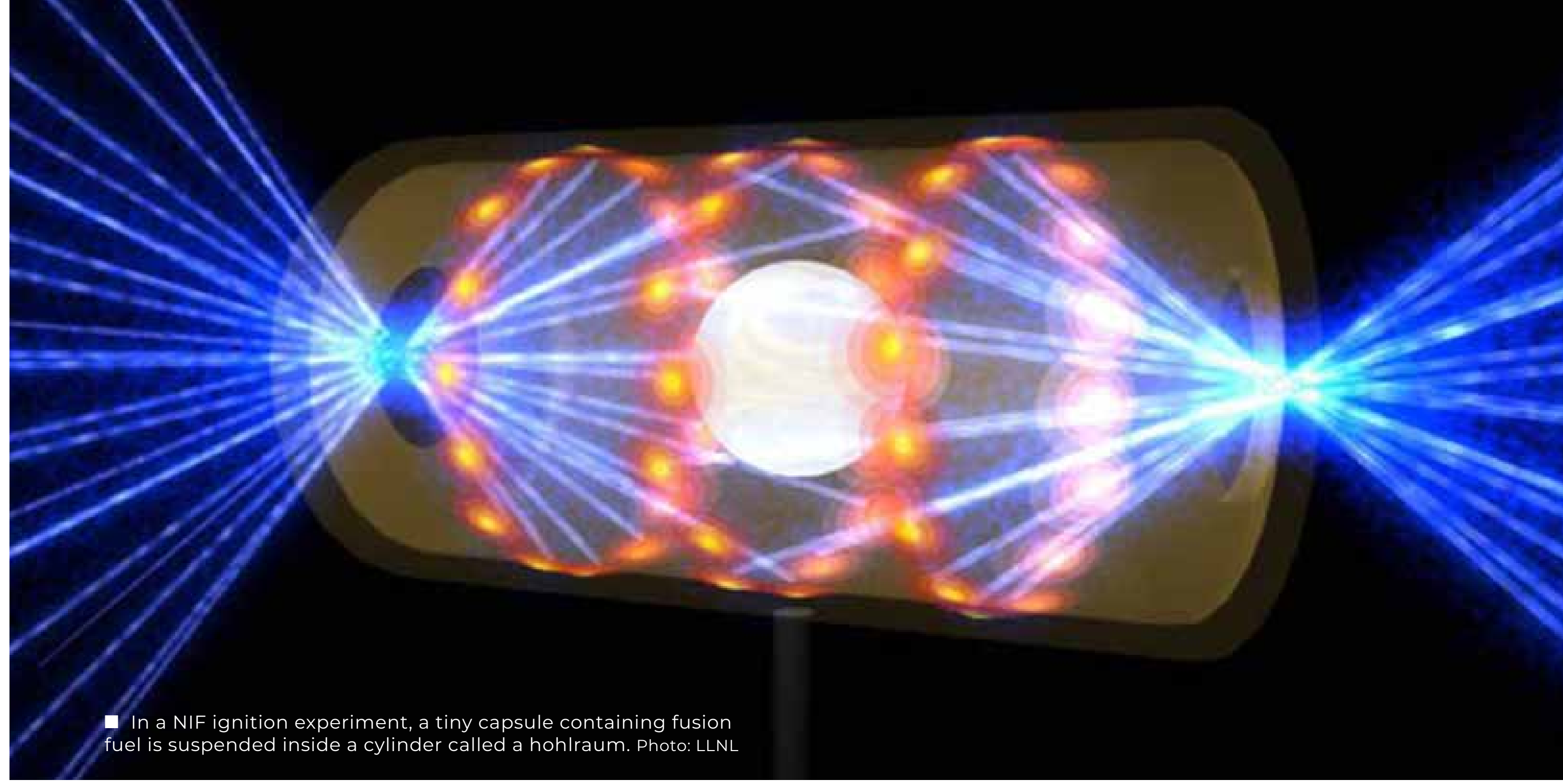
Double shells at NIF

At NIF, 192 laser beams focus their energy into a single pulse fired at a capsule of nuclear fuel the size of a peppercorn. In 2022, scientists first used NIF to achieve a condition called fusion ignition. This means they created a sustained fusion reaction that generated more energy than the lasers initially put in.

Achieving ignition represents a significant breakthrough for HED physics experiments and is crucial for studying certain aspects of weapons performance. "Ignition really opens the door to a whole new realm," says Ann Satsangi, the other co-director of the Los Alamos ICF program. "For many years we were trying to get to ignition. Finally, we are here."

Los Alamos scientist Ryan Lester explains a concept for extracting x-ray energy from an igniting capsule to drive radiation-flow experiments.





In a NIF ignition experiment, a tiny capsule containing fusion fuel is suspended inside a cylinder called a hohlraum. Photo: LLNL

In addition to collaborating with their Livermore colleagues on traditional NIF ignition experiments, Los Alamos scientists are focused on a series of experiments called the double-shell campaign. In these experiments, the NIF lasers shoot energy into a complex assembly called a double-shell target.

Double-shell targets, which are designed and made at Los Alamos, consist of two foam hemispheres and an aluminum outer shell surrounding an inner metal capsule.

> "A self-sustaining burning plasma is our goal."
> —Sasikumar Palaniyappan

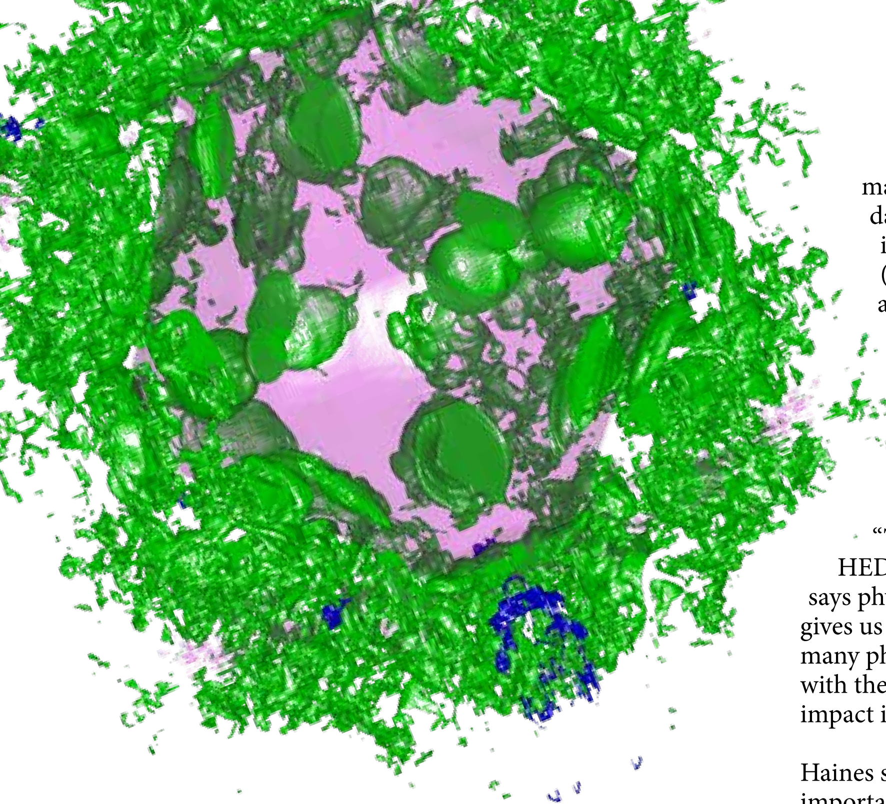
The tiny capsule, a couple hundred microns in radius, is filled with deuterium and tritium—the fusion fuel. Technicians at Livermore place the target inside what is called a hohlraum, a cylindrical container designed to capture the laser energy and convert it into x-rays that compress and heat the fuel capsule inside the double shells.

"It's an exciting physics platform because of the small scale and short time frame," Palaniyappan says. "We are dealing with a 30-micron target and process that lasts for 150 picoseconds." To put that into perspective, a human hair is typically 70–100 microns in diameter and a picosecond is to 1 second what 1 second is to 31,700 years.

Palaniyappan and physicist Eric Loomis say they are focused on changing one variable at a time, such as using new materials, like tungsten or molybdenum, for inner shells and using low-density foams made at Los Alamos to hold the inner shells in place. Unlike the single-shell targets used for ignition experiments, the double-shell targets allow scientists to study how new materials interact with burning plasmas. These experiments also reveal how incredibly small capsule-design details can impact the success of the implosion. Scientists are employing advanced diagnostics using high-speed imaging, neutron detectors, and spectroscopic techniques to analyze implosion dynamics.

"There's a variety of things we have to think about to come up with solutions for complex problems," Loomis says. "We have to find unique solutions using simulations, theory, and diagnostics. We have to develop unique ways to build a target. We have to develop novel ideas to overcome the challenges. Doing the science to see what will work, that's what inspires me every day."

Satsangi says that Los Alamos HED scientists have become more focused on the double-shell experiments in the past year.



A graphic produced using Los Alamos' xRAGE code allows scientists to study inertial confinement fusion (ICF). "Developments in xRage make it one of the world's most predictive (if not the most predictive) 3D ICF code," Doebling says.

"We had three successful tests in 2024, and we've been able to get a tenfold increase in energy and repeat our results," she says. "We are creating a solid platform where we can do repeatable, measurable science, and we are pushing forward the diagnostics we need for future stockpile work."

Smidt hopes to increase the cadence and types of experiments at NIF, which will result in more data. "We are already discussing updates to NIF that will provide higher energies and higher yields so we can explore questions about how nuclear weapons can survive hostile environments," he says.

Zipping over to Z

Unlike NIF or Omega, which use lasers, the Z Machine at Sandia National Laboratories creates HED conditions by using a strong electric current to generate intense magnetic fields. The magnetic fields "pinch" a plasma to create extremely high temperature and pressure, resulting in fusion conditions.

"The lasers at NIF and Omega are much more delicate and precise; Z works differently to achieve the same conditions, so it allows us to double-check our results in a completely complementary way," Doss explains. "Z throws out an enormous amount of energy. If you are in one of the adjacent buildings, it's like a small earthquake when it goes off. Kind of feels like the building went over a pothole."

New code capabilities

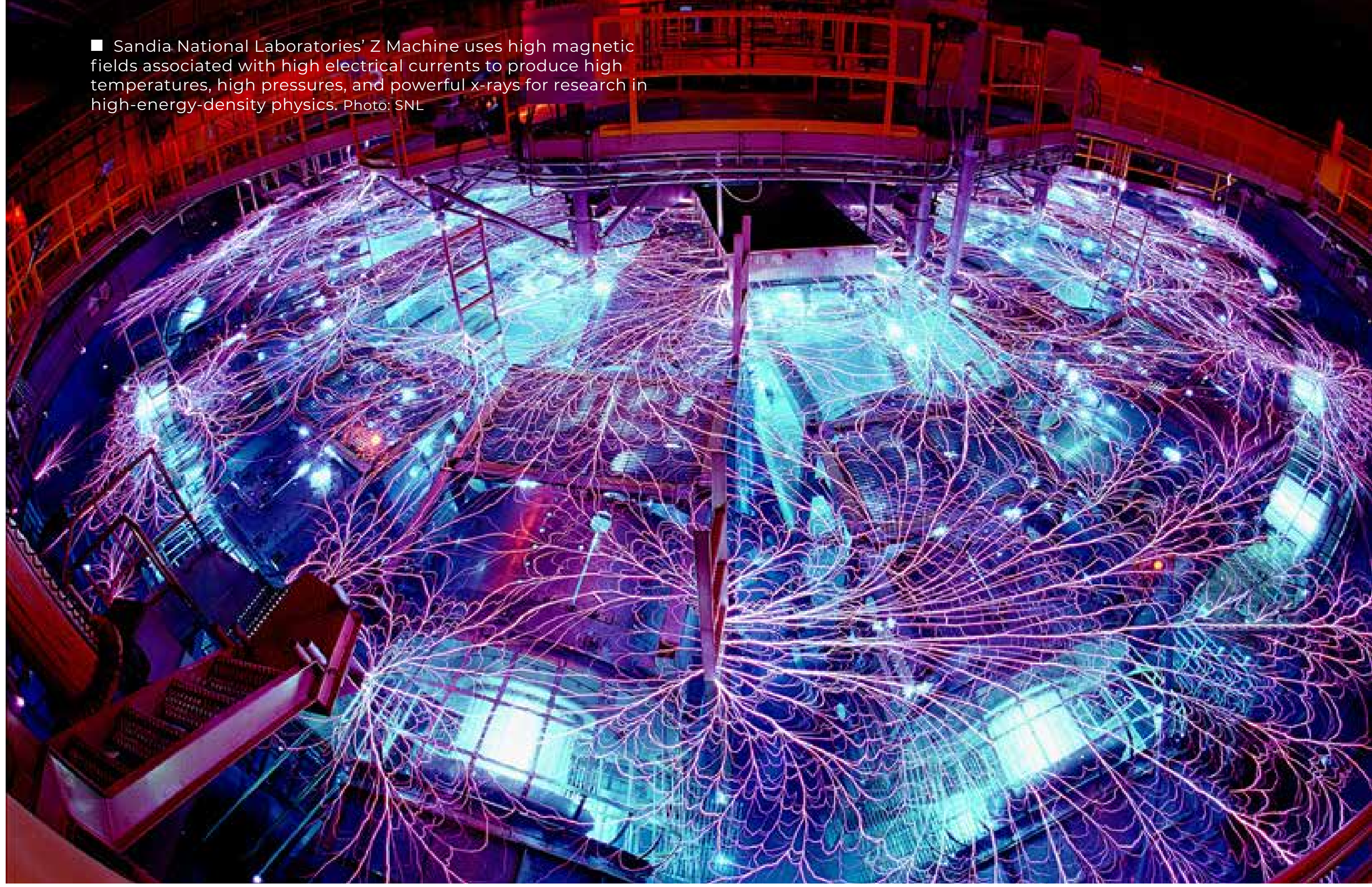
Because scientists rely heavily on computational simulations, data from HED experiments provide critical benchmarks for validating and refining simulations to make accurate predictions. To model and simulate data, HED physicists use computer codes—essentially instructions that tell a supercomputer what to do (see p. 22 for more). The Laboratory's state-of-the-art radiation hydrodynamics computer code used to simulate HED physics experiments is called xRAGE (Radiation Adaptive Grid Eulerian), and in 2023, xRAGE was enhanced to allow scientists to make more accurate 3D predictions of what happens when intense x-rays cause a fusion fuel capsule to compress and implode.

"This gives us a unique tool that can be used to study HED physics broadly and can push the ICF capabilities," says physicist Brian Haines, the team leader for the effort. "It gives us the ability to study multiphysics problems (meaning many physical processes can be modeled simultaneously with the code) and see how tiny features and perturbations impact implosions."

Haines says these new code capabilities have revealed the importance of capsule quality in obtaining a symmetrical (and therefore effective) implosion for creating a burning plasma. Los Alamos scientists are applying the code to both traditional NIF ignition experiments and double-shell tests.

"There are mysteries in implosions, and now we have a state-of-the-art tool to investigate those mysteries," Haines says. "What really makes xRAGE unique is that we can directly model tiny details in the capsules that are prohibitively difficult to model in other codes. This is due to how we generate and adapt the mesh, which is the computational representation of the experiment. The new xRAGE capabilities are allowing us to answer questions we couldn't answer before."

"Doing the science to see what will work, that's what inspires me every day."
—Eric Loomis



Sandia National Laboratories' Z Machine uses high magnetic fields associated with high electrical currents to produce high temperatures, high pressures, and powerful x-rays for research in high-energy-density physics. Photo: SNL

Smidt says that because the ICF experiments involve numerous 3D features, the 3D code capabilities are invaluable. "We put a lot of effort into getting the 3D features right," Smidt says. "Many of the recent advances in capsule design involved using 3D visualizations to figure out where the major perturbations on the capsules were and eliminating them," Smidt says. "These advances led to ignition."

Adding in AI

Like many scientists around the world, Los Alamos physicists are leveraging artificial intelligence (AI) to increase efficiency and decrease computational costs.

"We're scoping out some new and exciting ideas to give physicists the ability to use AI tools to search for new HED experiment designs," says physicist Michael Grosskopf. "By running lots of AI simulations, we can find optimal performance and robustness in an ICF target design." Grosskopf adds that AI can help physicists automate tasks and use resources more efficiently while still maintaining confidence in their results.

Physicist Marc Klasky notes that AI allows scientists to generate accurate 3D simulations much faster than they could previously. "We have come up with a way to piece together 1D and 2D simulations to get a 3D result," he says. "Before we developed this method, the computational demands and data sets were prohibitively time-consuming and expensive to generate."

Klasky and Grosskopf say AI represents a significant tool for physicists. "AI can allow HED physicists to use their knowledge more effectively," Grosskopf says. "It gives them a way to cast a wider net and scan possibilities in a way we have not been able to in the past."

Reaching for the stars

HED experiments provide data for understanding how materials behave under conditions of extreme pressure and temperature, which is crucial for understanding how material aging could impact performance over time.

"From conception to realization, these experiments are valuable for studying weapons science," Palaniyappan says. "These are not miniature weapons, but in many ways, they behave similarly to a detonating weapon on a significantly different scale."

Satsangi agrees. "This work is impacting stockpile science by answering key questions that allow us to avoid conducting full-scale nuclear testing," she says. "As we advance, we develop new diagnostic and assessment methods."

Smidt says the Los Alamos scientists' success in these areas is a testament to their scientific and technological capabilities. "It shows that the people who are sustaining the stockpile have a level of competency in this science that no other nation has achieved." ★

Advancing accelerators

Major upgrades and a new, state-of-the-art facility will support the nuclear weapons stockpile for decades to come.

By Jake Bartman

■ To evaluate the condition of LANSCE's components, technician Manuel Soliz inserts a fiber-optic bore scope into one of the accelerator's tanks.

ADVANCES AT LANSCE

During the last week of December, Los Alamos National Laboratory ceases all non-essential work for its annual winter closure. Among other things, the closure marks the end of a five-month "run cycle" at Los Alamos Neutron Science Center (LANSCE)—a kilometer-long particle accelerator that Los Alamos has operated for more than half a century. When the Laboratory reopens after the New Year, workers spend months completing extensive maintenance at LANSCE, readying the facility for its next run cycle when the accelerator will once again generate high-energy protons that are used for everything from creating cancer-treating medical isotopes to imaging small-scale explosions.

> "Los Alamos is NNSA's **accelerator laboratory.**"
>
> —John Tapia

In late 2023, however, LANSCE—which has suffered increasing downtime as it has aged—faced a backlog of critical experimental work. This backlog meant that LANSCE would need to run until February 2024, including during the winter closure. On Christmas Day, Eric Brown, who directs LANSCE's user facility, made a trip to LANSCE with food and cookies for staff who were there to keep the accelerator running. "I was expecting that they'd be frustrated to be at work during the holidays," Brown says. "But they were having a great time, working together and enjoying the collegial atmosphere."

That dedication is characteristic of those who work with the Laboratory's accelerators, Brown says, and arises out of the collaboration that working with such complex machines necessitates. And yet, the need to alter LANSCE's run-cycle schedule—which was caused in part by the failure of crucial accelerator components—reflects problems related to the facility's age (the accelerator celebrated its 50th birthday in 2022).

LANSCE isn't Los Alamos' only major accelerator facility. The Laboratory is also home to the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, which is used to conduct crucial experiments related to nuclear weapon components. Like LANSCE, DARHT is aging: The accelerator has been in use for around 25 years—long enough that many of its parts are, or will soon be, in need of replacement.

In addition to the challenges that go along with age, LANSCE and DARHT are being called upon to support more experiments than ever. Shea Mosby, of the Laboratory's Accelerator Strategy Office (ASO), says that each of LANSCE's five experimental areas—which use LANSCE's accelerator beam to conduct different kinds of research—are overburdened.

"Right now, LANSCE's user program is oversubscribed by a factor of between two and three," Mosby says. "And, at the same time, our reliability has been decreasing."

The ages of LANSCE and DARHT and the need for increased experimental throughput to support national security objectives are driving major initiatives to modernize the Laboratory's two flagship accelerators. In the next decade, the LANSCE modernization project will completely replace the front end of the accelerator, ensuring that LANSCE can carry out crucial national security research until 2050 or beyond. Meanwhile, the DARHT Capability Expansion project is refurbishing DARHT and preparing the accelerator for new types of experiments.

Los Alamos' accelerator expertise is why the Laboratory is also leading the development of a third major accelerator, the Advanced Sources and Detectors/Scorpius project, at the Nevada National Security Sites in southern Nevada.

"Los Alamos is NNSA's accelerator laboratory," says program director and ASO leader John Tapia, referring to the National Nuclear Security Administration, which oversees the laboratories, production plants, and national security sites that collectively support the nation's nuclear stockpile. "The Laboratory operates LANSCE and DARHT, and we're leading the efforts to construct Scorpius. These three accelerators, plus Lawrence Livermore National Laboratory's Flash X Ray induction linear accelerator, are the large-scale accelerators that make up the heart of NNSA's accelerator complex."

In 2023, the Laboratory's deputy director for Weapons and deputy director for Science, Technology, and Engineering jointly created the ASO to steward the Laboratory's accelerators and help ensure that new initiatives and technologies are brought to bear on facilities like LANSCE and DARHT. Tasked with developing an integrated accelerator strategy (which will be published this year) to ensure that these and other tools meet critical mission needs into the future, the ASO is helping unify Los Alamos' accelerator capabilities.

The ASO also indirectly supports the Scorpius project, which has recently met important milestones on its way to completion. Scorpius will build on the Laboratory's decades of accelerator experience, allowing researchers to carry out important experiments with plutonium. In the 2030s, when Scorpius comes online and the upgrades to LANSCE and DARHT are completed, the Laboratory—and the nuclear security enterprise—will have a comprehensive, complementary suite of tools to support the nation's stockpile for decades to come.

"As we get further and further away from historical underground nuclear testing, we're going to need the ability to do experiments that will help us answer important questions about our weapons," Tapia says. "We're working to understand what's necessary to sustain or modernize these accelerators so that we can future-proof them."

■ Jordon Marquis completes a practice replacement of the target at LANSCE's Target 4 flight path in 2019. By directing protons into a target made of tungsten, researchers can produce neutrons that are used in experiments at the Weapons Neutron Research Center.

In 2018, LANSCE's operators discovered a problem: a 12-inch crack in one of the facility's four accelerating tanks.

The accelerating tanks are part of LANSCE's "front end"—the first part of the accelerator, where protons are generated and accelerated up to 100 megaelectron volts (MeV). As the protons travel along the accelerator, they are subjected to electric fields that accelerate them up to 800 MeV. By that point, the protons are moving at 84 percent of the speed of light—fast enough to travel around the Earth almost 20 times per second (or to reach the Sun in a little less than 10 minutes).

Until the crack in the accelerating tank was repaired, high currents wouldn't flow through the tank, and LANSCE couldn't operate at full power. Fortunately, the crack was discovered during one of LANSCE's annual scheduled maintenance periods, and a welder was able to enter the tank and repair the crack. If the crack had been elsewhere—say, in the fourth accelerating tank, which is too radioactive for workers to enter—the damage would have been irreparable, and LANSCE could have gone offline indefinitely.

Although a worst-case outcome was averted, the incident underscored how LANSCE's aging components can fail in ways that put the whole facility at risk. LANSCE comprises thousands of parts whose failure could take the accelerator offline, and such failures are why LANSCE's beam only operates between 60 and 85 percent of the time that it is expected to.

"There are a few accelerators in the nation that are slightly older than LANSCE, but they have all had one, two, or more major modernization programs. We're still waiting on our first," Brown says. "We have to turn away key mission deliverables with some regularity because we just don't have the ability to deliver on them."

LANSCE is a linear accelerator, meaning that it accelerates particles—in this case, protons—in a straight line (rather than in a circle, as other kinds of accelerators do). Originally named the Los Alamos Meson Physics Facility, LANSCE was commissioned in 1972 to support research into some of the universe's most basic particles. Over the decades, LANSCE has proven a versatile tool, and new experimental areas installed along the "beam line"—the path that protons travel along the accelerator—have enabled LANSCE to support a broad range of fundamental and applied research endeavors. By accelerating protons into different kinds of targets, it is possible to produce everything from medical isotopes that are key to cancer treatments (at the Isotope Production Facility) to neutrons traveling at incredibly slow speeds that elucidate the properties of fundamental particles (at the Ultracold Neutron Source).

From the beginning, LANSCE has been an "open" facility that can be used by researchers from universities

■ LANSCE's Proton Radiography facility (pRad) is used to image key nuclear weapon components.

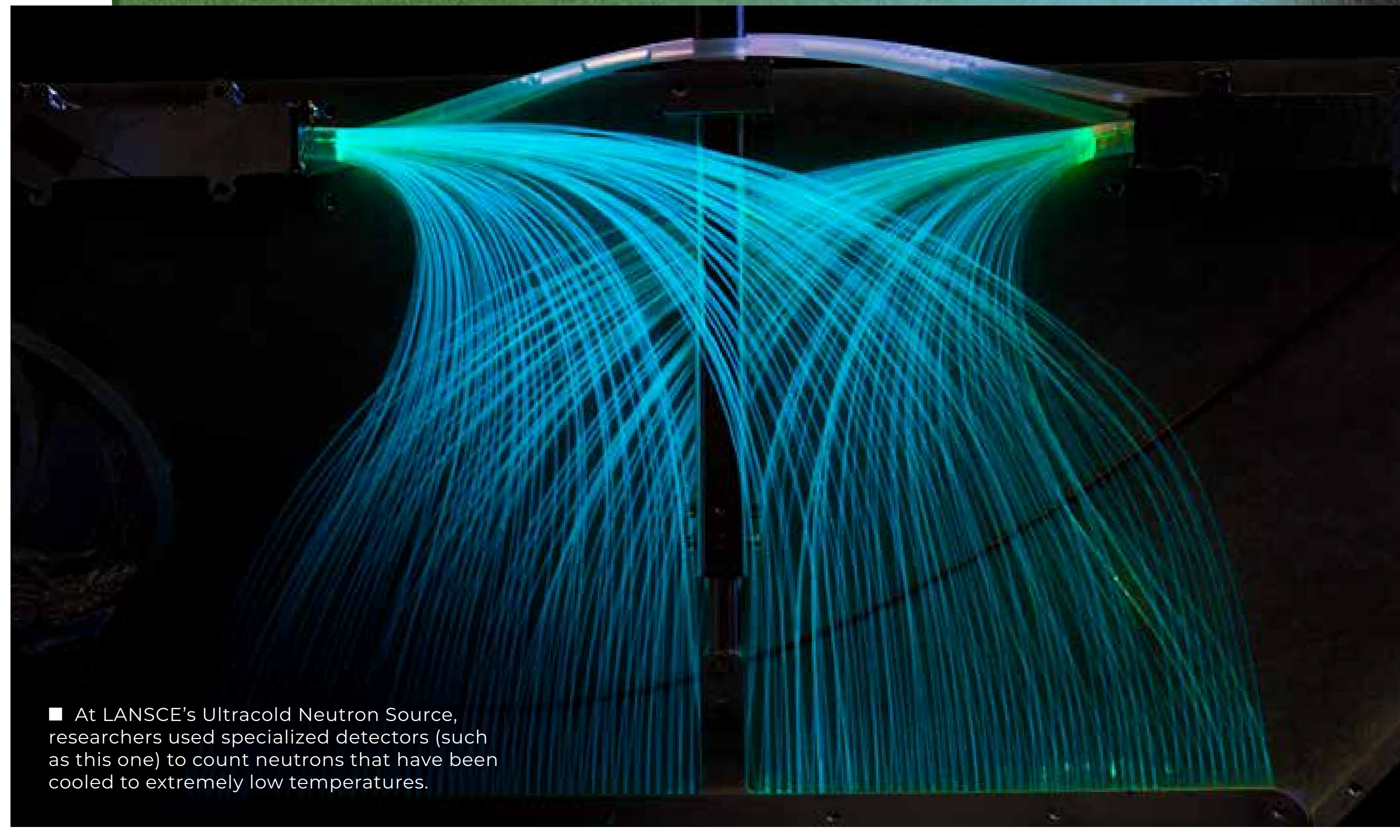
and other non-Laboratory institutions. In recent years, LANSCE has played an increasingly important role in supporting nuclear weapons–related research and development. Unlike DARHT and Scorpius, which test how weapon components work together in a system, LANSCE is suited for investigating, with a high degree of precision, individual components. These "focused" weapon experiments complement the other facilities' "integrated" experiments, which test (or, in Scorpius' case, will test) mockup systems.

"An integrated experiment frequently tells you what to worry about, but it tends to provide less detail as to why," Mosby says. "LANSCE comes into play when you have a complicated problem that you need to understand with relevant, underlying science."

Among the five experimental areas at LANSCE, the Proton Radiography facility, or pRad, has played an increasingly important role in weapons research and development. Using proton radiography—an imaging technique that was developed at Los Alamos in the 1990s—it is possible to make short movies (consisting of around 20 frames) of materials as they are detonated with high explosives.

In 2025, for the first time in two decades, a series of experiments involving plutonium will be undertaken at pRad. By detonating high explosives around very small amounts of plutonium, researchers expect to gain important insights into the metal composing the pits that are the heart of modern nuclear weapons. Data from these experiments will complement the insights to be gained from experiments at Scorpius, which will test larger quantities of plutonium configured in ways that more closely resemble the plutonium inside an actual weapon.

Neither pRad nor LANSCE's other experimental areas will be usable if the facility's front end fails, however. "Given the age of the facility and the critical downtime issues that we might encounter, the decision was made



■ At LANSCE's Ultracold Neutron Source, researchers used specialized detectors (such as this one) to count neutrons that have been cooled to extremely low temperatures.

by NNSA to start a major project, which is the LANSCE Accelerator Modernization Project, or LAMP," says Greg Dale, LAMP's director. "LAMP's goal is to fix key risks and to modernize the front part of the facility."

LAMP, a billion-dollar project that aims to keep LANSCE operational until 2050 or beyond, involves replacing every part of the front end of the accelerator. This section is responsible for producing protons and providing them with a first burst of acceleration on their journey from one end of LANSCE to the other.

A key part of LAMP will be replacing LANSCE's two Cockroft-Walton generators. These generators turn a relatively small amount of electrical current into a much higher current, which is used to give protons their initial acceleration. LANSCE's Cockroft-Walton generators are original to the accelerator and based on designs created in the 1930s. "So, you're running a vital accelerator with 50-year-old hardware, but the technology is even older than that," Tapia says. "There aren't many people in the world who know how to disassemble or replace equipment like this when it fails."

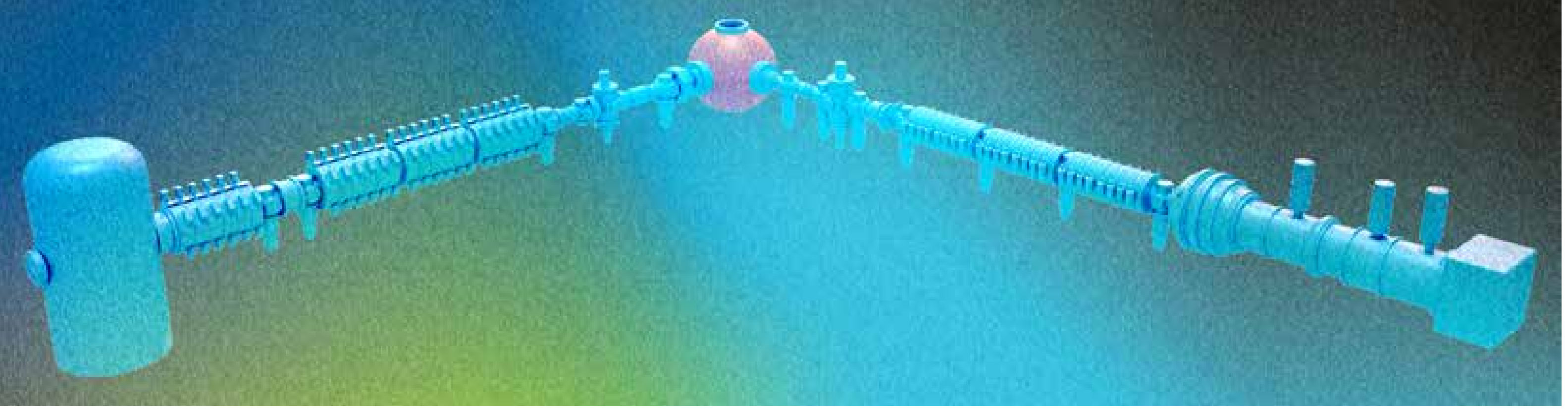
The Cockroft-Walton generators will be replaced with radio-frequency quadrupoles (RFQs). RFQs, which were developed at Los Alamos in the late 1970s, use alternating electric fields to accelerate protons while simultaneously compressing the protons into groups, or "bunches," that travel down the accelerator. RFQs are simpler and more reliable than Cockroft-Walton generators, and they are more efficient, too. RFQs have long since replaced Cockroft-Walton generators at accelerator facilities around the world (LANSCE is the only major accelerator facility in the United States that still relies on the latter).

As a part of LAMP, researchers are using a demonstration RFQ to ensure that these components are compatible with LANSCE's unique requirements, so that the upgrade, when it takes place, goes as smoothly as possible. LAMP recently received approval from NNSA, formally establishing the project and inaugurating the process of conceptual planning and design.

The upgrade itself is expected to take place in 2030, and the project team hopes to have it completed in around 18 months. "That's quite an aggressive timeline, but we need to provide beam to users. That's why we're here," Dale says.

The ASO is working to develop longer-term plans for upgrades to the three experimental areas that are most relevant to national security research (the Lujan Neutron Scattering Center, pRad, and the Weapons Neutron Research Facility). Such upgrades will help ensure that the front-end upgrades completed under LAMP yield high-quality data in support of NNSA's mission. LAMP is "the first major step" toward modernizing LANSCE, Brown says.

Mosby notes that ensuring LANSCE's reliability also helps attract talented young researchers to the Laboratory. Students often come to LANSCE to conduct unclassified, fundamental research, returning after graduation to support national security–related work. "Beyond direct programmatic deliverables, LANSCE helps ensure that the Laboratory will have the people it's going to need through 2050 and beyond," Mosby says.



ADVANCES AT DARHT

In some respects, the primary way DARHT is used—for hydrotests—resembles an enormous dental x-ray machine. When a dentist presses "Start" on an x-ray machine, a stream of electrons accelerates down a tube and into a heavy-metal target, which is usually made of tungsten. As the electrons pass near the nucleus of the target's atoms, they emit x-rays, which are directed through the object to be x-rayed and into a detector. The detector—which is a kind of camera—translates the x-rays it receives into an image (cavities and all).

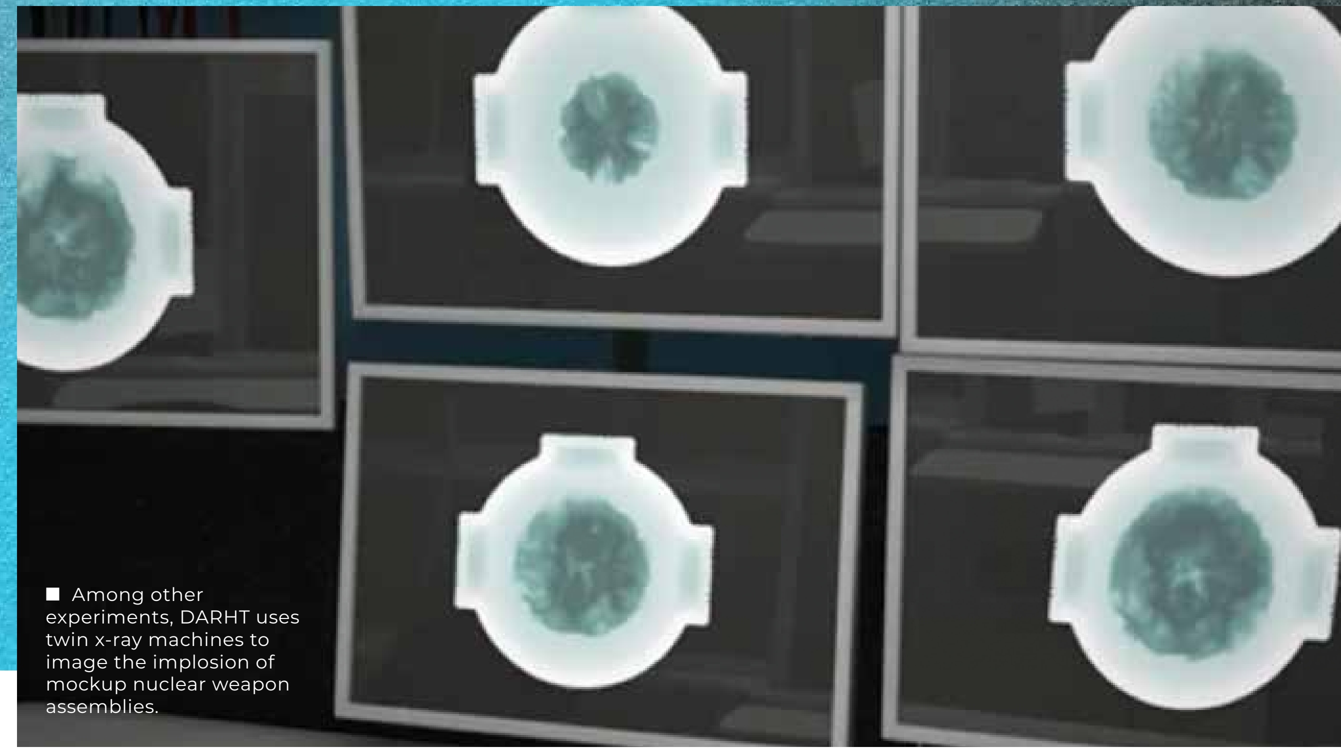
Like a dental x-ray machine, DARHT converts beams of electrons into x-rays by sending the electrons into heavy-metal targets. But while dental x-rays are used to image bone and gum tissue, DARHT's twin x-ray machines, which are arranged in an L shape around the "firing site," capture radiographs of mockup nuclear weapon assemblies that implode at speeds greater than 10,000 miles per hour.

In a real weapon, some of these components would be made with plutonium. In DARHT hydrotests, however, the components are made with a surrogate, non-plutonium metal. The implosion rapidly heats the surrogate to temperatures high enough to cause it to flow like water—which is why many DARHT tests are called hydrodynamic tests, or "hydrotests" for short.

■ DARHT is the most powerful x-ray imaging machine in the world.

Unlike a dental x-ray, which captures a static object, in imaging the implosion of a mock weapon assembly, DARHT must capture a process that takes place in a few millionths of a second. DARHT is also far more powerful than any x-ray machine used for medical purposes (in fact, DARHT is the most powerful x-ray imaging machine in the world).

DARHT's second axis includes a "kicker"—a device that chops the beam of electrons into four separate pulses. Each of these pulses can be used to create a separate image, and by combining the single image from axis one with each of the four images from axis two, researchers can create 3D mockups of an experiment. Data from DARHT hydrotests can then be compared with computer simulations that predict weapons' performance.



■ Among other experiments, DARHT uses twin x-ray machines to image the implosion of mockup nuclear weapon assemblies.

Like LANSCE, DARHT is aging. Axis one entered service in 1999, and axis two was commissioned in 2008; each axis has been "fired" more than 40,000 times for hydrotests and other applications, including for the recent Moonshine experiment (p. 8), in which the accelerator beam was used to change the state of a small amount of plutonium. Also like LANSCE, DARHT is being called on to support more research than ever. Currently, the Laboratory conducts between six and eight hydrotests per year. However, NNSA expects that 10–15 hydrotests will be needed each year to meet mission objectives. Many non-hydrotests, such as follow up experiments to Moonshine, are also necessary.

To address DARHT's age and enable it to sustain more tests, upgrades to the facility are needed, says George Laity, who leads the DARHT Capability Expansion Project (DCX). "These integrated weapon experiments are equivalent to modern versions of past underground tests," Laity says. "They provide the certification basis for stockpile stewardship, so they're very important tests. And the farther we get from underground testing, the more we need to successfully deliver these experiments."

The DCX project has three goals. The first has to do with upgrading the facility's infrastructure—aging parts of the facility, such as the cooling towers, HVAC system, and various concrete structures. The second is to improve the quality of the data captured by DARHT. The project team is exploring several avenues to achieve this goal, including upping the number of radiographs captured at axis two from four to eight, for example, or adding a third axis to the facility.

The third goal is to enable hydrodynamic tests that take place in simulated complex environments. Currently, almost every hydrotest conducted at DARHT has taken place at ambient pressures and temperatures. In practice, however, nuclear weapons must perform under less-than-optimal conditions, oftentimes after being exposed to challenging environments—after sitting inside a B-52's bomb bay on a hot runway (see p. 14 for more about the B-52) or flying in sub-freezing temperatures, for example. Enabling DARHT to conduct tests that simulate high temperatures or g-forces would help researchers certify weapons' performance and reliability.

Since DCX's launch in 2023, the project team has been assembling a comprehensive list of several hundred objectives and readying the highest-priority projects for implementation. These projects include revitalizing DARHT's control room, refurbishing the infrastructure at the firing point, adding diagnostic capabilities, and more. Taken together, the suite of upgrades planned for DARHT will ensure that the facility remains a key tool in ensuring the nuclear stockpile's reliability at a time when DARHT is being asked to accomplish more than ever.

"Ten years from now, we'll be more than 40 years from the last underground test," Laity says. "The type of experiments that we'll need to do in the 2030s to meet evolving mission requirements will be different than they were when DARHT was created. We want to ensure that, for the next several decades, DARHT continues to deliver the critical data that's needed to assess, certify, and qualify the stockpile."

ADVANCES AT Scorpius

DARHT and Scorpius—the yet-to-be-commissioned accelerator whose development Los Alamos is leading—have a lot in common. Both accelerators are designed to image implosions, and both create high-energy x-rays by bombarding a heavy-metal target with electrons.

Look closer, though, and you'll find important differences between the two accelerators. The most significant has to do with the fact that unlike DARHT, which uses a surrogate material as a stand-in for plutonium in experiments that model nuclear weapon components, Scorpius will use real plutonium.

The difference between using a surrogate and plutonium in these integrated experiments might seem small. But plutonium is a complicated element, and in the end, only experiments using plutonium will ensure that researchers understand what happens inside a nuclear weapon just before the plutonium goes supercritical, or achieves a self-sustaining chain reaction. (Experiments at Scorpius will approach criticality without crossing that threshold.)

"Scorpius will enable us to close a gap in our understanding of plutonium late in implosions," says Mike Furlanetto, who directs the Advanced Sources and Detectors project. "This tool will transform our ability to assess and certify the nuclear stockpile."

DARHT and Scorpius differ in other ways, too. Unlike DARHT, which uses two accelerators to image experiments, Scorpius will use only one. However, advances in accelerator and imaging technologies will allow researchers to gain higher-quality images than was possible when DARHT was commissioned.

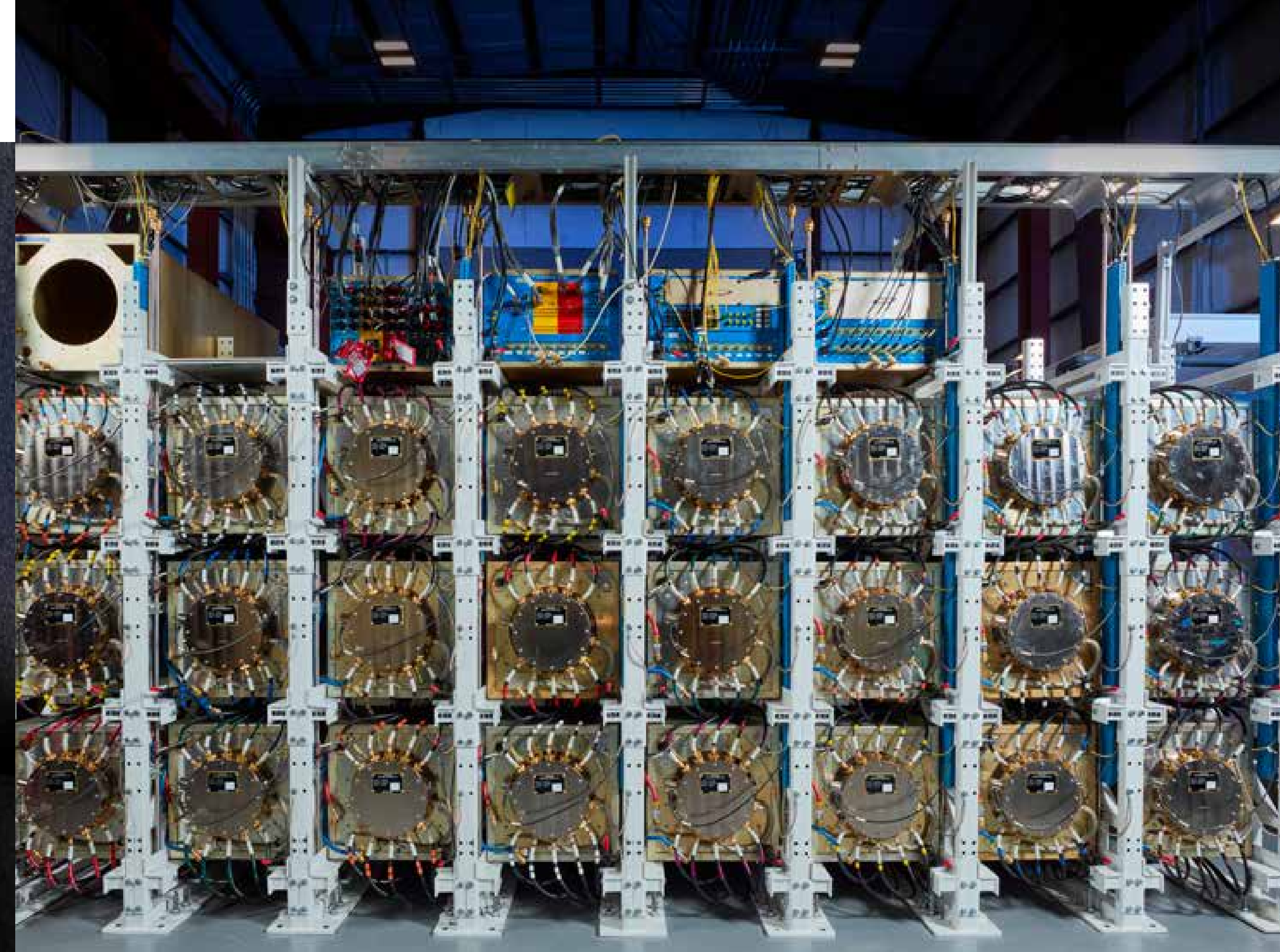
One advancement has to do with the "pulses" that Scorpius will use to capture images. DARHT's second axis, which can capture four separate images of each experimental detonation, works by producing a single, long pulse of electrons that are chopped by a "kicker" into four smaller pulses. Each of these pulses then passes through the experiment to produce an image.

Unfortunately, DARHT's design doesn't easily allow for the alteration of the pulses' length or the amount of time between them, constraining the data that researchers can collect. By contrast, Scorpius will use a solid-state pulsed power source (developed by Lawrence Livermore National Laboratory) and a state-of-the-art electron beam injector (developed by Sandia National Laboratories) that will enable far greater flexibility in imaging. Rather than produce one long pulse that is chopped into four, Scorpius will produce four separate pulses. Researchers will be able to control the length of each of these pulses and the time that separates them.

■ At the Integrated Test Stand (ITS) in North Las Vegas, Nevada, researchers are assembling a shorter version of the Scorpius accelerator to test critical components. Here, three injector cathode modules, which are the source of the accelerator's electrons, have been installed for testing at the ITS.

This advance will significantly increase Scorpius' capabilities. "Rather than design experiments to suit what the accelerator can do, at Scorpius, we'll be able to tune the pulses to provide what each experiment needs," Furlanetto says.

Another advancement is in the camera that Scorpius will use to capture images. This camera, which is being developed with the Massachusetts Institute of Technology's Lincoln Laboratory, will be able to capture images only hundreds of nanoseconds apart. (A nanosecond is one billionth of a second; most commercial digital cameras can capture around 500 images per second, a rate that is several thousand times slower.) One of these cameras will be incorporated into DARHT as well.



■ Researchers are testing 24 of the accelerator's pulsed-power units at the Integrated Test Stand in North Las Vegas, Nevada. The units were developed by Lawrence Livermore National Laboratory.

Given that both DARHT and Scorpius will be used to conduct integrated tests of mock weapon assemblies, one could wonder what role DARHT will play once Scorpius comes online. Laity says that an upgraded DARHT will remain a vital tool for integrated weapon tests that are focused on non-plutonium weapon assemblies.

"Many of the tests that we need to assess high explosives and other components don't require special nuclear material," he says. "The infrastructure that's being developed for Scorpius will support one or two tests per year. But the number of tests we need to accomplish that don't require nuclear material is much higher. We'll still need DARHT to complete those experiments."

Unlike DARHT and LANSCE, Scorpius won't be located at Los Alamos, but more than 1,000 feet underground in a tunnel at the Nevada National Security Sites, which is supporting the tri-laboratory collaboration to develop the accelerator. Currently, researchers are building the Integrated Test Stand (ITS) aboveground in North Las Vegas, Nevada. The ITS is a shorter version of Scorpius that allows key components of the accelerator to be tested before they are transported by elevator underground and assembled into the full-scale accelerator. Scorpius itself is expected to enter service in the early 2030s.

An accelerator culture

Whether an accelerator is underground in Nevada or atop a mesa in New Mexico, the Laboratory has the expertise to support its operation. Furlanetto says that Los Alamos is using its experience with accelerators such as LANSCE and DARHT to support the entire nuclear security enterprise and ensure that the nation's weapons stockpile remains safe, reliable, and effective. "Running accelerators is a culture," he says. "We at Los Alamos have decades of experience with accelerators, and we are leveraging that experience to meet the national security challenges of the future." ★

ACCELERATORS IN SPACE

Los Alamos boldly sends accelerators where few have gone before.

BY JAKE BARTMAN

Particle accelerators come in all sizes, from the 27-kilometer-long Large Hadron Collider outside Geneva, Switzerland, to machines that can fit comfortably into an average-sized room. Although Los Alamos National Laboratory is well-known for its large accelerators (such as the kilometer-long Los Alamos Neutron Science Center), the Laboratory's expertise extends to compact accelerators, too. Recently, researchers at Los Alamos have been using this expertise to design and build accelerators that are small and durable enough to be deployed in space.

The idea of sending particle accelerators into space isn't new. In the 1970s, researchers in the United States began exploring the deployment of electron beams in space, and in the 1980s, Los Alamos played an important role in the United States Strategic Defense Initiative, or SDI (commonly referred to as "Star Wars"). As part of SDI, in 1989, the Laboratory sent an accelerator into space for the Beam Experiment Aboard Rocket (BEAR) project, which yielded important data related to compact accelerators and missile defense.

After BEAR, research on the deployment of accelerators in space stalled. That changed in 2023, when Los Alamos, in collaboration with the National Aeronautics and Space Administration (NASA), conducted the Beam-Plasma Interactions Experiment, or BeamPIE.

For BeamPIE, researchers launched into space a compact electron beam accelerator that was designed and built at the Laboratory. The experiment was conducted to study how electron beams produce electromagnetic waves in space and to research new accelerator technologies. These technologies could enable the remediation of radiation belts left in the atmosphere by high-altitude nuclear explosions and solar flares.

In November 2023, the BeamPIE accelerator was launched into space from the Poker Flat Research Range near Fairbanks, Alaska.
Photo: NASA

Such radiation belts could damage the satellites that are central to national security. Researchers at Los Alamos think that by using a particle accelerator to create waves in the ionosphere (a plasma region above Earth's atmosphere), it could be possible to cause electrons to precipitate (in a manner akin to drops of water precipitating from clouds) from the radiation belts into the upper atmosphere, reducing or eliminating the belts and making space safe for satellites.

Although the BeamPIE accelerator successfully reached, and injected electrons into, space—significant achievements in their own right—the experiment didn't detect waves in the ionosphere at the times and frequencies that researchers expected.

"Putting a tiny accelerator on a rocket is really challenging," says Rebecca Holmes Sandoval, a researcher at Los Alamos. Holmes Sandoval is part of a team that is developing a follow-up experiment to BeamPIE called Beam2PIE. Like the original BeamPIE, Beam2PIE will involve launching a next-generation compact accelerator into space and attempting to produce (and measure) ionospheric waves.

Holmes Sandoval says that in addition to the shocks and vibration to which an accelerator is exposed during a rocket launch, there are challenges related to the high-voltage power sources that the Beam2PIE accelerator will use in space (where the low ambient pressure can cause electricity to arc, or jump between the power source's connections). Fortunately, the Laboratory has experience addressing obstacles like these, having developed power sources for the Curiosity and Perseverance rovers, which are exploring Mars.

Using an accelerator in space is challenging for other reasons, too. An accelerator launched into space must be compact, and the rocket's relatively small surface area—combined with the lack of an electrical ground—limits how much current the accelerator can produce. Other difficulties include the way that the Earth's magnetic field could affect the quality of an accelerator's beam, says Karl Smith, who leads Beam2PIE. The atmosphere's reduced gravity could also cause components to fall out of alignment, and the heat that builds up inside the accelerator during operation must be dissipated (the BeamPIE accelerator used "phase-change" materials that were designed to melt during the experiment, dissipating the heat).

"For projects like BeamPIE and Beam2PIE, you need both accelerator and space expertise," Smith says. "We have that at Los Alamos."

As part of Beam2PIE, researchers hope to develop a laboratory testbed that will allow them to expose accelerator components to the breadth of conditions that an accelerator would encounter on its way into, and in, space. Already, the project team has a test stand that allows them to test equipment in a vacuum, but a more comprehensive testbed could include a vibration table (to shake the components in ways that resemble a rocket launch) and other equipment to help ensure that Beam2PIE builds on the accomplishments of the original BeamPIE.

If it is completed, this accelerator testbed would be a unique capability among the national laboratories, Holmes Sandoval says. The Beam2PIE team is readying a proposal for NASA's Low-Cost Access to Space Program, which helped fund the original BeamPIE project. If all goes well, the team could send a new accelerator into space as soon as 2027. ★

In 1989, as part of the United States Strategic Defense Initiative (commonly referred to as "Star Wars"), Los Alamos conducted the Beam Experiment Aboard Rocket (BEAR) project, which involved launching a compact particle accelerator into space.

Remembering Charlie McMillan

Los Alamos National Laboratory's 10th director led with purpose, thoughtfulness, and integrity.

By Whitney Spivey

Using a music stand to hold his notes, McMillan addresses an audience in the Lab's National Security Sciences Building.

Former Los Alamos National Laboratory Director Charlie McMillan was on vacation in Belize when he received a phone call from current Laboratory Director Thom Mason. Mason was calling to see if McMillan might be interested in leading a Department of Energy–wide effort to streamline and execute various projects involving artificial intelligence (AI).

"I called him on a Saturday, and he explained that he was snorkeling," Mason remembers. "And I thought, this is not going to go well. Here I am trying to convince him that he ought to take on this challenge, and he is enjoying the life of a retiree, looking at beautiful tropical fish on reconstructed coral reefs."

But, as Janet McMillan notes, her husband was actually not very good at retirement. "I used to tease him that he was failing retirement because he joined the boards of two startup companies, and he continued to work with colleagues at the Lab," she says. So, she was not surprised when, after giving it some thought, McMillan accepted Mason's offer.

For the next year, McMillan worked part time on the new AI initiative. "But I would say part-time of Charlie is worth more than time-and-a-half of most people," Mason says. "He really jumped into it and made a huge, huge difference."

That work came to an abrupt and tragic end when McMillan died in a traffic collision on September 6, 2024.

In the months after the accident, as the impact of McMillan's career and character continue to be shared and understood, "there's much to recognize and much to celebrate," Mason says. "Charlie's contributions will be with us for a long, long time."

Early days

McMillan was born on October 25, 1954, in Fayetteville, Arkansas, where his father, a physicist, was taking graduate classes at the University of Arkansas. When his father got a job at Fort Belvoir, a U.S. Army garrison in northern Virginia, the family moved north, settling in Virginia and then in Maryland, where his mother worked as an elementary school math teacher.

When he was four years old, McMillan asked his mother if she could teach him to read words, but she instead taught him to read music, sparking what would become a lifelong passion. By 14, McMillan had learned not only to play piano but also to tune pianos. According to his younger sister, "he often took his tuning forks and tuning kit on family vacations in case of a piano-tuning emergency."

At Columbia Union College (now Washington Adventist University), McMillan became particularly proficient at playing the organ, so much so that his organ teacher encouraged him to add a music major to his curriculum. "He took lots of organ and lots of music classes and of course shined in them because he invested in anything that he

One of McMillan's three sisters, Cindy, recalled her adventures with the McMillans: "We swam in the Amazon River. We rode camels on safari in Tanzania. We took photographs at a workshop in Provence, France. We hiked in Bandelier, and we went on a really fun boating excursion on a lake in northern Minnesota. And always our family excursions involved playing a card game called rook, and … those were always very lively and competitive sessions." Here, McMillan rides an elephant in Nepal. Photo: McMillan family

"In the early 1980s, Charlie had a long and unruly beard," Anastasio says. "It kind of came down about mid-waist, at least that's the way I remember it." Photo: LLNL

was interested in," Janet says. "When he became passionate about something, he would learn everything possible about it."

In the end, McMillan decided to major in only two areas: math and physics, the latter of which he studied as a doctoral student at the Massachusetts Institute of Technology (MIT)—but not before marrying Janet and teaching English and science in Zambia for a year.

Janet says that whether her husband was attending school or teaching school, "Charlie's motto was always: do your best in whatever things you do. If you're going to do it, don't bother doing it halfway. That outlook is what drove him to success in everything he did."

A career in service begins

At the recommendation of a former MIT officemate, McMillan applied to be an experimental physicist at California's Lawrence Livermore National Laboratory, one of three national laboratories responsible for maintaining the United States' nuclear weapons (Los Alamos and Sandia are the others). When the job offer came through, the McMillans flew cross-country, and McMillan began work in the Advanced Experiments Group in January 1983.

Physicist Mike Anastasio recalls getting to know McMillan at Livermore. "I'd been there a few years when Charlie showed up. We got together to explore ways to understand and measure the ejecta from shocked metals. And Charlie's creativity showed through at the very beginning. He immediately came up with several different experimental techniques, and his excitement and aptitude for learning were manifest from the very beginning of our relationship."

McMillan's "first love was being an experimentalist—doing things, seeing things, and watching things happen that he designed," according to Janet. Moving beyond that environment into management was not an obvious or easy choice.

Yet, Anastasio, who was a few years senior to McMillan, saw McMillan's promise as a leader from the beginning. "The first time Mike asked Charlie to apply for a position outside of the experiments group, Charlie thought, why does he want me to apply for that? It's not my forte. It's not where I'm really good," Janet remembers. "But Mike said to him, I want you to practice applying for an upper-level job because I think you're going to grow into that. Mike saw the potential."

And so McMillan was promoted to a leadership role in Livermore's B Division in 1992, a pivotal time for the country's nuclear weapons laboratories, which had for decades conducted full-scale detonation tests on nuclear devices to both understand them and certify the safety and reliability of weapons in the U.S. nuclear stockpile. In September of that year, the United States not only placed a moratorium on nuclear testing but also decided not to introduce any new weapons into the stockpile. Ensuring the existing, aging weapons would work now required a different type of scientific understanding. Legacy testing data was combined with newer data from nonnuclear and subcritical experiments and then modeled and simulated using supercomputers. Nuclear testing had gone digital, so to speak, and key to the success of this new way forward were computer codes, which essentially told the computers what to do (see p. 22 for more).

As the head of B Division's weapons code development group, McMillan helped produce the first 3D parallel simulations of a primary (fission) explosion, which allowed weapons designers to "see" the early phases of a weapon detonating—without actually detonating it.

"He really pushed our code teams to be ambitious in the goals that they set," says Kim Budil, who joined B Division in 1999 and is now the director of Livermore. "We were writing all new high-performance simulation codes, and he really brought a physicist's mindset to that work: How can we advance the state of the art? How can we advance our knowledge and capabilities? How can we build better models? How can we build more modern tools for our weapons design community to use?"

Budil notes that some weapons designers are slow to adapt to change. "So, in some cases, it takes a special person to

■ During a tour of Livermore's experimental test site in August 2005, McMillan explains to NNSA Administrator Linton Brooks (second from right) the importance of the Flash X Ray machine, a diagnostic tool for hydrodynamic testing that enables scientists to capture images of an exploding device. Photo: LLNL

bring that community along to adopt a new approach. I think Charlie was identified as someone who was willing to take on whatever the new emerging challenge was in the division, whether it was something he'd done before or not. He learned a great deal about whatever it was he was taking on so that he could be very credible in that role, and I think people trusted that. He was not just managing a project or trying to promote a new way of doing things for no reason; he had good scientific motivations, and he spent time working with people."

McMillan's can-do attitude and willingness to tackle big challenges was perhaps why, in 1999, he was hired to lead the team that, at the direction of the Department of Energy, transferred responsibility for the W80, a thermal nuclear warhead designed for cruise missiles, from Los Alamos to Livermore. The transfer was significant because of the longtime rivalry between the laboratories and also because Livermore, in close partnership with Sandia National Laboratories, would begin a life extension program for the W80.

But McMillan, with his thoughtful and collaborative approach to tough scientific and people challenges, was just the man for the job. "This is a collaborative effort that will require the labs to work closely together and will tap the scientific capabilities and unique research facilities at all three laboratories," McMillan is quoted in a 2001 Livermore news release. In a nod to Los Alamos, he added: "We're fortunate that some of the scientists who originally designed and developed the W80 are still around to serve as a resource. They're an invaluable asset to this effort."

By 2001, McMillan had been promoted to B Division leader, responsible for all aspects of primary design for Livermore weapons systems in the stockpile, at that time the B83 gravity bomb and the W80 and W87 warheads.

The move to Los Alamos

In recounting his relationship with McMillan, Anastasio, who became the director of Livermore in 2002, described "the fateful brown bag lunch in the park at Livermore" in early 2005. Anastasio recalls sitting at a picnic table and probing McMillan's interest in joining a bid team to take over management at Los Alamos. As the potential new director of Los Alamos, Anastasio wanted to see if McMillan had interest in being an associate director, in charge of Weapons Physics. "To the surprise of many," Anastasio says, "we actually won the government's contract competition, which was a major change in both of our lives."

Janet, however, was not surprised. "When I heard he was on the team, I said, Charlie, your team is going to win. He said, nobody thinks we're going to win, but this is a fun exercise. I said, oh no, you're going to win. This is a stellar team. I knew the guys, they were A-plus guys. I had no doubt they were going to win."

Budil imagines that "it must have been an extraordinary experience to come from Livermore to Los Alamos in a leadership position. Charlie embraced Los Alamos and learned to be a part of this culture while still respecting and appreciating and celebrating the things that he'd done in the time he'd spent at Livermore," she says. "The two labs are very different. The joke always went that during the Cold War, the Soviet Union was the adversary, and Livermore was the enemy for Los Alamos, so it's hard to overstate how strange that transition must have felt. But he became such a beloved member of this community, I think because of that genuine, earnest commitment to the work, to the people, to being part of the community here. He really gave himself over to New Mexico."

Physicist Charlie Nakhleh, who is currently the head of Weapons Physics at Los Alamos, notes that Los Alamos employees were not only getting new managers with Anastasio and McMillan's bid team, but also a new management company. Instead of being run solely by the University of California (UC), the Lab was now operated by Los Alamos National Security, a private limited liability company formed by UC together with three other entities. "Many of us who had only known the University of California and who were proud of being UC employees were less than excited about the transition to an unknown 'corporate' ownership," Nakhleh says. But McMillan's steady hand helped alleviate any concerns. "I found myself working with Charlie—for Charlie—and was struck anew by his personal and leadership skills in this new role," Nakhleh says. "He had a remarkable ability to be both firm in direction and kind in manner all at the same time."

As the head of Weapons Physics, McMillan's accomplishments included leading integrated experiments and advancing computer modeling and simulations to evaluate the health and extend the lifetimes of America's nuclear weapons. Essential to this work were the $400-million Dual-Axis Radiographic Hydrodynamic Test facility and the world's first petascale computer, Roadrunner—both acquired under McMillan's watch.

From 2007 to 2011, Los Alamos made plutonium pits—the cores of nuclear weapons—to replace pits in some W88 warheads. This work took place in the Lab's Plutonium Facility, and Kane Fisher, who at that time was the deputy in charge of pit engineering, recalls that he started giving McMillan tours of PF-4 right away. "Charlie wanted to visit and he wanted to learn and he wanted to see—he was extremely present," says Fisher, who estimates that over the next 18 years, he toured McMillan around PF-4 at least 30 times.

In 2009, McMillan was promoted to the Lab's principal associate director for the Weapons Program—the person in charge of everything weapons-related at Los Alamos, not just physics but also engineering and production. The work occurred primarily in New Mexico but often took him farther afield. Subcritical experiments, which use nuclear material but do not result in a nuclear reaction, were executed at an underground laboratory at the Nevada National Security Sites. The innovative subcritical plutonium experiments during this time "helped to usher in an experimental 'golden age,'" McMillan wrote on his LinkedIn profile.

■ Only 26 days after McMillan became Los Alamos director, the Las Conchas Fire erupted just west of Los Alamos. The Lab was threatened, and the town was evacuated. "That was an opportunity for the whole world to see the great leadership and integrity that shined through Charlie as he handled that," Anastasio says. "He reassured the community and all the outside entities who were so concerned that all the right things were being done."

Despite moving up the org chart, Fisher notes that McMillan was always grounded, personable, and interested. "He wasn't a person who cared about status," Fisher says. "If I had something to say, he would listen—even back when I was a little peon."

Becoming director

In January 2011, Anastasio announced his retirement as Los Alamos director. Although McMillan was an obvious candidate to succeed Anastasio, "Charlie had to apply just like everyone else," Janet remembers. She also notes that "Charlie didn't have this big plan laid out of becoming the director of the Lab one day. He never thought that. His move into higher-level positions came as a result of his dedication to always doing a good job at whatever he was doing."

Fisher says McMillan was the rare combination of a talented physicist and a talented leader. "He could see problems faster and easier than other people," Fisher explains. "And he had the power to solve them—and not just technical problems. He had the whole enchilada."

The board members of Los Alamos National Security must have agreed because they hired McMillan to be the Los Alamos director and CEO, effective June 1, 2011. During an all-employee meeting on his first day, McMillan summarized his management style with a quote from *Lives of a Cell*, an essay by Lewis Thomas: "What [research] needs is for the air to be made right. If you want a bee to make honey, you do not issue protocols on solar navigation or carbohydrate chemistry, you put him together with other bees . . . and you do what you can to arrange the general environment around the hive. If the air is right, the science will come in its own season, like pure honey."

Among McMillan's priorities as director was helping people do their best work. "It brought him great satisfaction to be able to say, I helped create the environment where these guys do amazing things," Janet says. "His joy was to go out to the different areas and talk to people. He was very engaged. He would ask intelligent questions, listen to their responses, and ask more questions."

■ McMillan and New Mexico Senator Tom Udall prepare to break ground on a new research laboratory in May 2012.

■ McMillan (third from right) and Secretary of Energy Rick Perry (right) observe an experiment during Perry's visit to the Laboratory in May 2017.

■ In March 2016, McMillan flew with the U.S. Air Force's 93rd Bomb Squadron in a B-52 Stratofortress. The plane, which is currently capable of carrying the Los Alamos–designed and Livermore-maintained W80, flew from Barksdale Air Force Base in Louisiana, over Los Alamos, and back. Coincidentally, McMillan was responsible for the transfer of responsibility of the W80 from Los Alamos to Livermore in 1999. Photo: U.S. Air Force

In addition to technical questions, McMillan asked personal questions. "One of his rules was family first," Fisher says. "So he would ask me how my boys are doing. He was caring, he was compassionate. He was smart as hell. His recollection was off the charts. And he was open. He was just a remarkable human being."

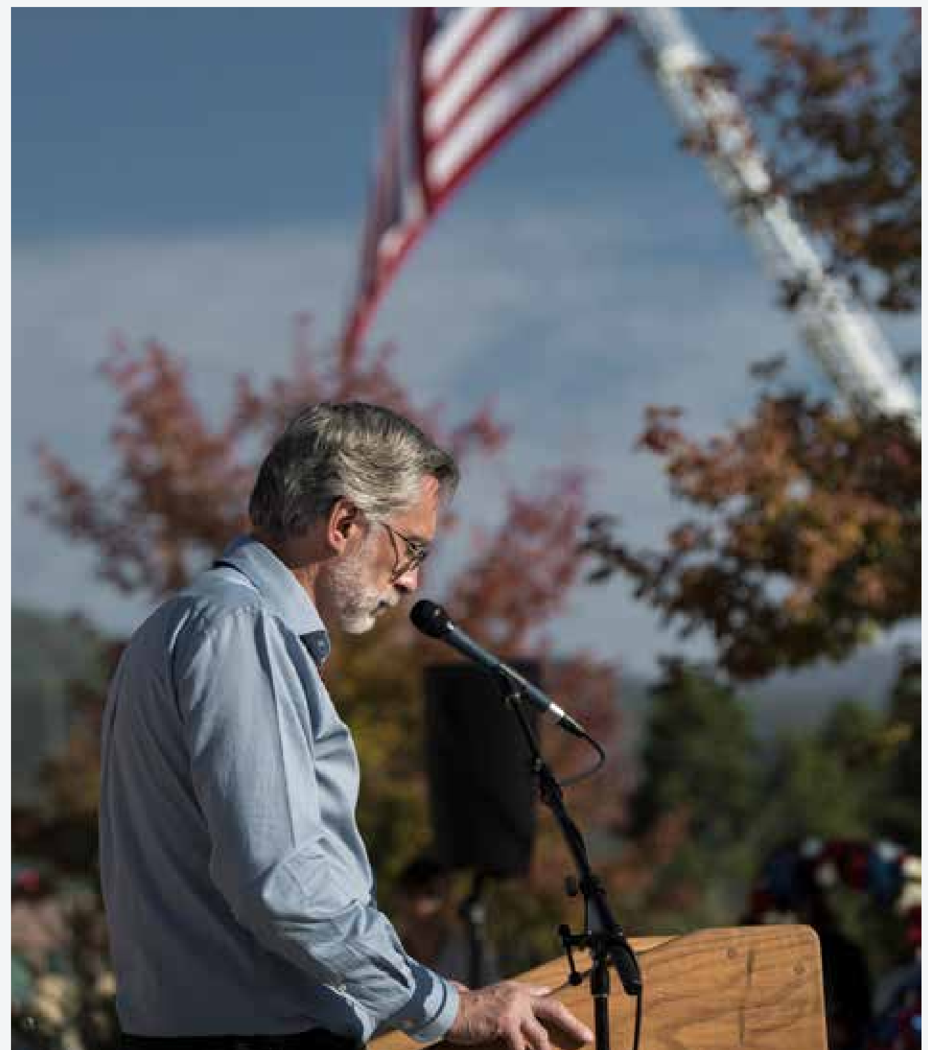
Liana Lovato, who served as McMillan's executive assistant for more than a decade, agrees. "He took his time to know each of us, really know us and our families. He celebrated with us during weddings, births, graduations, and he supported us through hard times," she said at McMillan's memorial service. "Charlie and Janet welcomed us into their home, hosting dinners and holiday parties and student gatherings. They shared their lives with us and we felt like part of the family."

According to Fred deSousa, who supported communications in the director's office, key to McMillan's personable nature was that "he understood that it's not only about being right from a factual or logical standpoint. He understood that things like credibility and trust and reassurance are really difficult to measure empirically. Without those things, it doesn't matter if you're right. If you disregard the emotional side of certain interactions, your message will be lost."

Although qualities like kindness and compassion came naturally to McMillan, others he had to work on. "He was, especially as a youth, a very shy person," Janet says. To improve as a public speaker, McMillan hired a speech coach who snapped his fingers every time McMillan said *ah*, or *like*, or *uh*. "That coaches you very quickly," says Fisher, who was later snapped at by McMillan during a mentoring session.

McMillan also leveraged decades of music recitals and theater performances to feel more comfortable in front of large audiences. ("When you dance on stage in tights, it just takes away different inhibitions," says Janet, noting that for years both she and her husband performed in the California Revels Christmas productions.) McMillan often used a music stand to hold his notes instead of a traditional podium. "He was a musician, and his approach to life was that he was far more comfortable behind a music stand than a podium," says Anne Menefee, formerly of the Lab's Protocol office.

■ McMillan speaks at a 9/11 remembrance ceremony at the Laboratory.



■ For many years, the McMillans performed in the California Revels Christmas productions. Photo: McMillan family

Often, from behind that music stand, McMillan would begin a talk by stating three things he wanted to speak about. "For most speeches or written pieces, three topics is the magic number," deSousa explains. "Less than that and you're not specific enough, more than that and you're too far in the weeds, and people are going to lose you. So he literally would say to his audiences, from members of Congress to regulators to high school students, I'm going to talk about three things. And then he'd list them and proceed in that order."

Lovato, whose work often involved helping her boss prep for those talks, says that "Charlie's leadership guided this Lab through good times and hard times. And he did it all with grace, dignity, and unshakable integrity. He was admired by so many, not just for his intelligence, but for the way he made every challenge seem surmountable with his steady hand."

Jill Hruby, until recently the head of the National Nuclear Security

■ McMillan greets New Mexico Governor Susana Martinez at the Laboratory's 70th anniversary celebration in July 2013.

Administration, was the director of Sandia when McMillan was the director of Los Alamos. "Being a lab director is a hard job," she says. "Nobody would do the job of a lab director if they didn't believe deeply in the mission. I know Charlie did." Hruby recalls McMillan saying to her once that he could have a thought standing in his closet in the morning and that by the time he got to work, everyone was talking about it. "It does feel like that," Hruby says. "It feels like your thoughts are being sought, your ideas are being scrutinized at all times, but Charlie, he knew that was part of the job, and he handled it remarkably well."

From integrating with local, state, and federal officials during the 2011 Las Conchas wildfire that threatened the Laboratory just 26 days after he became director to securing $3 million for local nonprofits in his last few months on the job, McMillan was always on the go. "Charlie was passionate about expanding Los Alamos' capabilities beyond Weapons," explains Los Alamos Deputy Director for Weapons Bob Webster. "While he recognized that Weapons was our foundation, he knew that we could and should excel in other technical fields as well. His leadership led to key investments and advancements that have strengthened the Lab's legacy of innovation and world-class science." McMillan was a major proponent of cutting-edge research in areas such as advanced manufacturing, vaccine development, Earth-system modeling, and Mars exploration.

Only seven years after acquiring Roadrunner, McMillan was instrumental in acquiring the Trinity supercomputer—the sixth-fastest supercomputer in the world at the time of its activation in 2015. Trinity played a major role in ensuring the safety and reliability of the nation's nuclear weapons.

As part of ensuring the soundness of the nuclear stockpile, McMillan also wrote and signed eight annual assessment letters, which inform the secretary of energy, the secretary of defense, and the chair of the Nuclear Weapons Council of the Lab's confidence that the stockpile remains safe, secure, and effective now and into the future because of the Lab's dedicated sustainment and modernization efforts.

The annual assessment letters are also platforms for Lab directors to raise concerns, and in the 2016 letter, McMillan voiced his opinion that the U.S. government was not producing enough tritium—a radioactive isotope of hydrogen that is a key ingredient in nuclear weapons—at its Tennessee Valley Authority (TVA) Watts Bar Nuclear Plant. "Under the current set of stockpile planning assumptions, one reactor is not adequate to provide the tritium necessary to fuel the future stockpile," McMillan wrote.

■ McMillan and Anastasio look through Manhattan Project badge photos in the Los Alamos National Security Research Center.

The words had their intended effect, and "in large part due to Charlie, two reactors are now operational at TVA for tritium production to meet the stockpile demand," explains Los Alamos engineer Brad Meyer, who worked closely with McMillan on the tritium issue.

Each annual assessment letter ends with "final thoughts" that summarize the year's challenges in maintaining the four Los Alamos weapons systems—the B61 gravity bomb and the W76, W78, and W88 warheads.

In his 2017 letter—his final letter—McMillan notes that despite a suite of challenges ranging from aging weapons components to inadequate infrastructure to production hiccups, the Laboratory was effective in executing its mission. "This year marks the 22nd anniversary of the Stockpile Stewardship Program," he wrote. "By most measures, it has been impressively successful. As intended by its creators, the development and application of powerful, modern assessment tools provide the technical basis for the moratorium on nuclear testing and have led to a deeper understanding of the science associated with nuclear weapons."

He concluded the letter by asking for collaboration—and funding:

"A proper balance among fundamental nuclear weapons science, robust nuclear weapons facilities, and stockpile modernization is important, but strategy must drive budget. Nuclear security enterprise stakeholders must work together to develop and execute a long-term strategic plan with a rational and sustainable budgetary structure for the nuclear deterrent."

■ McMillan was the proud father of two daughters and a son. In 2023, he welcomed a grandson.
Photo: McMillan family

Retirement

When McMillan was applying for the Los Alamos directorship, Anastasio told his longtime friend and colleague, "you may think you know what this job is about, but it is bigger than you imagine."

"And that was true," Janet says. "Charlie got a lot more gray hairs those six years." He announced his retirement in September 2017, telling employees that "it has truly been an honor and a privilege to serve as your director these past six years. Every day, I have been in awe of the people of this great Laboratory and what we have been able to contribute to this nation's security." His last day on the job was December 31.

But retirement for McMillan didn't involve games of horseshoes or relaxing in front of the television ("He didn't watch TV sitcoms or follow popular culture at all, really," explains deSousa, who notes that McMillan once sat beside Ashton Kutcher at a dinner party and didn't know who the actor was). Instead, McMillan remained active in national security work, including coordinating efforts in artificial intelligence and facilitating discussions about the importance of artificial intelligence oversight and its potential geopolitical implications.

But perhaps McMillan's most meaningful work in retirement was mentoring—everyone from students to upper-level managers. When the Laboratory launched an Executive Leadership Development Program in 2023, McMillan mentored five senior employees.

"He was delighted to serve as a mentor," Mason says. "And I know that the people he worked with really valued his input and his thoughtfulness. He made a big contribution to cultivating the next set of leaders for the Lab, and that's something that will pay dividends for a long time to come."

Fisher, who was among those mentored by McMillan, agrees. "Charlie was our guy; he spent 2 to 4 hours a week with us for a year," Fisher says. "He was so invested in us, and he said one of his crowning achievements was passing on his leadership knowledge to the next generation."

Fisher was also fortunate to interact with McMillan during the 2024 Oppenheimer Science and Energy Leadership Program, an annual program in which fellows from the 17 Department of Energy laboratories come together to explore the broader scientific, policy, and energy ecosystem within which the labs operate.

Three months after McMillan's death, Fisher was the final speaker at an event in Washington, D.C.—the last gathering of the 2024 Oppenheimer fellows. Fisher ended his remarks with a dedication to McMillan, whom he described as his mentor, hero, and a champion of the program. "The dedication included a rule that Charlie taught us," Fisher explains. "That if you care for and love someone, anyone, including coworkers, you have to tell them. So I told the Oppenheimer fellows that I cared for and loved them. Not many dry eyes after that."

The rule Fisher shared was one of three that McMillan lived by. In fact, they were printed on the back of the program for his memorial service, which was held October 10 at Ashley Pond in Los Alamos. They are

- Always do your best. Most things are difficult before they get easier.
- Always remember to work as a team. We can accomplish more and better together than alone.
- Tell those whom you love that you love them every day. Never assume that they know, and don't take those opportunities for granted.

"Internalize these rules and don't forget them," Janet says. "They make your life good." ★

■ McMillan relaxes on a beach in Belize in 2023. It was on this trip that he was contacted about leading an artificial intelligence initiative for the Department of Energy.
Photo: McMillan family

REMEMBRANCES

Past and present Los Alamos colleagues pay their respects to Charlie McMillan.

"Charlie will always be known first as a former Los Alamos National Laboratory director, but that hardly captures this man. I first got to know Charlie in 2005, and through 20 years at the Lab he became one of my closest friends and colleagues. He was brilliant, but more importantly, he was passionate, honest, and dignified. He was a talented musician, photographer, and since retirement, a fantastic watcher of the night sky. Charlie and I traveled a difficult journey at Los Alamos from contract changes, wildfires, accidents, and national security challenges. He was a man that I truly could trust—humble but skilled and always respectful. His fingerprints are all over things that are good at the Lab, and his influence on friends is deep."

–Terry Wallace • Director emeritus

"Charlie was the first executive I worked with at the Lab, and I helped him with his retirement process. I was so worried about that presentation, but Charlie and Janet made me feel so at ease. Both of them were so kind and appreciative in thanking me for the help walking them both through the process."

–Konstance Kurrle • Employee services representative, Human Resources

■ Senator Martin Heinrich and McMillan study a poster of the Mars Curiosity rover, which is powered by a heat source made at Los Alamos and carries Los Alamos–designed instruments. "As a leader and an individual, Charlie made invaluable contributions to our state, to science, and to our national security," Heinrich said after McMillan's death. "I will always be grateful to Charlie for his leadership at LANL, his work and partnership on supercomputing and artificial intelligence, and his commitment to serving the greater good."

"I met Charlie in the mid-1990s. He was at Livermore then, and he held a view common at Livermore—that plutonium material was completely understood. This was in contrast to the perspective many of us at Los Alamos held. Fast forward, and shortly after Charlie became the director at Los Alamos, new data from the Gemini subcrit provided surprising results in plutonium material response. I'll never forget sitting in Charlie's office and hearing him say that he was wrong. Hearing a Laboratory director say those words was remarkable—not only because that admission paved the way for the pit manufacturing mission we have today but also because in that moment, Charlie embodied what it means to be a true leader and scientist. He was committed to doing what was right for our Laboratory and our country."

–Bob Webster • Deputy Laboratory director for Weapons

"In 2016, the Director's Office requested a meeting with the Motorcycle Safety Committee. I thought it was going to be a simple photo op, but once I arrived, I realized that Director McMillan was genuinely concerned for the safety of motorcyclists at Los Alamos. He asked what the main issues were for motorcyclists on Lab property. It wasn't long after our meeting that Director McMillan spoke to the Lab about respecting others on the roads and putting phones down when you drive. That was my only interaction with Director McMillan, but I came away believing that he was a really good dude."

–Richard Sturgeon • Environmental professional

"The Lab's mission was of gigantic importance to the nation—and therefore to Charlie. It got the attention it deserved, but I never felt that it was done in a way that compromised the whole person that he was. To have the diversity of pursuits that he did was a reminder that, for any of us, if you're singularly focused on something, you can get yourself into a rut. Taking a break from it and returning to it can sometimes provide a path to the right answer. Charlie weaved in and out of those responsibilities in a manner that served the nation extremely well—and it didn't hurt that he had a Cray computer in his head. When those wheels were turning, there was a lot of forward momentum."

–Richard Kacich • Former deputy director

"I never ever saw him lose his temper, even under the most dire circumstances. I never saw him raise his voice. He was a gentleman, he was a scholar, his quiet leadership style is something I think a lot of people should emulate. He was a stickler for the facts. He did not like sugarcoating. He was a remarkable man. I can safely say, when Charlie was my boss, I enjoyed coming to work every day. His diligence and his commitment to the mission of the Laboratory was simply astonishing."

–Jon Ventura • Former executive advisor

"My young child and I ran into Charlie, his wife, and their rescued greyhounds while hiking on the Quemazon trail years ago. My child petted his dogs, and Charlie allowed my child to peek through his bird-watching binoculars. In that brief interaction with strangers, Charlie was warm and friendly. I'm grateful for his steady leadership of the Lab during the difficult times."

–Luce Salas • Intelligence analyst

■ As part of the Lab's Executive Leadership Development Program, McMillan mentored (clockwise from left) Theoretical Division Leader Marianne Francois, Program Director for Plutonium Modernization Kane Fisher, Emergency Management Division Leader Jeff Dare, Engineering Services Division Leader Michael Richardson, and Integrated Physics Codes Director Jimmy Fung. As a thank you, the cohort treated McMillan to lunch on February 5, 2024. Photo: Kane Fisher

"I met Charlie in 2015 at the United States Naval Academy when he was there to give a speech. I was his faculty representative and was immediately moved by his genuine personality and obvious leadership presence. After later accepting a job here at Los Alamos, many of my interactions with Charlie were around our mutual love of music. Before his untimely passing, we were planning to play some Baroque pieces that he was so fond of (and good at) in concert. I am extremely thankful that I had the opportunity to spend a small amount of time with Charlie and can say that his influence has changed me for the better."

–Jeremy Best • Classification analyst

"I worked with Charlie on several occasions where we hosted international visitors at the Laboratory. During these visits Charlie briefed foreign dignitaries on Los Alamos efforts in stockpile stewardship and nonproliferation, and the content and delivery of his talks were always superb and extremely well received. Watching Charlie present and interact with our guests, seeing how eloquently and reassuringly (and with such charm and grace!) he responded to even the most challenging questions from our visitors, always made me so proud to be a part of Los Alamos."

–Olga Martin • Program manager, Nuclear Nonproliferation and Security

"Charlie believed in me like no other mentor ever has. His unwavering passion for our mission drove him to pour deeply into our leadership, leaving an indelible mark on all of us."

–Michael Richardson • Division leader, Engineering Services

"At a recent quarterly Engineering Services conference, I ended up sitting behind Charlie. To my surprise, he turned around and started chatting with me. He asked me how I liked living here and where I was from. I walked away from the short conversation thinking 'what a nice and personable man.' I also could tell how much he loved his wife and his family. His eyes smiled when he talked about them. I loved what he said on stage too. He moved all of us that day. He was humble and authentic. I liked him instantly."

–Lisa Cantrup • Communications specialist

"What always struck me about Charlie was his quiet strength and how he treated everyone with the same respect, no matter who they were. Some of my most cherished memories are the moments when Charlie would take time to engage in small talk with me about our mutual love of photography. Growing up poor in Detroit, I could never have imagined having conversations with someone of his stature. Yet, Charlie made me feel like an equal, and those moments meant the world to me."

Derrick Key • Engineered systems technician

"Charlie and I once traveled together to Omaha. Our flight back was delayed, and Charlie and I sat in the airport for several hours as we waited. I remember talking about photography, what books we were reading, our families, and work. The airport was fairly quiet, and I remember how much I enjoyed talking with Charlie that evening about anything and everything. His kindness and genuine interest in people at the Lab and in Los Alamos was incredibly evident, and we all benefited from this."

–Brad Beck • Project-program director, Partnerships & Pipeline Office

"I had the privilege of knowing Charlie McMillan when he and I were both employed at Livermore. Sometime in the early '90s, he and I were on the same trip, and we shared a ride home from the San Francisco airport. At the time, Charlie was group leader of the B Division code group, and he emphasized to me that part of his management philosophy was, 'You take care of your people.' That impressed me at the time, and as I witnessed his ascendance into management positions at Livermore and Los Alamos, I've often thought that philosophy was part of the reason."

–Alan Harrison • Scientist

"My first memory of Charlie was when I interviewed with B Division at Livermore while he was division leader. I was also interviewing with A Division, and Charlie tried to make his organization more alluring by saying, 'If you come work for B, you get to blow up stuff at Site 300.' I ended up choosing A, and it turned out that one of the projects I was on was the rare effort that required A Division physicists to blow stuff up with high explosives at Site 300. I would occasionally remind Charlie that I got the best of both worlds."

–Greg Archbold • R&D engineer

"Earlier in my career I briefed Charlie several times, and I was always impressed with how engaged he was. It must be hard to be 'talked at' constantly as Lab director, but Charlie made it clear that he was always interested, engaged, and inquisitive about the topics brought to him. He asked the best questions of any high-level manager; he always went straight to the point and made it clear he was not just aware of the broad issues, but that he had a very deep understanding of both the physics and the way we do our work. I look at Charlie as the type of leader that I aspire to be: caring about the people first, capable, organized, and supporting the institution."

–Leslie Sherrill • X Theoretical Design deputy division leader

■ In June 2014, Microsoft co-founder Bill Gates visited Los Alamos. Here, McMillan and Gates stand in front of the Army Navy E Flag that was presented to Project Y personnel in October 1945.

"New to our neighborhood, my wife and I were walking our dog when we passed the McMillans, who were working in their garden. Charlie was quick to engage in friendly conversation and invited us in to check out his organ. It was not only his musical talent that impressed me but also his brilliant technical mind. Charlie had developed this software for his organ to make it sound just like pipe organs in different cathedrals around the world. Here was Charlie sitting behind his modest organ surrounded by electronic equipment, amplifiers, and speakers, and the sound was that of a full-scale cathedral. Leaving Charlie's home that evening, my wife and I had a greater appreciation for organ music, and a wonderful feeling of meeting new friends."

–Stein Sorbye • Nuclear facilities engineer

"He was a great mentor; one of the best I've had. Some of my leadership and relational style flows directly from his impact on me."

–Jimmy Fung • Director, Integrated Physics Codes

"I didn't know Charlie personally, but I knew his voice. I worked on the new hires team, and every Monday it was his voice that welcomed the new hires to the Lab in the orientation video. It was his voice and words that provided inspiration and an excitement that came with starting a new job and career at Los Alamos. I am so thankful for his wise words and the commitment he made me feel every single week."

–Landon Harrison • Talent acquisition specialist, Human Resources

"Charlie didn't know me well, but I operated one of his secure rooms for a while. Well, one afternoon I was opening the room, which includes many steps. I was in the middle of the process when I felt someone behind me. There he was—just about gave me a heart attack! He was very nice and said he was trying to be quiet so I could concentrate. We both had a great laugh together."

–Ted Stahl • Security specialist

"I used to work as a background investigator. My first week of investigating solo, I had a meeting with Charlie. I had no idea I was interviewing the Lab director. I am sitting in this huge office with all these windows, and I ask him what his job title is. He chuckles and says director. I had interviewed a lot of different directors that week, so I continue to question him. Director of what? He chuckles again and says director of Los Alamos. I was as red as a tomato, but he was very gracious, and I really admired him for that. That was my only encounter with him, but it gave so much insight to the kind of person he was."

–Adrianna Martinez • Research technician

"I'll always remember a wonderful dinner Charlie hosted at his home. His warmth and generosity were evident in every detail of that evening. It wasn't just a meal; it was an experience filled with laughter, connection, and the kind of hospitality that made us all feel truly valued. His legacy of kindness will continue to inspire us, and his presence will be deeply missed."

–George Steinkamp • Program manager

"I was performing in a concert that Charlie was recording. He had his equipment set up including a microphone 10 feet up on a tripod and his cell phone at the base of the tripod. Sometime during the middle of the concert, Charlie's phone went off. Of course, everyone knew who Charlie was and he blushed with embarrassment and quickly turned off his phone. A lighthearted moment showing that even Lab directors make simple mistakes."

–Jeremy Conlin • Safety Basis manager

"When Charlie moved to Los Alamos, he established Friday office hours during which any staff member could schedule a short meeting with him. I took advantage of those time slots several times and was able to get to know Charlie before my later management interactions with him. I have fond memories of his direct engagement in those meetings between staff scientist and senior leader. He was keen to solicit my perspective, share his, and ultimately work towards improving our Laboratory. Years later, as I became a manager and briefed him on several topics, I observed those same traits. Charlie was a leader, mentor, and kind person."

–Erik Shores • Scientist

"Just two days before we lost Charlie, I had the gift of working nearly the entire afternoon with him on a project. In an effort to help me and my team reduce our nervousness of presenting our work, he told us about how when he was a child and he got nervous, his foot would start to shake up and down uncontrollably. He reflected on his first piano recital when he was so nervous that he was unable to work the pedals on the piano. He eventually got over his nervousness by practice. We were all surprised by this story, as he was so incredibly polished in his presentation style. It resonated with us and allowed us to accept our nervousness and move on."

–Chuck Mielke • Scientist

"It was a great honor to work for Charlie. He was kind and funny and the first director to understand and champion the value of emotional intelligence. My career at Los Alamos, including the opportunity to be a group leader, would not have happened if it wasn't for this amazing man who understood that reading people and knowing what motivated them and made them feel valued was as valuable as knowing a complex formula, solving a physics problem, or doing great research."

–Michelle Silva • Technical project manager

"As a fire-certified archaeologist, I supported fire suppression and fire-break construction activities to prevent damage to the Lab's cultural sites during the Las Conchas wildfire. It was Charlie's first month on the job, and I don't remember if he ever went home during the peak of the crisis, I think perhaps he slept at the Emergency Operations Center and wore the same clothes. It was a very stressful time for those of us working during the emergency evacuation of the town and the closure of the Lab, but I was so impressed with his calm and confident leadership through it all."

Ellen McGehee • Historian

■ McMillan often traveled to various military bases and service academies. "We spent a great deal of time talking with the men and women who have day-to-day physical custody of the weapons that we've designed here at Los Alamos," says Jon Ventura, who was McMillan's executive advisor for many years. Here, McMillan is at the United States Military Academy.

■ McMillan at ground zero of the Trinity test.

"I once had the opportunity to visit Trinity site with Charlie. That was one of the most memorable days of my career. Charlie had never visited Trinity but felt it was his duty as director to make the pilgrimage on the eve of the test's 70th anniversary. I was able to take Charlie's photograph (pictured above) at ground zero in the same place where his predecessor, Robert Oppenheimer, once stood. Charlie took a photograph of me in the same place, and gave me signed prints of both images. He was a wonderfully gifted photographer, and a wonderfully thoughtful person. Charlie faced great challenges during his time as our leader, and he handled those challenges with dignity, integrity, and energy. I know of no one who could have done a better job."

Alan Carr • Senior historian ★

ANALYSIS

STEPPING BACK FROM THE NUCLEAR BRINK

Los Alamos Division Leader John Scott talks nuclear weapons policy.

In a recent episode of *Talking Policy*, a podcast from the University of California's Institute on Global Conflict and Cooperation (IGCC), Los Alamos National Laboratory physicist John Scott discussed all things nuclear weapons with former California Governor Jerry Brown and Alexandra Bell, Deputy Assistant Secretary for Nuclear Affairs in the Bureau of Arms Control, Deterrence, and Stability at the U.S. State Department. The conversation was moderated over Zoom by IGCC Associate Director Lindsay Shingler.

In addressing his decision to participate in "Stepping Back from the Nuclear Brink: a *Talking Policy* Roundtable," Scott, who leads the Laboratory's X Theoretical Design division, says now is the time to have this conversation. "During the Carter and Reagan administrations, there was so much conversation about nuclear weapons," he remembers. "And now there isn't—but it's not like they've gone away. I want to engage on these topics because I think there needs to be a real conversation as a country about what we are going to do and what we are going to advocate for."

Below is a condensed version of the episode. Scott's comments have been edited for clarity and length.

SHINGLER: You don't have to be an expert in nuclear weapons to know that concerns about them seem to be growing. Some influential voices are saying that we're entering a new, extremely dangerous nuclear era that will lead to an arms race. And others say that the dangers are greatly exaggerated. John, what about you?

SCOTT: Nuclear weapons were a big concern in the '80s and '90s, then 9/11 happened. We had two decades of what I'll call a focus on terrorism, and now that we've focused away from that, we've come back to it. We have China on the rise with their weapons. We have North Korea. And those situations are different today than the '80s and '90s in the sense that now we have this kind of three-near-peer situation, which is unfamiliar to everybody who's kept track of nuclear weapons throughout their history. And so, I think that is the challenge that we face today.

SHINGLER: John, as the nuclear scientist in the room, could you help us establish some basic facts about nuclear weapons, like how many nuclear weapons are there in the world? How many countries have them? And remind us, what do nuclear weapons do? What makes them different from other weapons?

SCOTT: So, there are eight declared nuclear states. The United States, Russia, China, France, the U.K., India, Pakistan, and North Korea. In the middle of the 1980s, there were about 70,000 weapons total across all those who have them. Today, there's about 12,000. The vast majority of the weapons that exist today belong to the United States and Russia. China has approximately 500, and the reports are that they're building up to 1,000 by 2030.

Nuclear weapons have been used twice—during World War II, against Japan. Those were Little Boy, used against Hiroshima, and Fat Man, used against Nagasaki. Their ability to destroy was quite evident when used. You had a couple hundred thousand deaths between those two events.

Nuclear weapons derive their explosive power from nuclear reactions, as compared to conventional weapons that derive their power from chemical reactions. The easy way to think about the energy difference between the two is that the energy release in a nuclear reaction is about 50 million times that of a chemical reaction. So, just on a per reaction basis, that's 50 million times more energy. That gives you a feel for the difference in power. That's a huge difference.

Lastly, there have been many technical advances since World War II; those allow us to make nuclear weapons that are much more destructive than the ones that were used at Hiroshima and Nagasaki.

SHINGLER: What do you think about the idea that nuclear weapons have, in some sense, secured the peace?

SCOTT: I think the idea largely worked when it was just the United States and the Soviet Union. But I'm more concerned as more countries get nuclear weapons. The risk increases because the complexity of the situation is larger and the unpredictability is going up. Even in a three-way race—between the U.S., China, and Russia—the U.S. will always have less than the other two combined. That brings to light the importance of arms control, and how you're going to need people at the highest levels of the government to be talking about this. That is going to be the way to make the situation better—everybody coming to the table.

SHINGLER: I want to ask about modernization. There's a strong effort underway to modernize America's nuclear arsenal—everything from updating the design of nuclear weapons, strengthening the delivery systems, building new facilities and, of course, increasing the number of weapons. There are strong voices for this and strong voices against this. Do more and better weapons make us safer, or do they make us all more vulnerable?

SCOTT: So let me restate your question a little bit, because I want to clear up what modernization might mean. Just because the weapon's being modernized doesn't mean it's becoming more destructive. Many of the weapons that are in the stockpile were built when I was a teenager or in elementary school. And if you think of the electronics and technology at that time, as those components age, they need to be replaced.

When you modernize a nuclear package, you aren't necessarily increasing its yield or making it more powerful. This is about modernizing in the sense of ensuring that they will work as we expect them to when we need to use them. Now, along with that could come delivery vehicle improvements. You can get more accurate, and that could lead them to being able to hit a target more adeptly, which will lead them to be more effective.

Does it make the world a more dangerous place? Just because we have modernized weapons to bring them up to technology today, we're not changing the capabilities in the stockpile. We are trying to update what we have. I argue that isn't necessarily changing things significantly in terms of the calculus that's involved. Nuclear weapons are still nuclear weapons. They're still very destructive, and that has always existed since nuclear weapons have existed.

SHINGLER: There are so many pressing challenges in the world. Can people be faulted for not spending their time thinking about nuclear weapons?

SCOTT: Figuring out what piece you want to grab onto first is tricky because they are interconnected.

It is unfortunate that nuclear has kind of dropped out of the spotlight. I think the longer you get from events like Hiroshima and Nagasaki, the harder it is for people to relate because you're not able to talk to enough people who experienced that. It's going to be a challenge to communicate to people the power of the weapons that you're dealing with here. It is important that you discuss the potential for their use, trying to deter their use, or just having fewer weapons, and the importance of doing that.

SHINGLER: A world free of nuclear weapons: a pipe dream or an achievable reality?

SCOTT: I would love to not have a job like the job I have if that means we get to a world free of nuclear weapons. But in the meantime, we are going to have them, right? So long as they exist, the United States is going to have a safe, secure, effective stockpile. What does that mean? That means that we need people who can do that job well, right? In my job, as the lead of the weapons-physics designers at Los Alamos, I'm always on the hunt for finding good technical people who are willing to spend their careers working on these things. This is a very challenging scientific topic. Having the awareness of the issue will, in my opinion, help me recruit people to allow the United States to maintain the stockpile that we have, and keep it safe, secure, and effective until we get to that point in time where it is no longer needed.

I work on these things every day, but boy, I do not want to see one be used because that is going to be a bad day. A day that none of us are going to forget who are alive at the time, and it's going to change the world when it occurs. But until we get to the point where we don't have these anymore, I'm just trying to make sure that we do the job that we are asked to do for the nation and in terms of maintaining our stockpile.

SHINGLER: For many of us, this subject provokes a lot of anxiety and dread and fear about not having control. Can you tell us, where do you find reassurance?

SCOTT: No one should feel alone if they have anxiety towards nuclear weapons. The use of a weapon can have such grave consequences, and that generates a lot of visceral feelings in people.

I take comfort knowing that nuclear weapons haven't been used since World War II. To me, that indicates that there are responsible parties out there who are thinking about the dire consequences. Many people are trying to make sure that they are not going to be used again. And I believe that as the perceived risk of their use increases, you're going to see folks rising up and saying, "We can't use these in a war." We are going to find a way. The question will be how soon we can get there, and what will be that tipping point? ★

Author Ian Tregillis, pictured here in Beastly Books in Santa Fe, recently coauthored a paper with George R. R. Martin.

THE PHYSICS OF A FICTIONAL UNIVERSE

Scientist and author Ian Tregillis' latest work—co-authored by George R. R. Martin—combines science and fantasy.

BY IAN LAIRD

In his 23 years working as a physicist at Los Alamos National Laboratory, Ian Tregillis has published numerous academic papers that detail aspects of his research. But his latest paper, published on February 1 in the *American Journal of Physics* (*AJP*), was written off the clock. As its title suggests, "Ergodic Lagrangian dynamics in a superhero universe" has nothing to do with Los Alamos and everything to do with Tregillis' side hustle: fiction writing. As part of his hobby, Tregillis contributes to *Wild Cards*, a science fiction and superhero anthology series edited by George R. R. Martin, who penned the *Song of Ice and Fire* fantasy novels that were adapted into the *Game of Thrones* television series.

Wild Cards authors occasionally blog about the series, and in 2020 Tregillis introduced a mathematical model to evaluate the behavior of the Wild Card virus—the spread of which is the foundational event responsible for characters' superpowers. The model doesn't necessarily look at how the virus spreads through a group of people, but rather evaluates the different outcomes for a given group with the virus. With each blog post, the model became more elaborate. By March 2024, Tregillis' model was, he decided, too complicated for a general audience to enjoy.

"I realized it would literally be easier to write an article intended for a physics journal than to write another blog post," Tregillis says. "So, kind of jokingly, I said what if I tried instead to write an honest to goodness, peer-reviewed physics paper?"

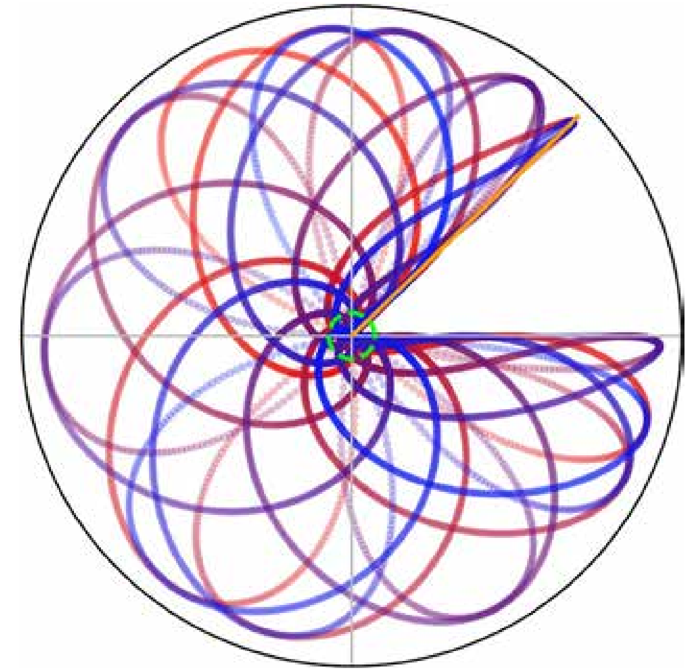
Martin seemed open to the idea, so Tregillis began writing. The finished paper, co-authored by Martin, was submitted to the *AJP* and published earlier this year. Note that *AJP* uses a double blind peer-review system so Martin's fame had no influence on the paper's publication chances.

Tregillis says the response to the paper has been positive. Although the content is perhaps above the head of the average reader (an article in *Forbes* stated: "Of course, 'simple' may not be the word many readers would use to describe a paper packed with equations and technical language like 'ergodic trajectory'"), Tregillis says his fellow *Wild Cards* authors have supported his endeavor. "I think they tolerate me and this weird thing I did. They sort of grit their teeth when I talk about it," he laughs. "Developing a physics and math model for *Wild Cards* is kind of inexplicable to normal people. They're like, okay, that's nice, Ian. Now please shut up and go away."

Looking back

That Tregillis is today both a physicist and a writer comes as no surprise to anyone who knew him as a kid. "In high school I had a mentor who asked me 'If you couldn't do physics, what would you do?'" Tregillis remembers. "And I said I think I'd be a writer."

But in his youth, writing was always on the back burner as Tregillis pursued degrees in physics and astrophysics from the University of Minnesota. During that time, Tregillis says he simply didn't have time to write. "I didn't really indulge that desire," he says. "I'm not a very good multitasker, and I felt like if I started indulging this side passion of writing, I would never finish my doctoral thesis."



In his recent paper, Tregillis builds a physics model to evaluate a critical event in the *Wild Cards* series.

Instead, Tregillis pursued a career in science. In 2002, he was hired as a postdoctoral researcher at Los Alamos, which allowed him to return to New Mexico, a place he had become enchanted with ever since taking a spring break trip to the state as an undergrad.

Unexpectedly, securing a position at the Lab allowed Tregillis to spend more time writing. "I didn't know anyone in Los Alamos, so I had this plan: I'll write evenings and weekends and try to hone my craft," he says. "In retrospect, it seems like a crazy thing to do."

By 2005, Tregillis was looking for avenues to take his writing to a more professional level. He submitted a writing portfolio to the Clarion Workshop—a six-week residential writing workshop at Michigan State University for fantasy and science fiction writers—and was accepted. However, Tregillis was simultaneously being considered for a staff scientist position at Los Alamos. Attending the Clarion Workshop would mean stepping away from the Lab at a critical juncture in his career. Fortunately for Tregillis, his boss was supportive and encouraged him to attend.

In Michigan, Tregillis got the break he needed. One of his instructors was Walter Jon Williams, a member of the northern New Mexico–based writers group Critical Mass. Williams invited Tregillis into the group. "Here I was, this aspiring writer starting from scratch with no idea that I'd moved into the middle, geographically, of this really vibrant community," Tregillis says.

Upon returning to New Mexico, Tregillis' career and hobby took off simultaneously. He was converted to a staff scientist at the Lab, and through Critical Mass, he got to know Martin and Kay McCauley, a literary agent who helped him start publishing his work. Since 2010, he's published seven novels and co-authored dozens of papers.

"I think writing has made me a better scientist—so much of being a scientist is communicating ideas," says Tregillis. He smiles and adds: "Whether I'm good at either pursuit is an open question." ★

ACHIEVEMENTS OF LOS ALAMOS EMPLOYEES

BETTER SCIENCE = BETTER SECURITY

Hardworking people—the Laboratory's most important asset—enable Los Alamos to perform its national security mission.

Stefano Gandolfi, of the Nuclear and Particle Physics, Astrophysics and Cosmology group, was awarded the Laboratory's Fellows' Prize for Research for his work on the nuclear many-body problem, which promises to have a great impact on previously intractable problems in nuclear physics. His work has implications for understanding nuclear properties and for neutron star matter research, which is important for basic science and adds to the efforts to extract fundamental physics from neutron star mergers.

Shizeng Lin, of the Physics of Condensed Matter and Complex Systems group, was awarded the Los Alamos Fellows' Prize for Research for his contributions to the field of skyrmion physics. His work has had an impact on quantum materials theory and has branched in multiple creative directions, including superconductors, magnetism, and topological defects such as vortices and skyrmions.

Denise Neudecker, of the Materials and Physical Data group, was awarded the Los Alamos Fellows' Prize for Research for her major nuclear data contributions. Neudecker was among the first to bring machine learning methods to nuclear data, guided her field toward more systematically quantifying sources of uncertainties, and contributed significantly to important nuclear databases.

Kary Myers, of the Space Remote Sensing and Data Science group, was awarded the Los Alamos Fellows' Prize in Leadership for creating inclusive communities that foster technical excellence, provide opportunities for early-career researchers, and enable multidisciplinary, multiorganizational collaborations. She established the Conference on Data Analysis to connect and showcase data-focused researchers and ideas from across the Department of Energy.

Greg Dale and Shea Mosby of the Lab's Accelerator Strategy Office were selected for the Department of Energy's Project Leadership Institute 2025 cohort. The yearlong professional development program is designed to cultivate a diverse network of successful Department of Energy project delivery practitioners.

Mark Davis, formerly the chief operating officer for Weapons Production at Los Alamos, is the Laboratory's new deputy director for Operations. Davis has over 40 years of experience in nuclear operations, including more than 30 years of strategic, operational, and policy experience for the Department of Defense and the Department of Energy.

David Dooley, former senior director of Defense Programs at the Lab, is now the associate Laboratory director for Weapons Production. Dooley has 27 years of leadership experience in stakeholder and workforce relationships, production, complex nuclear facility operations, research and development, decontamination and demolition, and environmental waste remediation and disposal.

As the new vice chair of the American Physical Society's Four Corners Section, Verena Geppert-Kleinrath helps support the professional development of scientists and college students in New Mexico, Arizona, Colorado, and Utah. Her four-year term began in October 2024. Geppert-Kleinrath is a deputy group leader for Dynamic Imaging and Radiography in the Lab's Physics division.

Garrett King and Evan Rule of Theoretical division received American Physical Society (APS) Dissertation Awards in Nuclear Physics. The annual award recognizes doctoral thesis research of outstanding quality and achievement, and recipients give an invited talk at the Fall Meeting of the APS Division of Nuclear Physics.

R&D engineer Kelsey Amundson was honored with the Young Member Excellence Award at the American Nuclear Society Winter Conference. Amundson conducts basic research in nuclear chain-reacting systems and benchmark evaluations for the International Criticality Safety Benchmark Evaluation Project.

Richard Feynman Distinguished Postdoctoral Fellow Isuru Ariyarathna earned a Wiley Computers in Chemistry Outstanding Postdoc Award. The program is organized by the American Chemical Society's Computers in Chemistry Division. Ariyarathna says his passion is "to discover and interpret chemical and physical behaviors of molecular systems beneficial for various scientific purposes."

Bade Sayki was named a "sPHENIX Hero" for her efforts in the operation of the high-energy particle physics experiment underway at Brookhaven National Laboratory's Relativistic Heavy Ion Collider. Results from sPHENIX (Super Pioneering High Energy Nuclear Interaction Experiment) will shed new light on the fundamental building blocks of matter and the physics that formed them in the microsecond after the Big Bang.

The Lab's contributions to forensic science and emergency management response were recognized with a Secretary of Energy Appreciation Award. Former Secretary of Energy Jennifer Granholm nominated the U.S. Department of Energy Forensics Operations team for the award for its rapid development of nuclear forensics collection capabilities amid the ongoing conflict in Ukraine.

Srinivas Iyer is the new associate Laboratory director for Chemical, Earth, and Life Sciences, which houses the Lab's Chemistry, Earth and Environmental Sciences and Bioscience divisions. It also manages the Applied Energy and Biological and Environmental Research programs. Previously, Iyer led the Laboratory's program office for the Department of Energy's Office of Science. ★

54 YEARS AGO

Commissioned in 1963, the Pulsed High-Energy Radiographic Machine Emitting X-Rays (PHERMEX) linear accelerator at Los Alamos National Laboratory was "designed and built not by nuclear physicists but by a group whose inherent professional interests lie in fluid dynamics, chemical kinetics, and extreme states of matter," according to a December 1964 article in *Physics Today*. During a PHERMEX experiment, such as the one pictured here in 1971, electrons were directed to a target, and the resulting burst of x-rays was used to make radiographs of a simultaneously timed explosion. By the time PHERMEX was decommissioned in 2004, more than 1,000 hydrodynamic experiments had been performed there. PHERMEX was the predecessor of the Dual-Axis Hydrodynamic Test facility—see p. 38 for more. ★

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THEN & NOW

In 1989 at White Sands Missile Range, Los Alamos scientists watched the Lab's suborbital rocket launch carry an ion accelerator into space, as part of an experiment called BEAR or Beam Accelerator Aboard a Rocket. With the first operation of a neutral particle beam accelerator in space, the BEAR flight demonstrated that accelerator technology could be adapted to a space environment. (Learn more on p. 48.)

In November 2024 at Spaceport America, Los Alamos launched a suborbital rocket carrying a payload of experiments and components for testing. The goal was to test how weapons systems and components perform in conditions similar to those seen in an intercontinental ballistic missile launch. Up Aerospace Inc., a space launch and flight test service based in Colorado, conducted the launch for the Lab's Stockpile Responsiveness Program (SRP), completing the SPR's fourth successful suborbital flight test. ★