LOS ALAMOS NATIONAL LABORATORY ◇ WINTER 2021

NATIONAL ★ SECURITY SCIENCE

THE PLUTONIUM ISSUE

Atomic number 94: A comprehensive history—81 years—of plutonium at Los Alamos and beyond.

Pit production explained: The plutonium cores of America's nuclear weapons are aging. Why is Los Alamos the best place to recycle them into new cores? And why now?

+ PLUS:

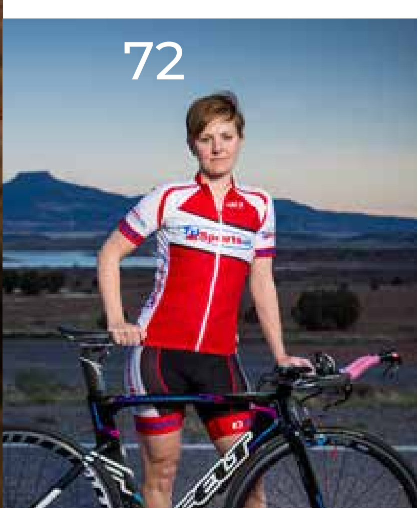
Los Alamos launches a payload from Spaceport America	A virtual visit from the U.S. Secretary of Energy	Harnessing star power at the National Ignition Facility

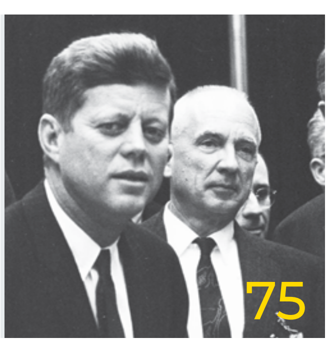
PHOTOBOMB

If an explosive is detonated on the ground, the resulting shock wave and fireball typically appear hemispherical. However, during a November 2020 experiment at the Nevada National Security Site, researchers detonated a 14-sided device that resulted in a spiked fireball and pyramidal shock wave. "Shock wave collisions within the device resulted in focused high-temperature jets—fireballs—directed from the center of each face," explains Steven Pemberton of Los Alamos National Laboratory, which led the experiment. "This led to the apparent asymmetry in the photo." ★

SCAN QR CODE WITH A SMARTPHONE CAMERA

Watch a video of this explosion.





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About the cover: Los Alamos National Laboratory is a world leader in plutonium research and development. The better scientists can understand plutonium's nuclear and chemical properties, the better they can predict its behavior. For example, the unique electronic structure of the pictured plutonium-gallium-cobalt alloy causes it to be superconductive. ★

THE PLUTONIUM ISSUE

Element 94 has a complex 81-year history and a starring role in Los Alamos' current mission to produce at least 30 pits—nuclear weapon cores—per year by 2026.

BY WHITNEY SPIVEY, EDITOR

Every so often, I talk to folks who've spent the bulk of their careers working in the Plutonium Facility (PF-4) here at Los Alamos National Laboratory. As Matt Johnson, Pit Technologies division leader, explains on p. 54, PF-4 is one of the safest places in New Mexico—the safety standards and security precautions are through the roof (and rightfully so—plutonium is radioactive). The average PF-4 employee must wear protective clothes, be scanned for radiation multiple times a day, and submit to regular psychological and drug testing.

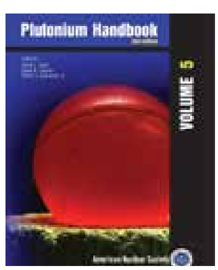
To an outsider, working at PF-4 might seem like kind of a hassle. But what I've learned over the years from talking to these long-standing employees is that they love working there. I am not exaggerating when I say that every single one of them uses the word "family" to describe their coworkers. It seems that working on a remote mesa-top in the middle of New Mexico at America's only plutonium facility fosters a comradery that runs deeper than the average work-place relationship.

It's a magic combination of great coworkers and mission-specific work that really allows people to enjoy their jobs at PF-4. This work—for example, making plutonium pits for nuclear weapons (see p. 46) or fabricating plutonium heat sources to power rovers on Mars—is critical to America's national security and our scientific understanding of the universe. The work has purpose and consequences, and its significance is not lost on the people who clock in at PF-4 every day.

PF-4 work also has a legacy—a history—of which workers are proud to be a part. Here at Los Alamos, plutonium's past, present, and future is nearly synonymous with the Laboratory's past, present, and future. As the nation's Plutonium Center of Excellence, the Laboratory has been—and will continue to be—the place for cutting-edge plutonium research and development. (See p. 22 for a comprehensive timeline of plutonium history.)

Plutonium is the theme of this issue of *National Security Science*, and you'll find plenty of plutonium-related content. But you'll also find interesting reads about biofuel research (p. 10), detonators (pp. 8, 12, and 15), rocket launches (p. 60), and much, much more.

If you have any feedback on this or other issues of the magazine, please email magazine@lanl.gov. I'd love to hear from you just as much as those PF-4 employees enjoy going to work every day. ★



■ For a more in-depth, technical look at plutonium research and development, check out the *Actinide Research Quarterly* magazine and the second edition of the *Plutonium Handbook*, both produced by Los Alamos National Laboratory.

MASTHEAD

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National Security Science (*NSS*) highlights work in the Weapons and other national security programs at Los Alamos National Laboratory. *NSS* is unclassified and supported by the Lab's Office of National Security and International Studies. Current and archived issues of the magazine are available at lanl.gov/magazine. Unless otherwise credited, all images in the magazine belong to Los Alamos National Laboratory.

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LA-UR-21-31263

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NSS STAFF SPOTLIGHT

▼

The *NSS* team—Whitney Spivey, Virginia Grant, Brenda Fleming, and Weston Phippen—stands inside Jumbo at White Sands Missile Range in New Mexico. Jumbo was built (but never used) to contain plutonium in the event that the Trinity test failed. For more on the Trinity test—the detonation of the world's first atomic bomb—see the summer 2020 and summer 2021 issues of this magazine. For more on Jumbo, see p. 28.

■ Los Alamos Director Norris Bradbury (right) in January 1965, on his way to view an experiment.

LETTERS

THE ART OF THE MORATORIUM

During the Cold War, nuclear testing stopped and started according to the changing of the political tides.

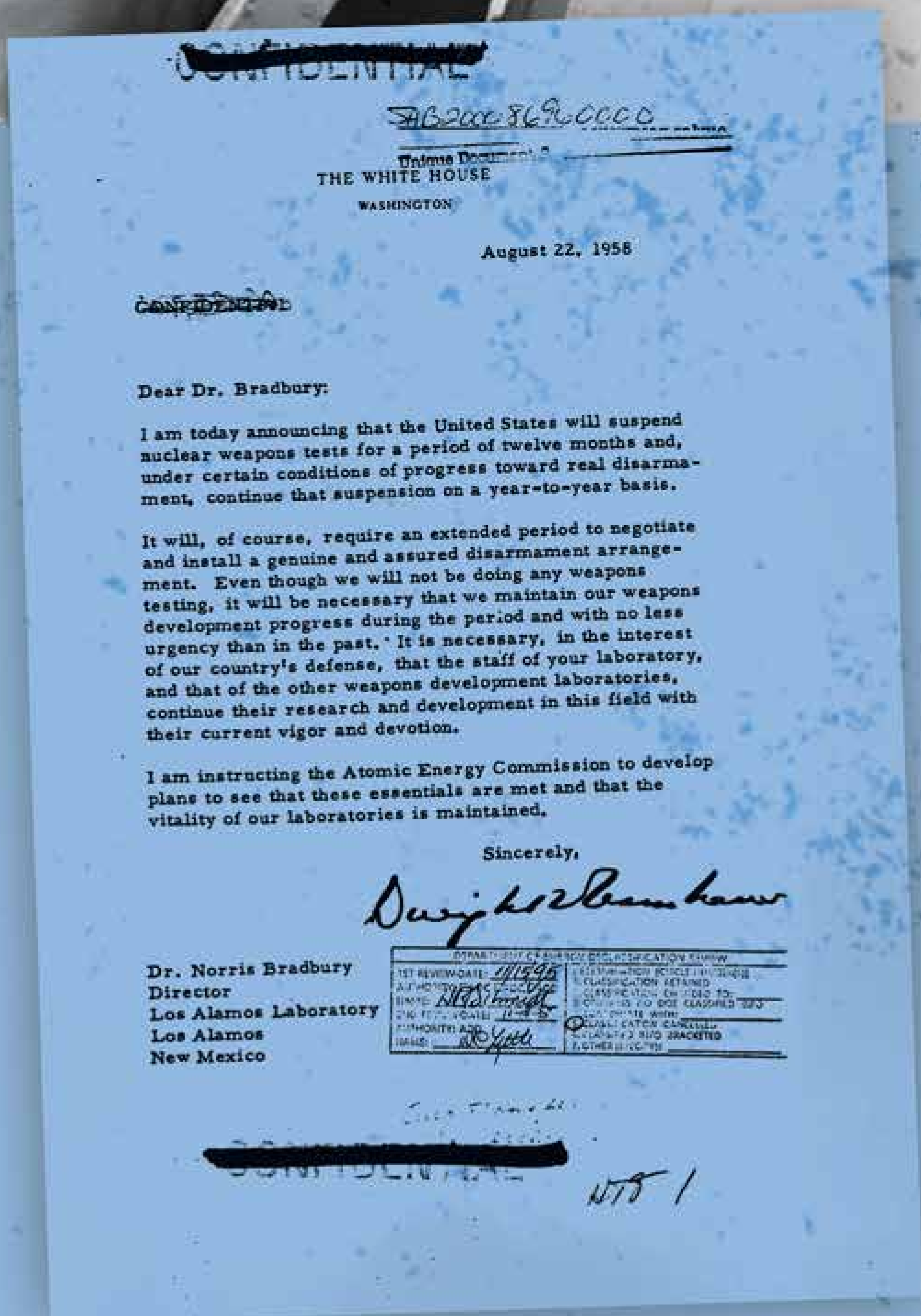
BY VIRGINIA GRANT

In 1958, President Dwight D. Eisenhower sent a letter to Norris Bradbury, then director of Los Alamos Scientific Laboratory, instructing the Laboratory to halt all nuclear testing. This was the first in a long sequence of moratoriums—periods during which the United States and the Soviet Union agreed to end nuclear testing.

This moratorium was a preliminary step toward of nuclear weapons altogether. But the hold on testing did not mean a hold on weapons development. In fact, the president instructed Los Alamos to keep going on all research and development related to nuclear weapons.

The practice of moratoriums on testing has carried beyond the Cold War. The United States conducted its last test in 1992, and in 1996 the U.S. signed (but has not ratified) the Comprehensive Nuclear-Test-Ban Treaty, which includes an agreement not to conduct any nuclear tests. ★

For more on the end of nuclear testing, see "Bridging Divider" in the spring 2021 issue of this magazine.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THE WHITE HOUSE
WASHINGTON

August 22, 1958

[redacted]

Dear Dr. Bradbury:

I am today announcing that the United States will suspend nuclear weapons tests for a period of twelve months and, under certain conditions of progress toward real disarmament, continue that suspension on a year-to-year basis.

It will, of course, require an extended period to negotiate and install a genuine and assured disarmament arrangement. Even though we will not be doing any weapons testing, it will be necessary that we maintain our weapons development progress during the period and with no less urgency than in the past. It is necessary, in the interest of our country's defense, that the staff of your laboratory, and that of the other weapons development laboratories, continue their research and development in this field with their current vigor and devotion.

I am instructing the Atomic Energy Commission to develop plans to see that these essentials are met and that the vitality of our laboratories is maintained.

Sincerely,

Dwight D. Eisenhower

Dr. Norris Bradbury
Director
Los Alamos Laboratory
Los Alamos
New Mexico

[redacted]

INFOGRAPHIC

THE INTERSECTION

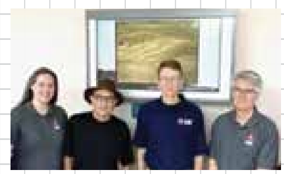
Science and culture converge in Northern New Mexico —and beyond.

Sara Del Valle and Bette Korber (pictured) are featured in *Vaccination from the Misinformation Virus*, a PBS documentary that explains why vaccines are safe and important. Photo: PBS.com

In June, Los Alamos, New Mexico, was named among the friendliest small towns in the United States by TravelAwaits. That same month, Los Alamos was named the healthiest community in America by *U.S. News and World Report*. Photo: Los Alamos County

On September 30, Los Alamos County premiered *Adventures of a Mathematician*, a film about Manhattan Project physicist Stanislaw Ulam. The movie played at historic Fuller Lodge, which Ulam would have likely frequented during his time in Los Alamos.

Los Alamos mathematical epidemiologist Sara Del Valle is featured as a character in a science mystery adventure called *The Case of the COVID Crisis*. In this book for third- to sixth-graders, two teens travel through space and time to unravel the science, math, and history behind the pandemic.



For years the "News from Mars" screen on Central Avenue in downtown Los Alamos showed images from the Curiosity rover. Now, pedestrians can enjoy images from the Perseverance rover, which landed on Mars in February. Los Alamos scientists designed instruments on both rovers. Photo: Los Alamos Daily Post

CULTURE

SCIENCE

QUOTED

> "Think of the DPAEs as the Olympics for national defense. As you know from Tokyo, not everyone makes the cut, and the competition is always tough. Like elite athletes, you remained undaunted and persevered to ensure America is never without a safe, secure, and effective nuclear deterrent."

—U.S. Air Force Brigadier General Stacy Jo Huser, principal assistant deputy administrator for Military Application at the National Nuclear Security Administration, who presented plaques to the Laboratory's winners of the 2019 Defense Programs Awards of Excellence (DPAEs). ★

MAJOR MILESTONES FOR THE W88

After a nearly 10-year update, the warhead is stockpile-bound.

BY KEVIN ROARK AND WHITNEY SPIVEY

The W88 warhead, which can be launched on missiles from Ohio-class submarines, entered the nuclear weapons stockpile in 1988. Deployed now for more than 30 years, the warhead has been updated to maintain its current state of readiness.

More specifically, the W88 has undergone an alteration (alt), which includes changes to the weapon's systems, subsystems, or components. An alteration is a limited-scope change that affects the assembly, maintenance, and/or storage of a weapon. An alt may address identified defects and component obsolescence, but it does not change a weapon's operational capabilities.

The W88's alteration—officially called the W88 Alt 370—began in 2012 to replace the warhead's arming, fusing, and firing subsystem and to include safety enhancements, such as a lightning arrestor connector. Sandia National Laboratories and Lockheed Martin were the primary organizations involved in the alt. Los Alamos National Laboratory, which had designed the original warhead in the 1980s, had a minor role.

But then, in 2015, the Nuclear Weapons Council expanded the scope of the alteration and asked Los Alamos—the design agency for the weapon's nuclear explosive package—to become more involved. The Lab would be responsible for "CHE refresh activities," which means that the conventional high explosives (CHE) and related components in the weapon's nuclear explosive package would be replaced.

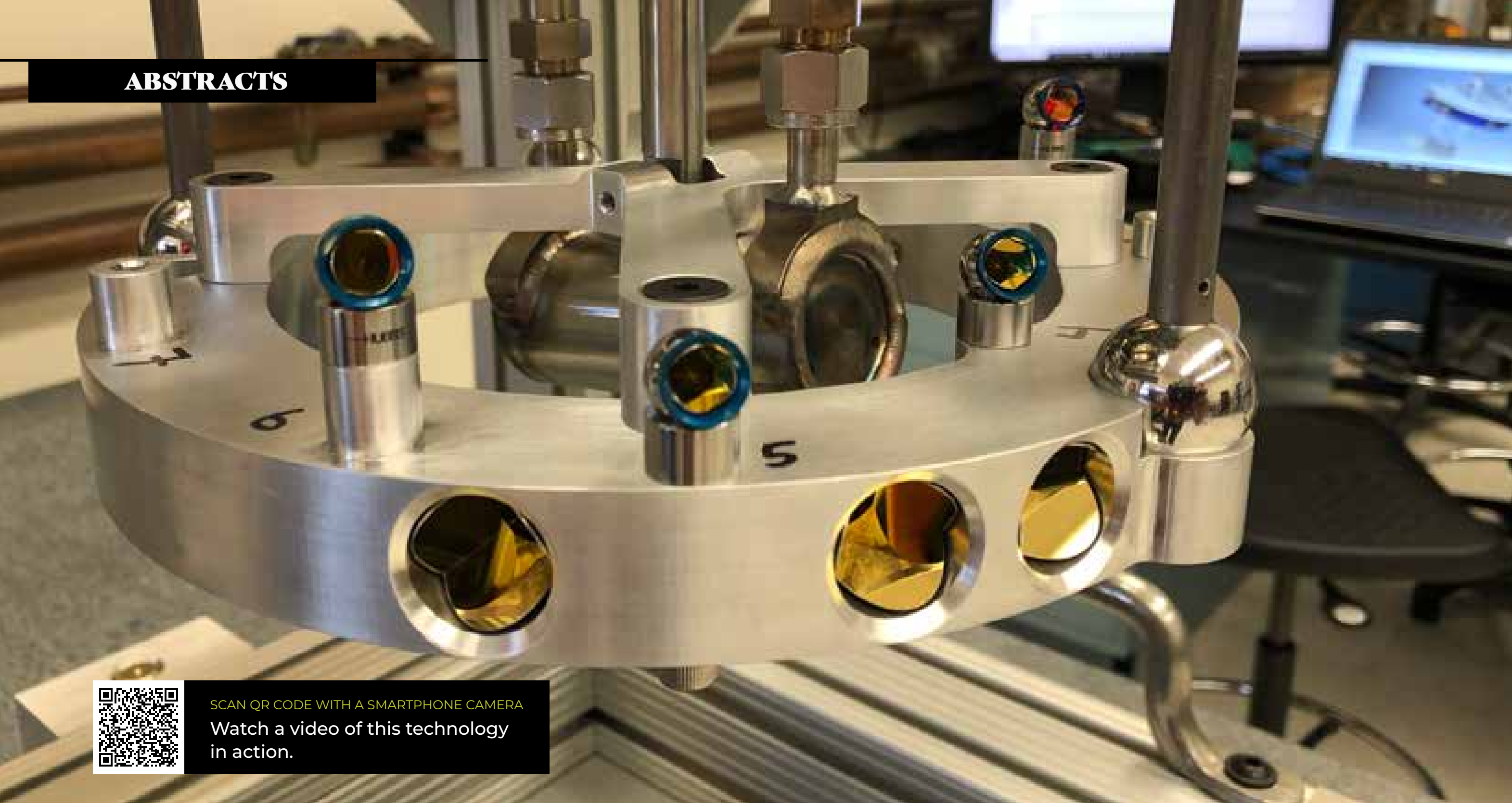
"The scope added into the ongoing Alt 370 project was significant, and there was no schedule flexibility to accommodate this effort," says James Owen, associate Laboratory director for Weapons Engineering. "Nevertheless, we were confident that challenging Los Alamos to find innovative ways to accelerate our work—while maintaining the utmost in technical standards, quality, and project management—would result in remarkable success for the W88 and the nation's deterrent."

In July 2021, the first production unit (FPU) was delivered. In the FPU phase of the nuclear weapons life cycle, all weapons components have been produced through qualified processes; all the necessary qualification testing, engineering analysis, and physics certification activities have been completed; and the first production unit has been built at the Pantex plant, near Amarillo, Texas. In essence, all the processes required to produce the weapon are qualified and exercised.

In October 2021, the W88 Alt 370 successfully passed the Design Review and Acceptance Group review and is now a standard stockpile item, which means that the updated W88 warhead will gradually replace the older W88 warheads in the stockpile.

"I am extremely proud of the performance of our Los Alamos team; we rose to the challenge of supporting the deterrent by completing a large body of work in nearly record time, which is quite an accomplishment," says Rob Bishop, who leads the Lab's Stockpile Modernization group, which was largely responsible for the alteration. "The W88 Alt 370, with the CHE scope, will allow the W88 to continue to be reliable and effectively support the deterrent for future decades." ★

■ Dolphins lead the way as an Ohio-class submarine returns to Naval Submarine Base Kings Bay.
Photo: U.S. Navy/James Kimber



▲ A new spallation target assembly is part of the WNR facility upgrade.

TECHNOLOGY

BETTER MEASUREMENTS FOR BETTER PHYSICS

Upgrades at Weapons Neutron Research facility enable new levels of precision.

BY BRIAN KEENAN

With a half-life of only six days, the radioisotope nickel-56 does not reward procrastination. In preparation for an experimental campaign with the short-lived material, a Los Alamos National Laboratory team of scientists and engineers optimized a neutron beam transport system at the Weapons Neutron Research (WNR) facility. The upgrade, which took 18 months, brings the facility up to a best-in-class standard and allows future experiments on a range of materials.

The team upgraded the facility's spallation target, a tungsten slug that generates a neutron beam source from within a 40-foot concrete crypt. When combined with the modern metrology infrastructure installed at the facility, the target's position deep inside that crypt can now be measured with laser trackers, allowing the target's absolute position to be measured to +/- 68 microns with 95 percent confidence. "Being able to directly measure the spallation target with laser trackers is a huge development for WNR," says R&D engineer Brad DiGiovine of the Lab's Nuclear and Particle Physics and Applications group. "You need to know where these instruments are, and you can't just go in there and look."

In a WNR experiment, materials, such as nickel-56, interact with a neutron beam after the neutrons have traveled down a flight path in the crypt. A newly designed brass shutter insert and advanced collimation system in the flight path form the neutron beam and keep down unwanted interactions with background neutrons. At the end of the flight path, another new instrument, the "hot" low-energy neutron-induced charged-particle chamber, is where researchers measure a material's nuclear properties as it interacts with the neutron beam.

"This kind of upgrade had never been done at this facility before," DiGiovine says. "It's hard to corral neutrons in a beam to get them to go where you want. You really need to precisely constrain the allowable neutron trajectories to keep background down while maximizing the amount of neutrons in the material sample."

In November 2020, the more precise neutron beam system measured nickel-56's cross-section (the probability that certain particles will collide and react in certain ways). In nature, nickel-56 is an abundant "seed nucleus"—the starting point for a fusion chain reaction—so better understanding its cross-section is useful for basic science applications and perhaps for researchers whose work focuses on similar, human engineered, fusion chain reactions.

Effective neutron transport relies on precision, and the researchers executed the alignment of the entire experimental system to within 10 microns—approximately one-tenth the thickness of a piece of paper—of the equipment's ideal position. Although perfection is unattainable, that excellent level of precision attained can be applied to future experiments in a variety of areas.

"The WNR upgrades allow us to optimize our experiments," says physicist Shea Mosby. "You want your calculation tools to have the best possible physics in them, for whatever it is you are doing. The entire realm of nuclear technology benefits when we get one reaction improved." ★

ASK AN ASSOCIATE DIRECTOR

Dave Eyler, associate Laboratory director for Weapons Production, answers three questions.

BY MAUREEN LUNN

When a high school counselor recommended that Dave Eyler consider going to college at the U.S. Naval Academy, that's exactly what he did. "I liked the idea of serving the country and getting a good education at the same time," he remembers. "I didn't know anything about submarines, but traveling around the world was definitely going to be different than my hometown of Monroe, Michigan."

Eyler went on to spend 29 years in the Navy. In 2018, he was hired to lead the Weapons Production associate directorate at Los Alamos National Laboratory. Eyler is responsible for the 1,300 employees who develop and produce plutonium pits (see p. 46); nonnuclear weapons parts, such as detonators; and other national security components, including those for deep space missions.

Here, Eyler talks to *NSS* about his time at the Laboratory.

What drew you to Los Alamos?

Los Alamos has a certain gravitas and history. And it's in a part of the country I'd never lived in before. Like the Navy, the Laboratory is national security–focused. The work is really interesting. I'd worked around nuclear processes, nuclear facilities, and explosives my entire life, but Los Alamos is different in that here we're actually manufacturing with plutonium and manufacturing explosive components.

What's a strength of Weapons Production?

There are a lot of hardworking, dedicated people who are figuring out how to work at different stages of production. I'm seeing people learn from each other about how to manufacture, how to make process improvements, and how to scale up.

For example, in the Detonator Production division, we're producing at scale. In the Plutonium Facility, we're ramping up production in the heat source arena for NASA and other customers. When it comes to plutonium pit production, we're in the development phase, proving our processes. A lot of people believe that we're only thinking about pits. I won't deny that we think a lot about pits. But we do a lot of other things that are important, too. We need to keep them all in balance.

What is the Laboratory's biggest strength?

Our technical expertise. There's a lot of brain power here. Our other strength is leveraging that expertise and using it to advance the interests of the United States, from a national security perspective and in other scientific areas. When it comes to nuclear materials, you can do things at Los Alamos that you can't do anywhere else. It's a very dynamic and interesting place to work. Is it hard? Yes. Can it be frustrating? Yes. But nothing worthwhile is easy. The people who work here are here because it's a really worthwhile mission. ★

Eyler retired from the Laboratory in October 2021. "Dave Eyler's leadership has been instrumental in creating improvements in our conduct of operations," says Bob Webster, deputy Laboratory director for Weapons. "But most importantly, he provided that leadership with deep appreciation and respect for his staff."

DETONATORS

A LASER FOCUS ON SAFETY

Optical detonators will be less susceptible to accidental detonation.

BY VIRGINIA GRANT

Los Alamos, New Mexico, where the bulk of the nation's work is done on the development and manufacturing of detonators, is an area with a lot of lightning. To make detonators safer even when the sky lights up, scientists at Los Alamos National Laboratory are working to create optical detonators—detonators that are initiated by lasers.

Traditional high-energy detonators are electrically initiated and, although extremely safe, require thousands of volts to work. Care must be taken to ensure they can't be triggered by other electrical sources, which can range from lightning strikes to human electrostatic discharge, such as carpet shock. Now, a team at Los Alamos is working to move away from detonators that are susceptible to electrical insults—things that can set off detonators through an accidental electrical stimulus.

The goal is to replace electrical energy with optical energy, that is, laser light.

"We are developing optical detonators to improve the safety and efficiency of explosive experiments," says Mike Bowden of the Laboratory's Detonation Science and Technology group. "The team is developing a complete optical initiation system, including the laser that provides the optical signal, the electronics that power the laser, fiber optic cables to transport the optical signals from the laser to the detonator, and the optical detonator itself."

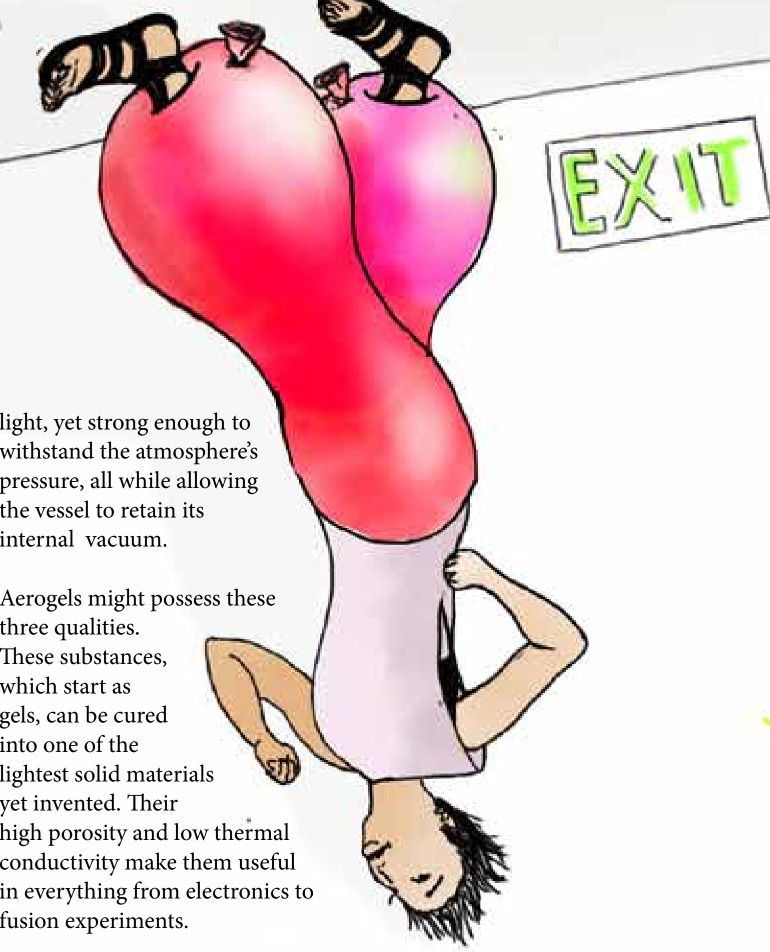
Because Los Alamos is both the design agency and the production agency for detonators, the Laboratory has been able to efficiently design, manufacture, and test several prototype optical detonator designs for a variety of applications in science, engineering, and technology. ★

■ Lightning strikes above the main campus of Los Alamos National Laboratory.

BUILDING A BETTER BALLOON

Scientists are on the cusp of solving an age-old engineering problem.

BY JAKE BARTMAN



Would it be possible to engineer a pair of pants that enabled a person to walk upside down across the ceiling?

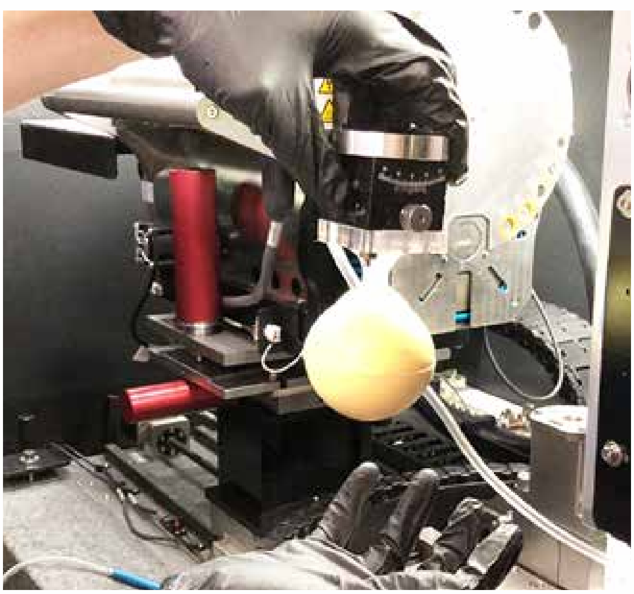
According to materials chemist Chris Hamilton, the idea proposed by an excited member of the public made such an impression on experts in the Engineered Materials group at Los Alamos National Laboratory that now any out-there idea involving aerogels—ultralight substances often used as insulators—earns the moniker "Project Pants."

However, a current Project Pants endeavor led by materials scientist Miles Beaux is anything but crazy.

Beaux's goal is to develop an aircraft that floats without heat or helium. The craft would be a hollow sphere containing a vacuum, which would make it lighter than the surrounding air—and thus able to stay aloft.

"There is a lot of skepticism about the idea," Beaux says. "Everyone says, 'That's never going to work.' But their ideas are always based on a misconception."

The concept of an air-buoyant craft was proposed as early as the 17th century, although certain technical challenges have always kept it on the ground. Such a craft would need to be sufficiently light, yet strong enough to withstand the atmosphere's pressure, all while allowing the vessel to retain its internal vacuum.



▲ One air-buoyant solid prototype clung to its vacuum chuck for more than a minute, supported by nothing more than ambient air pressure.

Aerogels might possess these three qualities. These substances, which start as gels, can be cured into one of the lightest solid materials yet invented. Their high porosity and low thermal conductivity make them useful in everything from electronics to fusion experiments.

Beaux first heard about aerogels while in graduate school. But it wasn't until he got to know Hamilton, an aerogel expert at Los Alamos, that he considered applying the substance to the air-buoyant craft problem.

Polyimide, the aerogel that Beaux and Hamilton are using for the project, has proven both stronger and far better at holding a vacuum than expected. One prototype adhered to its vacuum chuck for more than a minute after the pump was turned off, buoyed by its low density.

The project's current challenge lies in scaling its prototypes, which have ranged from lemon- to soccer-ball-sized, to the 1.4-meter-diameter sphere that Beaux expects a truly air-buoyant craft will require. Beaux and Hamilton have acquired a mold that should allow them to fabricate the prototype in a vacuum chamber.

If realized, an air-buoyant vessel might be kept aloft thanks to penny-sized vacuum pumps on its surface. Unlike helium balloons or other craft, the innate buoyancy of these new vessels means that they could be deployed cheaply and stay aloft indefinitely.

Air-buoyant crafts' potentially low expense and sustainable design means that they might be deployed en masse to form an atmospheric telecommunications network, which could help stabilize the energy grid's cybersecurity or bolster the United States' missile defense system.

Many technical hurdles remain before the project achieves its goals. But the concept of an air-buoyant craft is appealingly simple.

"There's a beauty in simplicity," Beaux says. "Buoyancy is a simple concept to understand. But people have a hard time believing it's possible." ★

■ Zhenghua Li conducts an experiment to quantify the renewable carbon content in a biofuel.

CLEAN ENERGY

BIOFUEL BETA

Fossil fuels are increasingly blended with biofuels—and getting the ratios just right requires technology developed by three national laboratories.

BY J. WESTON PHIPPEN

One day, all cars and trucks may run on electricity or hydrogen. But there are many years between now and that "one day." To help the country reduce harmful greenhouse emissions in the interim, many companies are developing ways to supplement fossil fuels with cleaner biofuels.

For example, many companies mix fossil fuels, such as gasoline, with ethanol, a renewable carbon-based biofuel derived mostly from corn. Ethanol is considered an energy-positive fuel—meaning the amount of energy to produce it is less than the energy it produces. But like fossil fuels, biofuels undergo a complicated refining process, and this is where the Los Alamos National Laboratory has stepped in to help.

"It's too expensive right now to build new refineries solely focused on biofuels," says Zhenghua Li, of the Lab's Earth System Observations group. "What we want to do is use existing refineries, and that requires understanding how much biofuel we can introduce into the co-processing system, and to do that we need to chemically track these biofuels."

Li's work focuses on chemically analyzing bio-fossil mixtures to ensure the percentage of renewable carbon fuel is what companies claim (so that they can receive a financial credit from the government), usually about 10 percent biofuel to 90 percent gasoline.

Often that biofuel is ethanol, but ethanol has a problem—as a derivative of corn or soy, it's also a valuable food resource. So, the National Renewable Energy Lab in Golden, Colorado, and the Pacific Northwest National Laboratory in Richland, Washington, are developing biofuels from carbon sources that would otherwise go unused—everything from forest overgrowth to human fecal waste.

Scientists use pyrolysis, or extreme heat, to refine these waste sources into hydrocarbon-heavy oil, which can be sent to a refinery and co-processed. However, scientists are determining the ideal conditions for co-processing these types of waste, and they still need to know how much of their original mixture ends up in the final product.

One way to do this is by measuring carbon-13, an isotope of carbon. Li devised a way to trace how much carbon-13 a waste source begins with and how much of the isotope remains after the refining and co-processing. Li has also proposed an entirely new, much more efficient way for companies to track these metrics themselves. Normally, renewable carbon tests are conducted through an accelerator mass spectrometer, a device used for radiocarbon dating, which is expensive, limited, and time-consuming. Li, though, is working on tracing these carbon isotopes using a device that's much more available, cheaper, and quicker—called an isotope ratio mass spectrometer.

Eventually, Li hopes these systems will be installed in refineries so that co-processed fuels can be characterized in real time. ★

QUOTED

"We can't get so caught up in delivery that we forget to innovate because we won't be able to deliver if we don't innovate."

—NNSA Administrator Jill Hruby, who visited Los Alamos on August 26 and toured the Lab's Plutonium Facility. She is pictured here (on the far right) with Actinide Material Processing and Power Division Leader Stacy McLaughlin. ★

PHYSICS

THE PRESSURE'S ON

Better understanding how materials behave in extreme conditions might unlock secrets of the universe.

BY J. WESTON PHIPPEN

Nathaniel Morgan and a team at Los Alamos National Laboratory are developing codes—complex mathematical equations—that will allow them to build a model to simulate, using supercomputers, how any material—any gas, plasma, liquid, or solid—behaves under any amount of pressure and heat.

"If we think about this more broadly," Morgan says, "we're concerned with solving the governing physics equations, which apply to all materials, to see how things move under intense pressure and energy."

High-energy density physics—the study of how materials behave under extreme pressures and temperatures—has been studied by researchers for decades. At Lawrence Livermore National Laboratory's National Ignition Facility (NIF), for example, scientists blast capsules of deuterium and tritium gases with a laser, trying to create a fusion reaction (see p. 20 for more). The codes that Morgan is developing could help in this pursuit because, using the resulting model, scientists would be able to simulate experiments using different amounts of gases before actually doing an experiment. If fusion is one day successful, scientists would better understand the origins of stars and planets and unlock a source of clean energy.

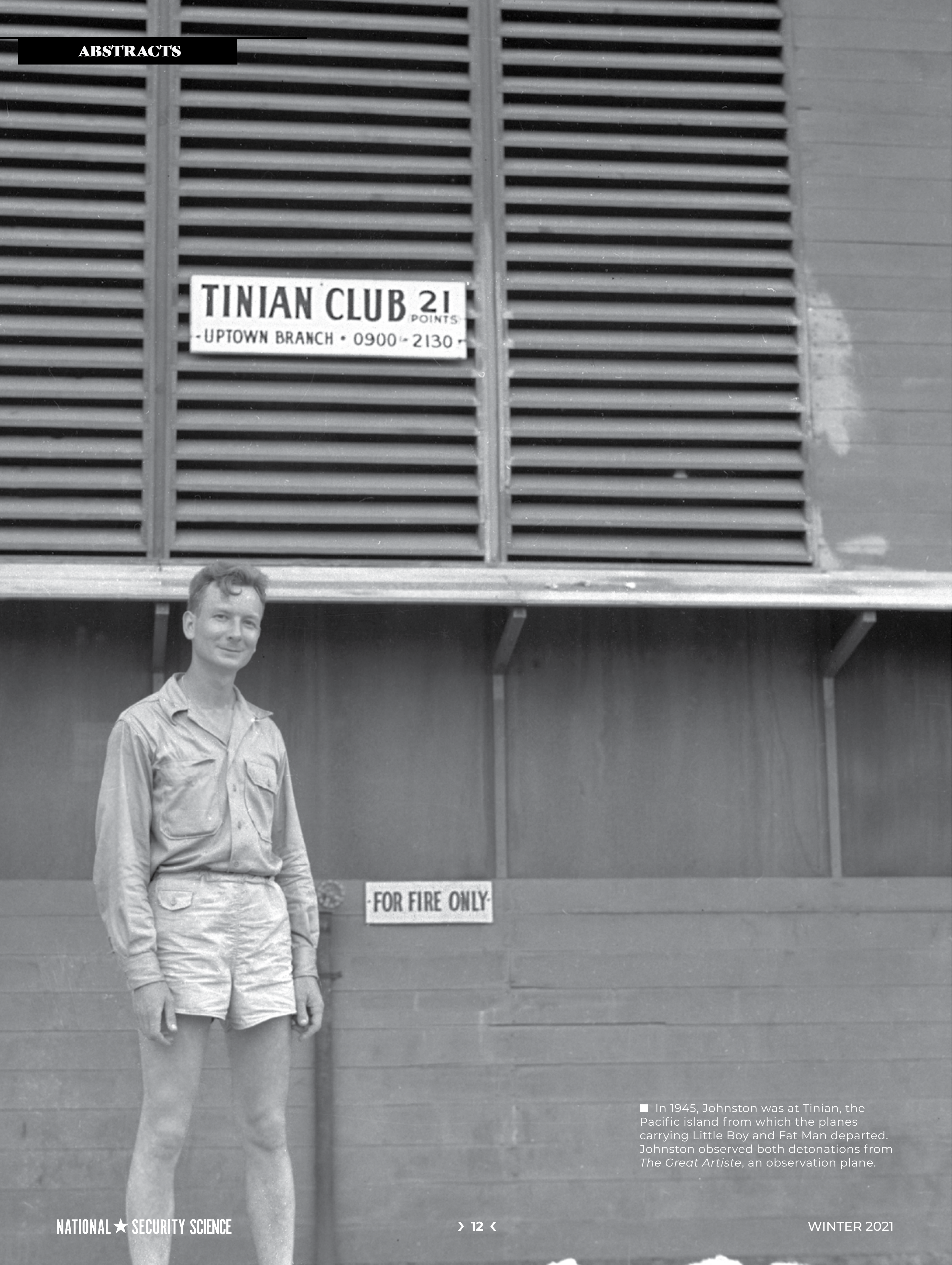
▲ Lawrence Livermore's National Ignition Facility is 10 stories tall and as wide as three football fields. Its main entrance is pictured here. Photo: LLNL/Jason Laurea

Models for materials that have uniform composition, such as gases, can be more straightforward because these materials tend to behave consistently. "It's difficult to model materials in the low-energy density physics realm that need to be more grounded in the theoretical nature of the material," according Evan Lieberman, a computational materials scientist who works with Morgan. "For example, metal is made up of a crystalline structure with specific orientations based on the manufacturing process. By accounting for this structure, we can simulate the effects of a variety of scenarios much more accurately."

A metal, perhaps the hood of a car, begins as a solid that resists deformation. Yet a collision can produce enough energy to make solid metal behave fluid-like. The degree of bending, twisting, and crumpling that occurs is based on the physical properties of the specific metal. By plugging these properties into their model, Morgan and Lieberman—and eventually car manufacturers—can simulate what happens as the metal smashes into a concrete wall, for example.

Morgan's work could also be the catalyst for eventually making cars from alternative materials, such as aluminum alloys. Unlike steel, aluminum alloys are prone to tearing when pressed into some car parts. But Morgan's model could help people in the auto industry understand the ideal pressures and conditions in which to stamp out these parts. Aluminum alloy cars would be lighter, which would reduce fuel consumption, which would reduce greenhouse gas emissions. The cars would also hold up better in crashes, thus saving lives.

The same could be done for aircraft manufacturing (companies want to know how materials will hold up in a variety of situations) or even body or vehicle armor. "It's all about the physical laws of nature," Morgan says. "Whether it's at NIF, in a car safety test, or even stamping out the shapes for soda cans, the governing equations for material dynamics must be solved, and if we can get this right, it could have an enormous impact." ★

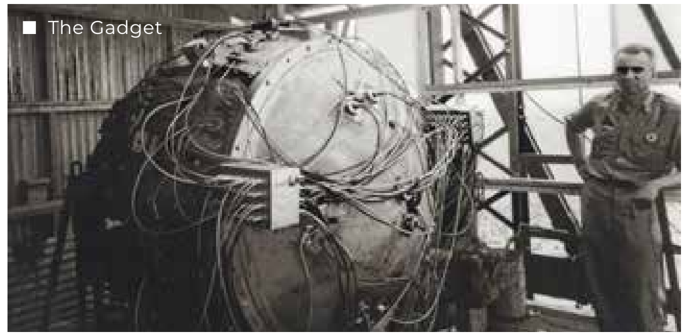


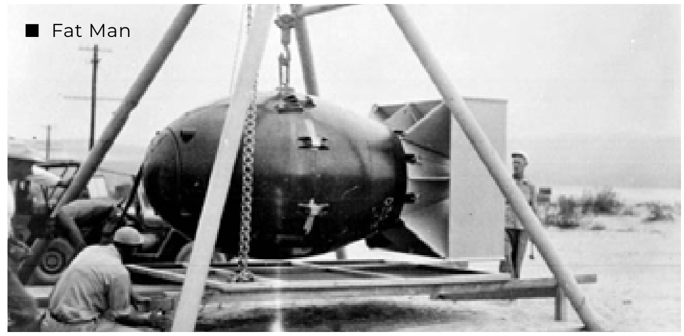
■ In 1945, Johnston was at Tinian, the Pacific island from which the planes carrying Little Boy and Fat Man departed. Johnston observed both detonations from *The Great Artiste*, an observation plane.

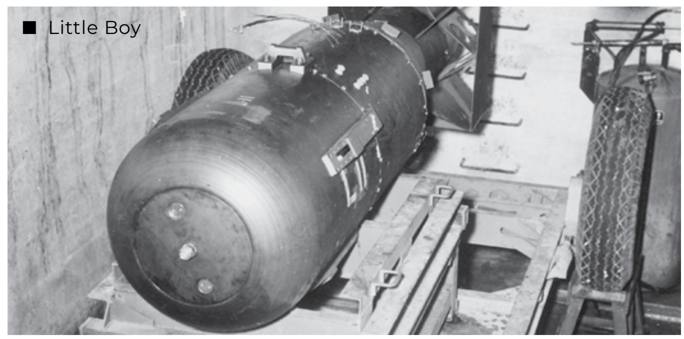
REMEMBERING LAWRENCE JOHNSTON

The inventor of the exploding bridgewire detonator was the only person to witness the detonation of the world's first three atomic bombs.

BY VIRGINIA GRANT


The Gadget


Fat Man


Little Boy

Lawrence Johnston, known to most as Larry, was born in 1918 in Shandong, China, where he spent the first five years of his life. His parents were American missionaries, his father a Presbyterian minister. The family moved to Santa Maria, California, in 1923. After completing an associate degree at Los Angeles City College, Johnston completed a bachelor's degree in physics at the University of California, Berkeley, where he met Louis Alvarez, a future Nobel laureate, who was working in Berkeley's Radiation Laboratory.

Johnston followed Alvarez to the Massachusetts Institute of Technology (MIT), where the two worked in the MIT Radiation Laboratory on ground-controlled approach radar. Then, in 1944, Alvarez and Johnston moved to Los Alamos to work on the Manhattan Project—the U.S. government's top-secret effort to develop atomic bombs to help end World War II.

At Los Alamos, the two developed the exploding bridgewire (EBW) detonator, which uses an electrical charge to heat a bridgewire—a very thin wire inside the detonator. Even today, no one is quite sure exactly what happens when that wire heats up, but most likely it vaporizes, creating a shock wave that causes the explosive inside the handlebar to detonate. When these detonators cause the high explosives surrounding a nuclear weapon's plutonium pit to explode, the pit then implodes, resulting in a nuclear explosion.

"Lawrence proved in the first EBW detonation on June 10, 1944, and in the following 13 months, that the design was ready for the greatest science experiment of all time—Trinity," says R&D manager Daniel Preston, referring to the detonation of the world's first atomic bomb.

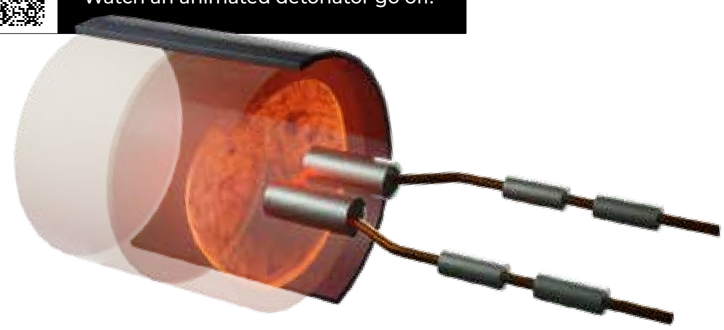
Used in both the Trinity test and in the Fat Man bomb above Nagasaki, the EBW design was critical to the safety of those and future nuclear weapons because it requires a specific energy source (electricity) to detonate, reducing the possibility of an accidental explosion.

After their work on the EBW, Johnston and Alvarez developed equipment to measure the strength of atomic explosions. Johnston was therefore present at the Trinity test on July 16, 1945. Less than a month later, he witnessed the world's second and third atomic blasts, which occurred above Hiroshima and Nagasaki, Japan, respectively. Johnston was the only person to witness all three explosions; he viewed each from the air, in a B-29 Superfortress.

When World War II ended, Johnston returned to Berkeley, where he completed a PhD in physics. He became a professor at the University of Minnesota, where he worked for 14 years. Johnston then spent three years as head of the Electronics Department at the Stanford Linear Accelerator Center. He finished his career as a professor of physics at the University of Idaho, from which he retired in 1988. He maintained the title of professor emeritus until his death in 2011.

SCAN QR CODE WITH A SMARTPHONE CAMERA

Watch an animated detonator go off.



June 10, 2021, marked the 77th anniversary of the first test of the exploding bridgewire (EBW) detonator. "Lawrence's EBW invention was the heartbeat of this nation's initiation systems for nearly three quarters of century," Preston says. "The spirit, ingenuity, and technical competency that Lawrence exhibited in inventing the EBW is exercised every day at Los Alamos." ★

For more on detonators, see "Devils in the Details" in the winter 2019 issue of this magazine.

EXPLOSIVES

TOWER POWER

A new drop test capability helps ensure high explosives safety.

BY MANDY SEE

What if the unexpected happens and a high-explosive (HE) device falls accidentally? Will it detonate? To find out, the Lab built a very large tower, dropped a device, and studied the effects. "A drop test is an experiment in which you subject an article to a free-fall and rapid deceleration, then assess its response," explains Ray Guffee of the Lab's Dynamic Structure Design and Engineering group, who served as lead engineer and project manager for the new drop tower.

The tower was built at the Lab's Meenie/Bravo firing site, which includes a bunker that needed repairs to accommodate the new tower structure and return the site to service. "We reconstituted an aging facility practically overnight," notes James Owen, associate Laboratory director for Weapons Engineering.

The new 90-foot-tall tower can drop up to 4,500 pounds from about 70 feet. Data from drop tests can be captured using high-speed photography, radiography, accelerometers, and other diagnostics.

Constructed during the pandemic, the tower and facility upgrades were completed one month early and under budget. The tower was used for the first time in April 2021 when the W88 Alteration and Refresh Programs group tested the response of a mock W88 warhead containing live HE. The test simulated an accidental drop scenario, which demonstrated that the HE would not inadvertently react.

Members of Los Alamos' Focused Experiments group and others from across the Laboratory deployed high-speed cameras and measured onboard accelerometer diagnostics to provide direct dynamic response data. The test was successful—no kaboom—with high-quality data return.

The new drop test tower "allowed us to assess weapon safety and deliver a critical stockpile test just in time to support modernization of the W88 Alt 370," Owen says. (For more on the W88 Alt 370, which is an update to the W88 warhead that can be launched from missiles on submarines, see p. 5.)

"Furthermore," Owen continues, "the tower re-establishes a critical capability to assess weapons safety performance in the future." Going forward, a range of devices can be dropped—from weapon-related devices to storage and transportation containers. The possibilities are almost endless. ★

■ Up to 4,500 pounds—about the weight of a compact car—can be dropped from the Laboratory's new drop tower.

■ From left: Explosives scientist Virginia Manner, postdoctoral researcher Nicholas Lease, explosives technician Maria Campbell, and R&D engineer Nathan Burnside work together on an experiment.

SCAN QR CODE WITH A SMARTPHONE CAMERA

Watch a GIF of a detonator impact test.

DETONATORS

AGING GRACEFULLY

A recent study reveals robust performance in aged detonator explosives.

BY KEVIN ROARK AND WHITNEY SPIVEY

Detonators are small devices that convert an input signal, usually electrical or percussive, into a high-pressure shock output, which causes an explosive inside of them to detonate. This mini explosion causes whatever the detonator is attached to (typically another explosive) to detonate. Detonators are used in bombs, demolition explosives, and mining explosives, among other applications. Detonators must be reliable and safe, even after years of fielded service in adverse environments.

Since the Manhattan Project, pentaerythritol tetranitrate (PETN) has been a preferred explosive inside the Los Alamos National Laboratory–designed detonators used in the weapons in the U.S. nuclear stockpile. And although scientists have been studying PETN aging for decades, a comprehensive, statistically significant study connecting PETN aging to detonator performance had never been done until recently.

"PETN is a common initiating explosive used extensively in commercial detonators and in the U.S. nuclear stockpile, but batch-to-batch variability has made it difficult for us to definitively show how it responds to aging," explains Virginia Manner, an energetic materials chemist at the Lab and the project lead for the study. "So, we brought together several groups and divisions at Los Alamos to create a very large-scale study that would put to rest all the questions we and others have had about PETN stability."

The researchers divided PETN powder from a single source into four batches. Three batches were treated with different stabilizers, which "significantly slow the aging process of the PETN over time and elevated temperature," says Nicholas Lease, a scientist in the Laboratory's High Explosives Science and Technology group. One batch was left unstabilized.

Then, the researchers filled 2,000 detonators with the different batches of PETN powder, thermally aged the detonators, analyzed the powder characteristics, and tested detonator function with a statistically significant sample size.

Findings from the study indicate that aging significantly changes the surface area and particle size of unstabilized PETN, leading to increases in detonator function time—essentially the amount of time it takes for the detonator to work. Function time "should be as prompt as possible," explains R&D manager Daniel Preston. "Increases in time indicate eroding detonator health."

Conversely, PETN powder coated with certain stabilizers exhibited no aging effects in free-flowing powder nor in commercially prepared detonator pellets, despite the high temperature aging.

"This study was the first of its kind to connect multiple disparate smaller-scale investigations on PETN stability that our lab and others have been conducting for almost half a century," explain Manner and Preston.

The team, which, in September 2021, won a 2020 Laboratory Distinguished Performance Award for its work, continues to analyze the results from the study. ★

The research was funded by the Laboratory's Aging and Lifetimes Program and would not have been completed without the dedicated work of Nicholas Lease, Nathan Burnside, Maria Campbell, Geoff Brown, Reid Buckley, John Kramer, Joseph Lichthardt, Kristina Gonzales, Spencer Anthony, Hongzhao Tian, and Sky Sjue, along with years of previous work conducted in the Detonation Science and Technology group at Los Alamos National Laboratory.

NUCLEAR TESTING

AN UNCONVENTIONAL WEDDING VENUE

The crater formed by a 104 kiloton-yield nuclear test provided the backdrop for a Los Alamos couple's wedding.

BY VIRGINIA GRANT

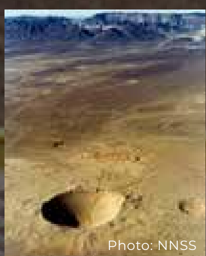


Photo: NNSS

■ The Sedan Crater.

Most people who elope to Las Vegas end up in a small chapel, perhaps with an Elvis impersonator presiding over the ceremony. But on March 31, 2001, Merri Wood and Rodney Schultz, both Los Alamos National Laboratory employees and former designers of underground nuclear tests, drove from New Mexico to Nevada for an unconventional elopement.

"Our youngest child was still at home," Merri explains, "but we had other children spread across the country, so we decided to elope." The couple originally considered a wedding in Las Vegas, she says, "but we quickly wondered if the test site would be an option." During their careers as test designers, Merri and Rodney both spent time working at the Nevada Test Site (now the Nevada National Security Site), just north of Las Vegas, where 928 nuclear tests were conducted between 1951 and 1992.

Merri contacted the Department of Energy's Nevada Area Operations Office to request use of an old chapel there that Rodney remembered. The person Merri spoke to said, "If it is was me, I would get married at Sedan Crater."

"That was perfect for us," Rodney says.

The Sedan underground nuclear test was carried out in 1962 by Lawrence Livermore National Laboratory, not Los Alamos—but the setting was ideal. "As the largest crater at the site," Merri says, "it is a spectacular example of nuclear weapons effects, and its modern and safe viewing platform made it very practical for a ceremony."

On April 1, the couple was married by an officiant from a Las Vegas wedding chapel who had to obtain a temporary uncleared security badge. The captain of the Nevada Test Site guard force served as both official witness and wedding photographer.

"When we returned to the security center at the entrance to the test site," Rodney remembers, "we found that a mini reception had been provided, with a carrot cake for us in the guard break room."

"We are both proud and happy that we were afforded the honor of being married at the Nevada Test Site because of its contributions to national security," Merri says, "and its importance in our own work to support nuclear deterrence." ★

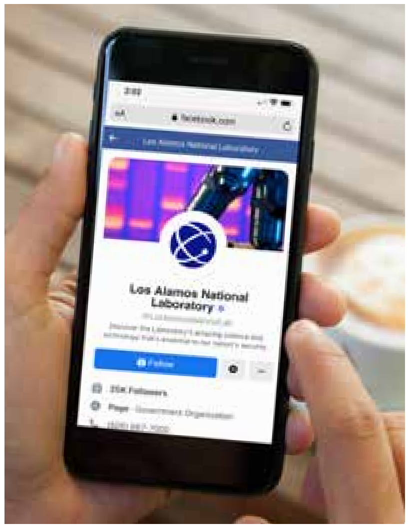
For more of Merri Wood-Schultz's work in underground nuclear testing, see "Bridging Divider" in the spring 2021 issue of this magazine.

■ The Wood-Schultzes were married on the platform that overlooks the Sedan crater.

SOCIAL MEDIA

GIVE US A FOLLOW!

If you like the articles in *National Security Science*, you'll love the social media posts from Los Alamos National Laboratory. Check out the Lab on Facebook, Twitter, LinkedIn, and Instagram to learn about cutting-edge science, employee profiles, news, job postings, and more. ★



QUOTED

"National security touches every aspect of our lives, and it will continue to. We don't know exactly how, but it will. When you work in intelligence, you learn how hard it is to predict the future, so I try not to—but I know that the Lab's future is bright."

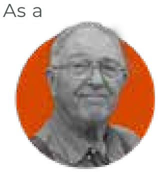
—Los Alamos Director Emeritus Terry Wallace, who retired in June after 18 years at the Laboratory. ★

CAREERS

HAPPY ANNIVERSARY!

In 2021, many Los Alamos Weapons Programs employees celebrated 30, 35, and even 45 years of service to the Laboratory. Here are just a few highlights from some of their careers.

James Goforth — **45 years**



...is a third generation New Mexican. As a kid, he was familiar with Los Alamos because his favorite uncle was the grandson of a homesteader on the Pajarito Plateau, where the Laboratory is located.

Joyce Ann Guzik — **35 years**

...had one of the very first Macintosh computers, which was given to her on the condition that she share it with others. She recalls the final W88 certification report being written on that computer.

Mary Esther Lucero — **35 years**

...worked in the Plutonium Facility for about a decade and became pretty good at working in a glove box. She could even pick up broken glass without getting a puncture in the gloves.

Ted Martinez — **30 years**

...worked out at the Lab's K Site, where there was a full-time resident—a cat, who "served as our resident mouse patrol," he remembers. In true Los Alamos fashion, the group members named the cat NOMADD, after a diagnostic system they used.

Jacqueline Valdez — **40 years**

...had the opportunity, in 1991, to tour underground tunnels at the Nevada Test Site, where the Laboratory performed nuclear tests. The most exciting part of that trip? "I had a kidney stone attack and had to go by ambulance into Las Vegas," she remembers.

Tracy Wenz — **30 years**

...traveled to Japan to install nondestructive assay instrumentation at Japanese plutonium facilities in support of International Atomic Energy Agency safeguards. "The more people you meet from all over the world, the more you realize how much people have in common," she says. ★

ANALYSIS

ANALYZING THE *ARKANSAS*

The battleship sank during a nuclear test—but how exactly?

BY JEREMY BEST

Commissioned in 1912, the USS *Arkansas* battleship served in both World Wars before being used as a target in Operation Crossroads-Baker, a Los Alamos Scientific Laboratory–designed test used to study the effects of nuclear weapons on naval vessels. Detonated 90 feet underwater on July 25, 1946, the Baker test device displaced 2.2 million cubic yards of water that shot up into a thick column before crashing back down into the Pacific Ocean.

A well-known photo of the test shows a dark area on the right of the column. For decades, many people assumed this dark spot was the *Arkansas*—which had been placed approximately 660 feet from ground zero—being swept into the column.

However, by using some basic physics calculations, the unclassified weapons test reports from Operation Crossroads, and critical thinking, it is possible to bust the pervasive myth that the *Arkansas* was lifted vertically into the column of water.

During the Crossroads test, pressure data was collected on selected ships, and some ships were more instrumented than others. Although pressure data was lost as the *Arkansas* and other ships close to surface zero sank, the pressure in the water around the blast was recorded. Thus, we know the maximum pressure recorded was 4,800 pounds per square inch (psi) above the blast in the region of the resulting water column.

The *Arkansas* was 562 feet long, with a 93-foot beam (widest part of the ship) and a 28-foot draft (the depth of the bottom of the ship). She displaced (weighed) around 26,000 tons, so she would not be moved easily in any direction. Not to mention that the *Arkansas* was anchored to the sea floor by both her bow and stern, which would provide substantial resistance to lifting and tipping movements.

Approximating the bottom of the ship with simple flat plates and doing some fundamental math based on *force* = *mass* × *acceleration* = *pressure* × *area*, one arrives at a vertical acceleration of around 400g (400 times the acceleration of gravity). This acceleration lines up well with the maximum recorded accelerations from the other ships in the array during the blast, namely the USS *Pensacola*, USS *New York*, and USS *Nevada*.

This also lines up with a supercomputer simulation of the blast that was done using one of the Lab's hydrodynamic physics codes.

▼ A supercomputer simulation shows the right side of the Crossroads-Baker water column.

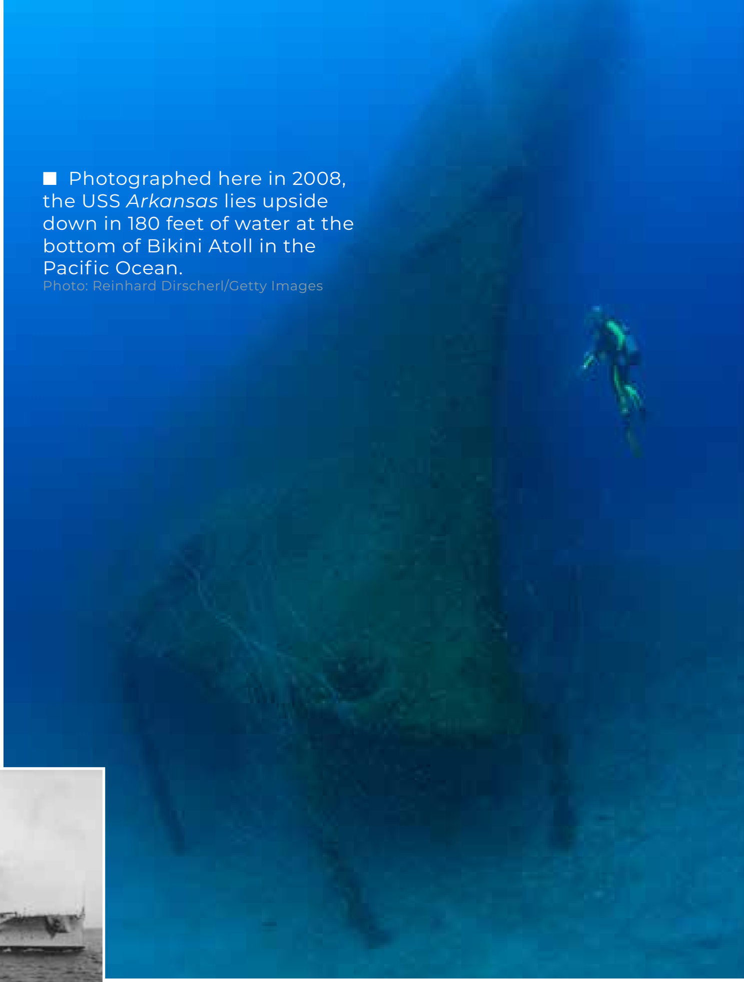
The most interesting fact of this situation is that the shock duration (the time of the pressure pulse that would have caused the ship to accelerate upward) was recorded by many gauges and generally referred to as "less than a millisecond," which would not produce enough resulting force to lift the entire ship out of the water.

The final discussion point is what the sunken USS *Arkansas* looks like at the bottom of the lagoon. The description in the reports indicates that the port (left) side hull was largely intact while the starboard (right) side nearest the blast and resulting water column was dished in, deformed, and had many hull plates separated. This indicates that the force was strong enough to deform the ship on the side of the blast but not enough to lift it out of the water.

So what is that dark area on the Crossroads-Baker photograph?

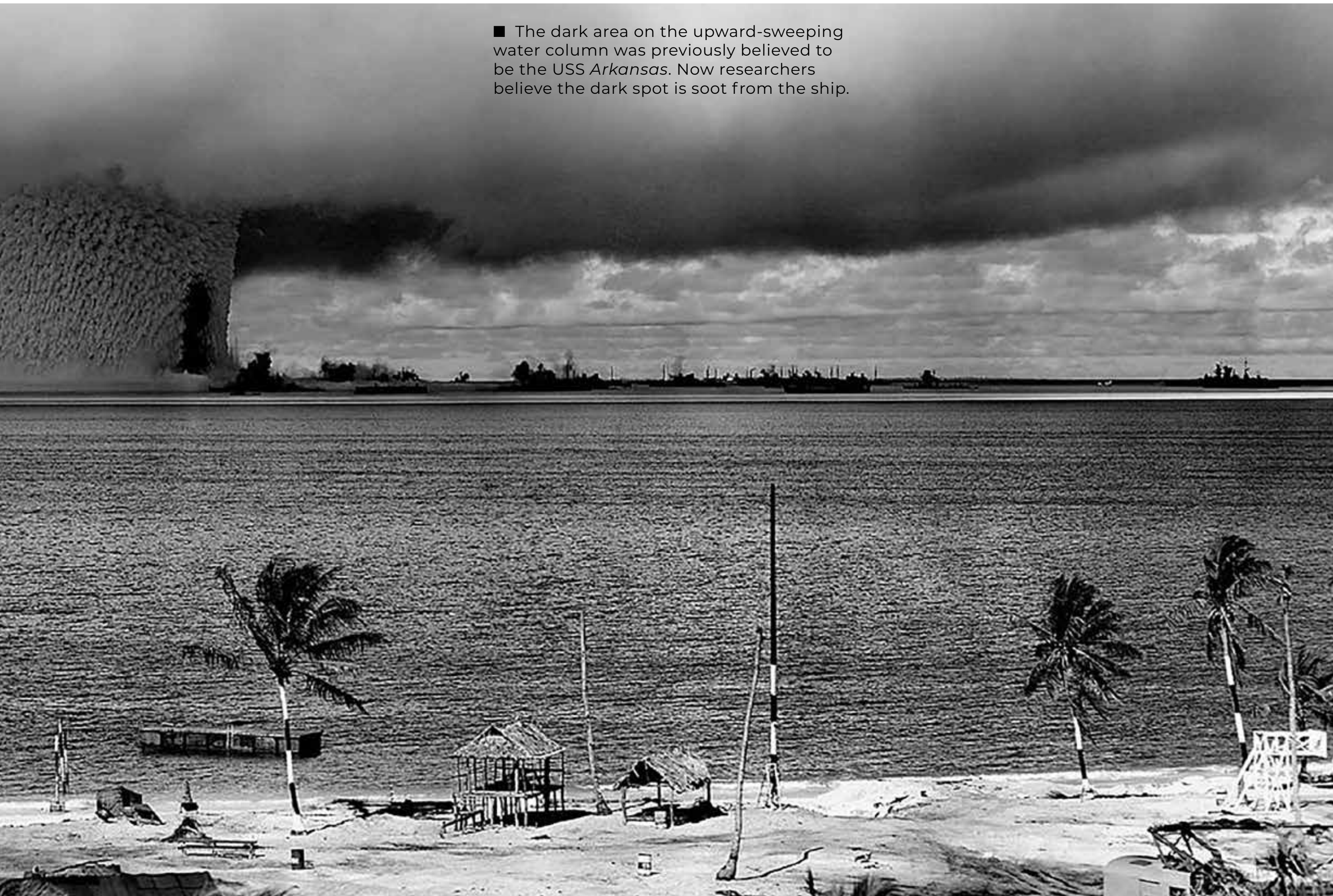
The general consensus among many experts is that the soot from the boilers on the *Arkansas* was shaken loose from a previous test and was pushed out of the stacks as the pressure wave hit the bottom of the ship and traveled up through it, leaving the cloud of soot mixing with the water vapor just above the ship in the photograph. ★

Laboratory program manager Jeremy Best was the principal investigator for this work, which was also supported by senior historian Alan Carr, scientist Christopher Mauney, and retired scientist Tom Kunkle.



■ Photographed here in 2008, the USS *Arkansas* lies upside down in 180 feet of water at the bottom of Bikini Atoll in the Pacific Ocean.
Photo: Reinhard Dirscherl/Getty Images

■ The USS *Arkansas*



■ The dark area on the upward-sweeping water column was previously believed to be the USS *Arkansas*. Now researchers believe the dark spot is soot from the ship.

PHYSICS

HARNESSING STAR POWER

In August, the National Ignition Facility became one step closer to the holy grail of clean energy: fusion.

BY J. WESTON PHIPPEN

The path to create fusion—the type of nuclear reaction that powers the sun and stars—has a long history, involving some of the greatest minds in physics. British astrophysicist Arthur Eddington first conceived of fusion, and, in 1925, he published a seminal paper theorizing that stars fuse hydrogen into helium. Nuclear physicist Hans Bethe advanced the science, and from there, physicists Enrico Fermi and Edward Teller used fusion to create a thermonuclear bomb.

Yet, the "holy grail" of fusion, according to Los Alamos National Laboratory postdoc James Sadler, is to use fusion as an energy source that would emit no pollution, last almost indefinitely, and result in little or zero waste. Sadler and Hui Li, both of the Lab's Nuclear and Particle Physics, Astrophysics and Cosmology group, have been working to better understand how this might be achieved.

To replicate the environment of the sun, the National Ignition Facility (NIF), at California's Lawrence Livermore National Laboratory, uses lasers—lots of them. In a lab the size of three football fields, 192 lasers are amplified, reflected, and focused into a point. These beams can generate temperatures of more than 180 million degrees Fahrenheit and the pressure of 100 billion Earth atmospheres. Their target is a small capsule the size of a pencil eraser, filled with hydrogen gas.

Under intense pressure and heat from the lasers, the electrons surrounding hydrogen gas break their atomic bonds and become a plasma. Deuterium and tritium nucleons (both isotopes of hydrogen) fuse to form energetic helium, which share its energy with more deuterium and tritium, driving a self-sustained reaction, called ignition.

Ignition, however, has not yet been achieved. One major hurdle is that as electrons move about the confined capsule, they take energy from hotter regions and share it with cooler regions, which reduces the overall temperature and slows the reaction. To prevent this sharing of energy, researchers have applied external magnetic B-fields to the capsules, hoping to contain the roaming electrons in a super-heated pocket.

Sadler and Li, however, believe that perhaps those external magnetic fields are unnecessary. They discovered that the fusion process spontaneously creates its own, self-generated magnetic fields. These alone might be powerful enough to insulate the electrons from sharing their energy, though the researchers cannot say for certain yet because the simulation codes used by national labs to model the behavior of fusion at NIF don't account for self-generated fields.

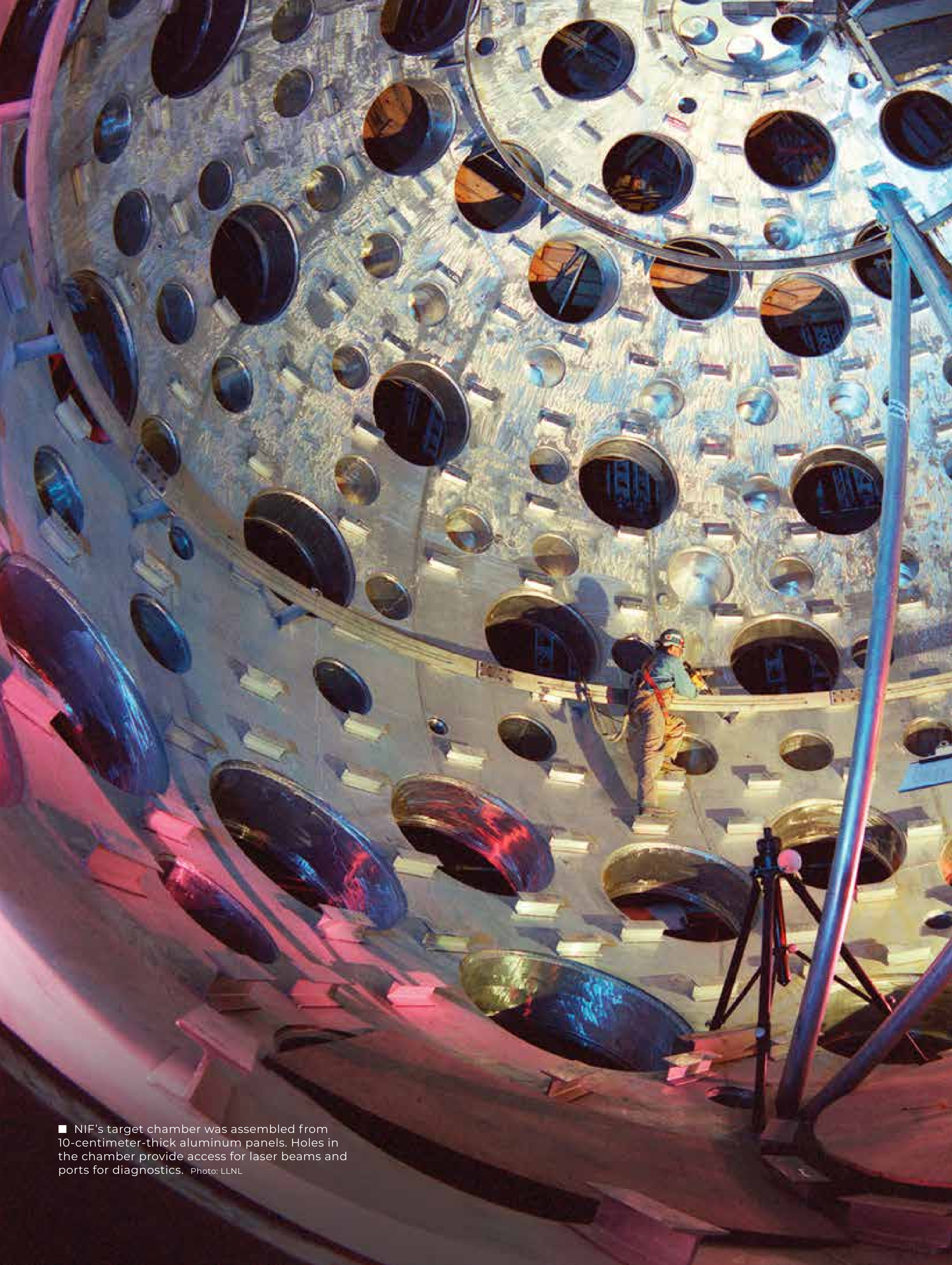
▲ "It's very challenging to replicate the super-dense environments you find on stars as they form, and trying to do this in a lab setting then presents its own challenges," says Sadler (right), who is pictured here with Hui Li.

"We don't know if these fields should be a high priority concern," Li says. "So what we're doing is introducing these fields into our models to see how they change the parameters of ignition. If we learn they're a low priority, they will at least make our models more accurate. If we learn they're a high priority, reaching ignition may be easier than we think."

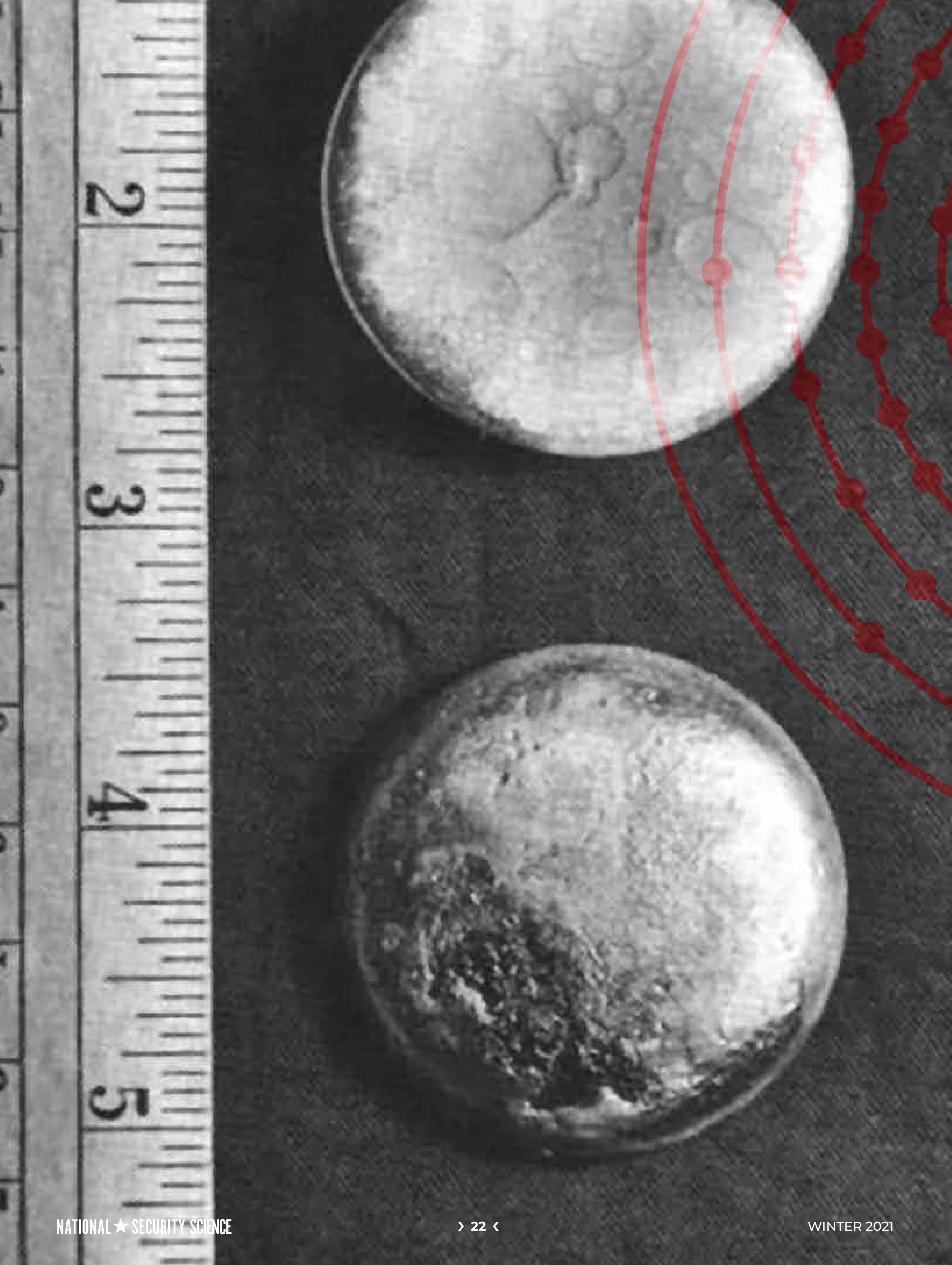
Shortly after Li spoke with *NSS* magazine, in August 2021, NIF almost reached ignition. What happened? Sadler and Li suspect that the self-generated magnetic fields they discovered reduced heat loss between electrons by 10 percent or more, enhancing the energy yield by more than a factor of three.

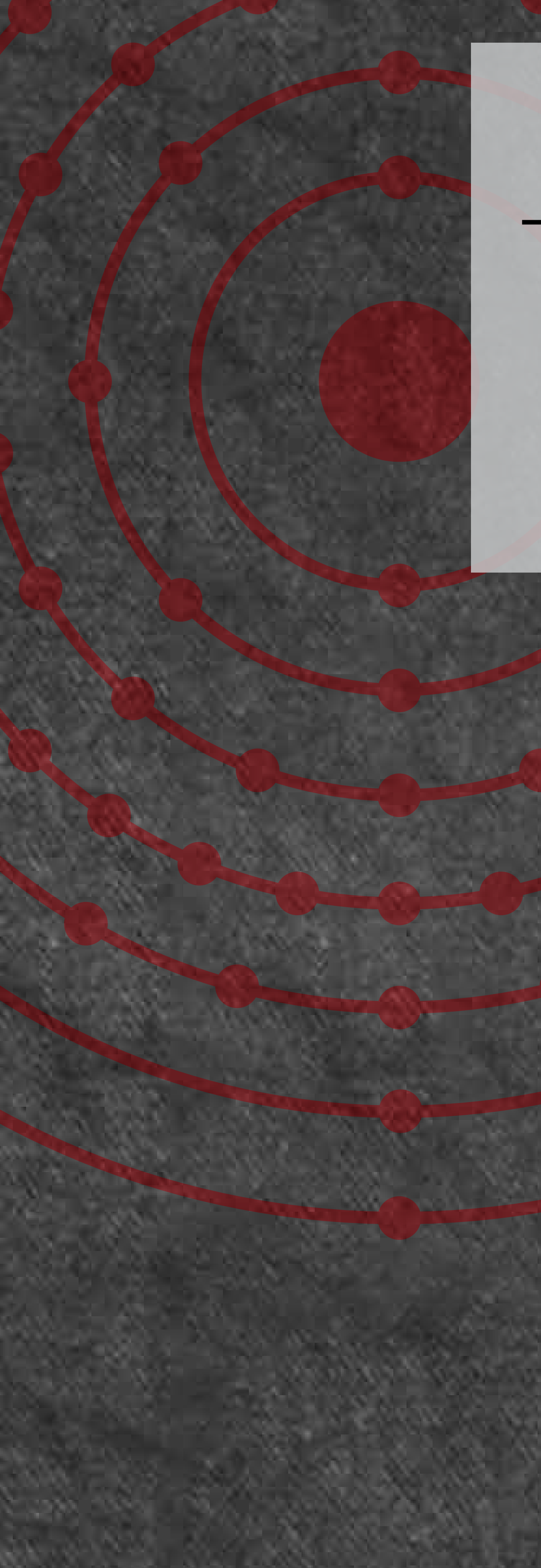
That being said, Li realizes many variables—such as temperature, how long the lasers are active, and alterations to the capsules that hold the tritium and deuterium—may have also contributed to the August results. Scientists at NIF and Los Alamos will be analyzing the data for years to come. But the near-success is a good indication that, for the first time, humans may be on the threshold of creating fusion power.

"The moment you can generate fusion," Sadler says, "it can be used for many things: to learn how stars form and live, to produce an intense neutron source, and ultimately, to create a clean energy source." ★



■ NIF's target chamber was assembled from 10-centimeter-thick aluminum panels. Holes in the chamber provide access for laser beams and ports for diagnostics. Photo: LLNL





■ Plutonium buttons photographed at the Laboratory in 1945.

ATOMIC NUMBER 94

The element plutonium was discovered only 81 years ago, but its impact on the world has been monumental.

By Virginia Grant

On December 14, 1940, chemist Glenn Seaborg and his colleagues at the Berkeley Radiation Laboratory used a 60-inch cyclotron to bombard the element uranium with deuterons. Initially, the reaction produced an isotope of the element neptunium (neptunium-238), which has a two-day half-life and decayed quickly into an isotope of an element with 94 protons. Two months later, scientists would confirm that this was in fact a new element. They named it after then-planet Pluto, and their ability to create it changed the course of human history.

Plutonium is "one of the most exotic metals in the periodic table—maybe the most," Seaborg said in an interview with the Atomic Heritage Foundation in 1965. "It undergoes change in ways that are different: in expansion, in contraction, in heating and the effect of temperature on electrical conductivity, and things of that sort are all anomalies." Learning how to produce the element in usable quantities was a feat in and of itself; the first identifiable plutonium existed only in trace amounts. Learning how to harness and use such a volatile element has been a monumental effort that continues to this day.

The following timeline highlights notable developments in plutonium history, along with plutonium-related milestones in the history of Los Alamos National Laboratory.

1940

BIRTH OF Pu

December 14, 1940: Chemists Glenn Seaborg, Joseph Kennedy, Edwin McMillan, and Arthur Wahl, all of the University of California, Berkeley, use a 60-inch cyclotron to produce the (yet unnamed) isotope plutonium-238, element 94.

February 23–24, 1941: Seaborg's team performs the first chemical identification of the new element, confirming the discovery of plutonium. Plutonium-239, the isotope that will be of major importance for use in nuclear weapons, is discovered as the decay product of neptunium-239, produced by cyclotron neutrons.

Glenn Seaborg (left) and Edwin McMillan were awarded the 1951 Nobel Prize in Chemistry for "their discoveries in the chemistry of the transuranic elements," which are the elements with atomic numbers greater than 92. Of plutonium, atomic number 94, Seaborg said, "Although the chemical symbol might have been 'Pl' we liked the sound of 'Pu,' for the reason you might suspect.' Photo: Berkeley Lab

March 28, 1941: Seaborg, Kennedy, and physicist Emilio Segrè determine the fissionability of plutonium-239 with slow neutrons. They keep the discovery a secret for fear that an adversary might use it to develop a weapon.

Plutonium discovered

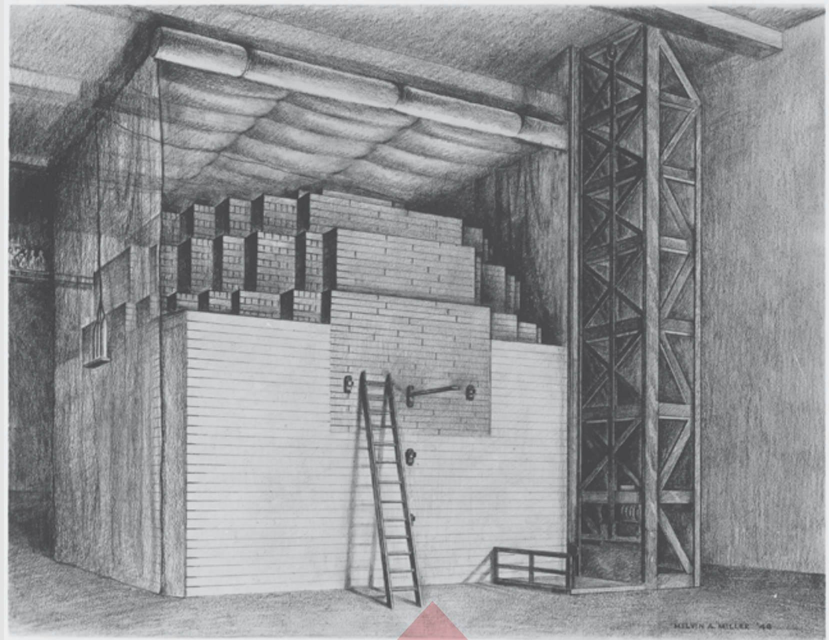
March 21, 1942: The element discovered before plutonium was neptunium, named after the planet Neptune, so Seaborg, Wahl, Kennedy, and McMillan propose the new element 94 be named "plutonium" after then-planet Pluto.

Eric and Margaret, the children of Ernest Lawrence, sit inside a 60-inch cyclotron, invented by their father and used in the discovery of plutonium. Photo: Berkeley Lab

June 1942: Scientists at the University of Chicago's Metallurgical Laboratory (Met Lab) begin designing the first full-scale plutonium production reactor, in support of the United States' wartime effort to create an atomic weapon.

August 20, 1942: At the Met Lab, chemists Burris Cunningham and Louis Werner isolate an approximately 1-microgram sample of plutonium-239, making plutonium the first man-made element obtained in visible quantity.

September 10, 1942: The first weighing of plutonium is carried out by Cunningham, who measures a 2.77-microgram sample of plutonium oxide.



The world's first nuclear reactor, built in 1942 under the stadium at the University of Chicago's Stagg Field, was sketched by Melvin Miller, a draftsman at the school's Met Lab.
Photo: DOE

December 2, 1942: At the University of Chicago, physicist Enrico Fermi leads a team that achieves the world's first self-sustaining fission chain reaction with the Pile-1 reactor at the Met Lab.

First self-sustaining fission reaction

Seaborg stored the first sample of plutonium-239 in this cigar box.
Photo: DOE

"THE ITALIAN NAVIGATOR HAS LANDED IN THE NEW WORLD."

—This code message conveyed the news that Enrico Fermi had, using the Chicago Pile-1 nuclear reactor, achieved the world's first nuclear reaction

During the 1940s, winding roads, mud, and switchbacks made Los Alamos quite difficult to access.
Photo: Atomic Heritage Foundation

Los Alamos chosen for Project Y

January 1, 1943: Los Alamos, New Mexico, is established as Project Y of the Manhattan Project, the U.S. government's top-secret effort to design and build an atomic bomb—possibly by using plutonium—to help end World War II.

July 1943: The first physical experiment completed at Los Alamos is the observation of neutrons from the fissioning of plutonium-239. The neutron number is measured from an almost invisible speck of plutonium and is greater than the number of neutrons from fissioning uranium-235, which justifies the already-made decision to construct a plutonium reactor at Hanford.

December 1943: The D-Building is constructed at Project Y for plutonium chemistry, metallurgy, and processing.

1943

October 1943: Construction begins on the B Reactor, the world's first large-scale plutonium production reactor, at the Manhattan Project's Hanford Site in Washington.

1943–1945: Manhattan Project scientists code-name all plutonium "49," a combination of the end of plutonium's atomic number, 94, and the end of the isotope plutonium-239.

Safety News

H.E.W.

SEPTEMBER SAFE HOURS PILE UP

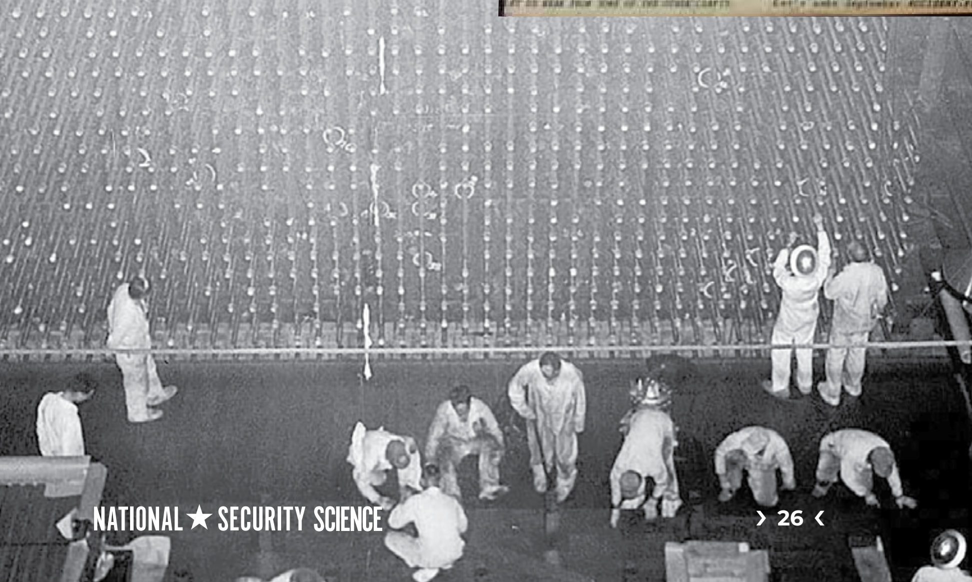
You CAN DO IT

MAKE SEPTEMBER ACCIDENT - FREE

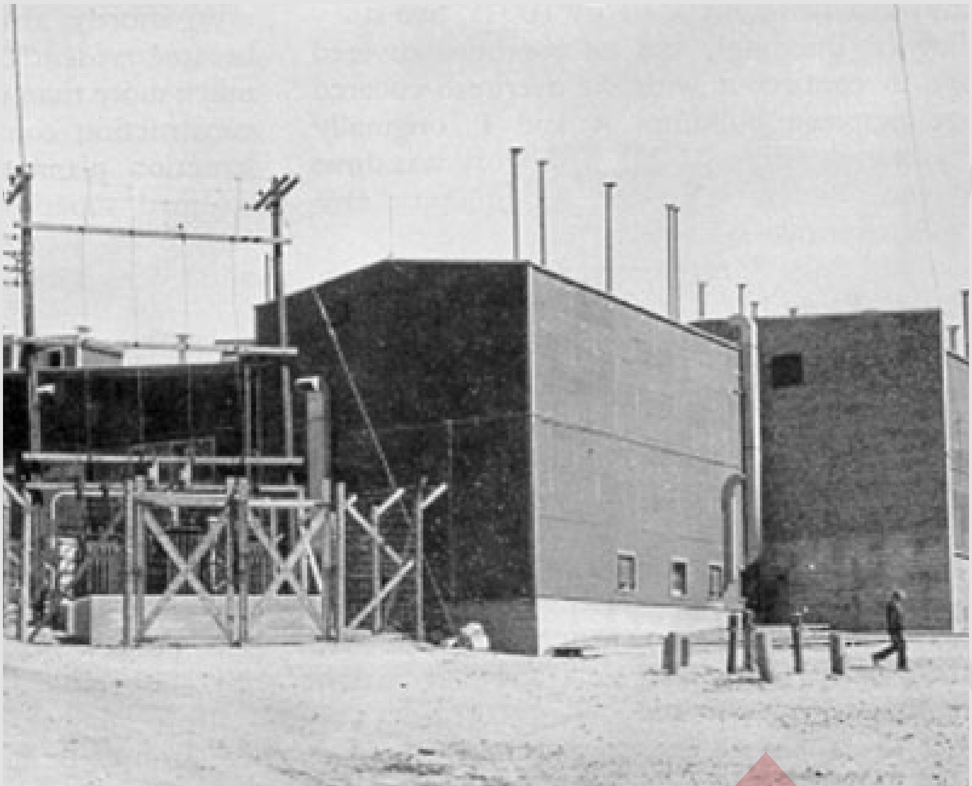
Carpenters crowing — with very good reasons

TWO MILLION MARK TOPPED SIX TIMES

A 1944 safety newsletter from the Hanford Site spotlights multiple crews that had gone over 2 million hours without injury—all while working on scaffolding up to 56 feet high.
Photo: DOE



The Hanford Site B Reactor produced plutonium until 1968.
Photo: DOE



Project Y's D Building.

Pu isolated in pure form

“IF SOME NUCLEAR PROPERTIES OF THE HEAVY ELEMENTS HAD BEEN A LITTLE DIFFERENT FROM WHAT THEY TURNED OUT TO BE, IT MIGHT HAVE BEEN IMPOSSIBLE TO BUILD A BOMB.”

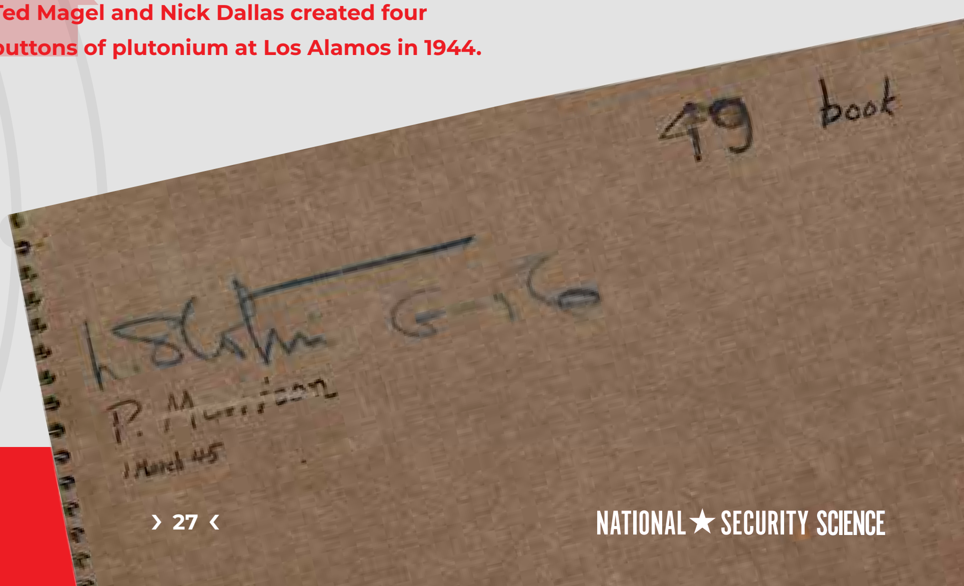
—Physicist Emilio Segrè

March 23, 1944: At Los Alamos, metallurgists Ted Magel and Nick Dallas use a centrifuge to isolate plutonium in a pure metallic form. This makes it possible to use solid plutonium in potential weapons.

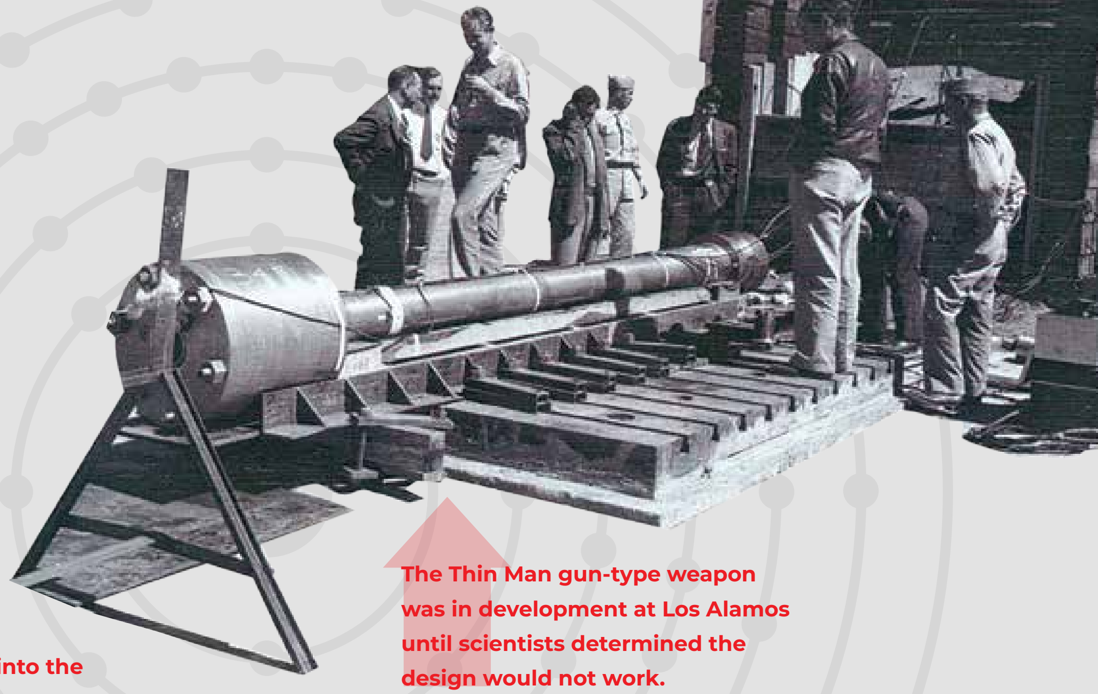
1944: At the Hanford T Plant, scientists scale up the bismuth phosphate process, which is used to separate plutonium from uranium and fission products.

Ted Magel and Nick Dallas created four buttons of plutonium at Los Alamos in 1944.

Los Alamos physicist Louis Slotin’s “49” notebook, now part of the collections at the Laboratory's National Security Research Center, includes research notes and plans for a pulsed fission reactor.



April 5, 1944: Los Alamos receives the first sample of reactor-produced plutonium-239 from Oak Ridge, Tennessee. Segrè discovers plutonium-240 in the sample. Plutonium-240 spontaneously fissions at a much higher rate than plutonium-239, so the presence of this contaminant makes the Thin Man weapon design, a gun-type weapon, impossible. The spontaneous fission of plutonium-240 would have caused the plutonium to pre-detonate—to lose its explosive potential before the pieces could be brought together.

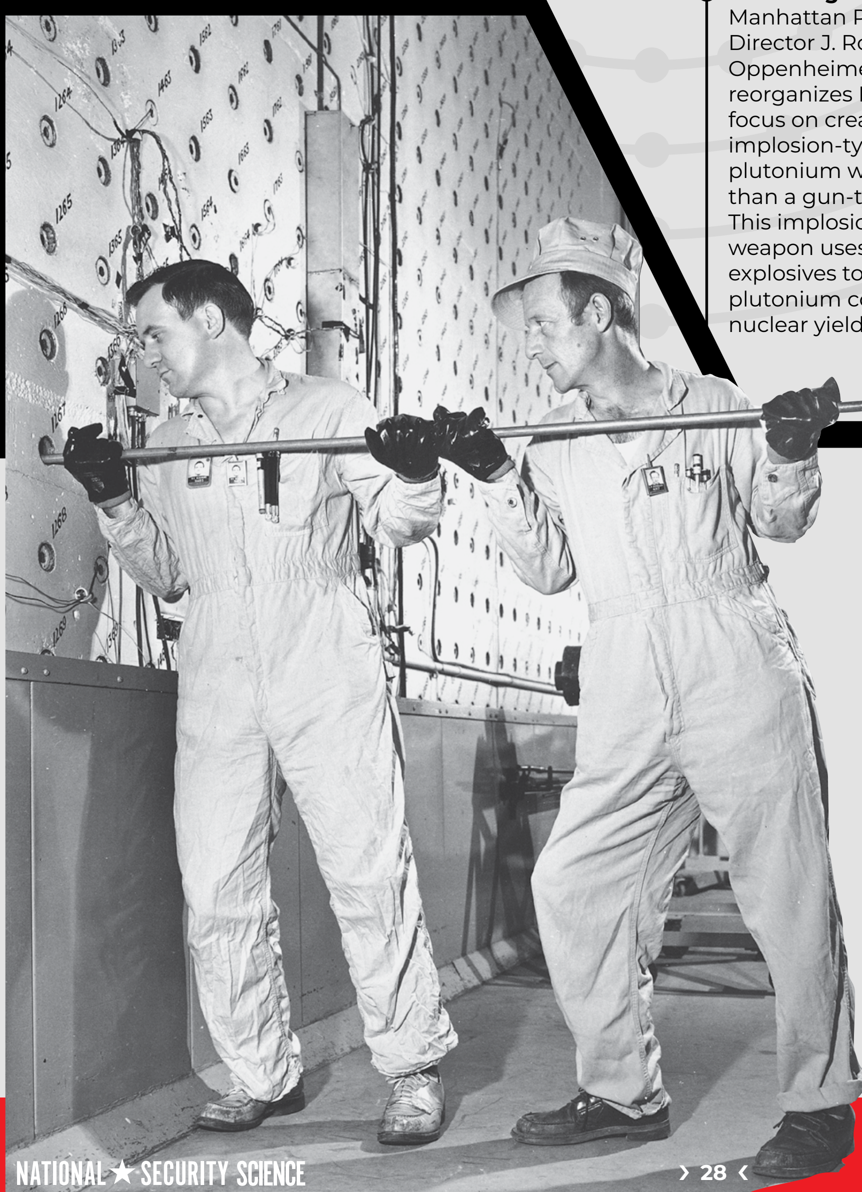


The Thin Man gun-type weapon was in development at Los Alamos until scientists determined the design would not work.

Project Y refocuses on implosion

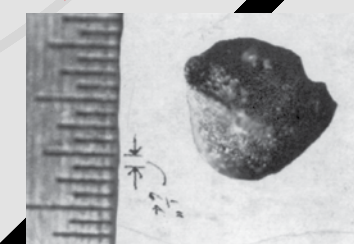
Workers push uranium slugs into the Graphite Reactor in Oak Ridge, Tennessee. The reactor showed that plutonium could be extracted from irradiated uranium slugs.

Photo: ORNL



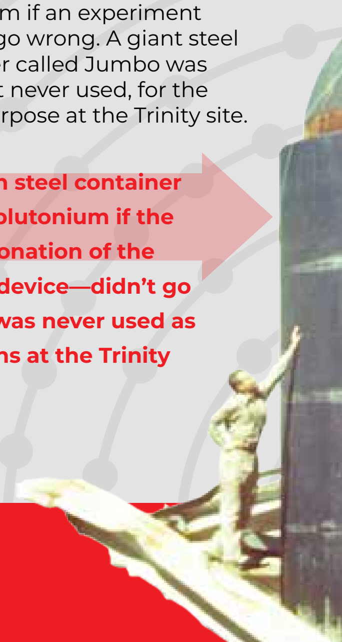
June–August 1944: Manhattan Project Director J. Robert Oppenheimer reorganizes Project Y to focus on creating an implosion-type plutonium weapon rather than a gun-type weapon. This implosion-type weapon uses high explosives to compress a plutonium core to create nuclear yield.

The first gram-scale quantity of plutonium-239 was produced on March 23, 1944, at Los Alamos.



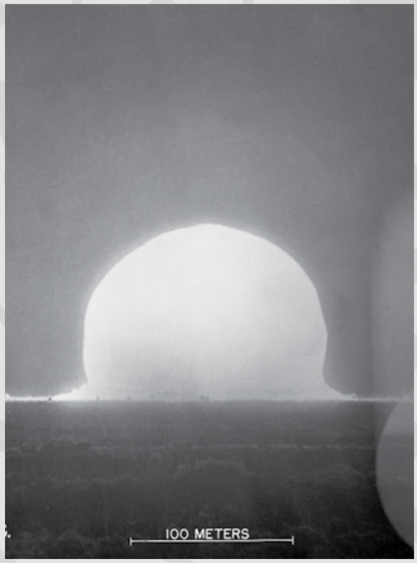
1944: Los Alamos researchers realize the scarcity of plutonium and build the Concrete Bowl, a 200-foot catchment, to recover plutonium if an experiment were to go wrong. A giant steel container called Jumbo was built, but never used, for the same purpose at the Trinity site.

Jumbo was a 214-ton steel container that would contain plutonium if the Trinity test—the detonation of the world's first atomic device—didn't go as planned. Jumbo was never used as intended and remains at the Trinity site today.



September 26, 1944: The Hanford Site's B Reactor goes critical at 10:48 p.m. The reactor produces plutonium-239, specifically for implosion-type atomic bombs. Los Alamos receives the first shipment in February 1945.

April 1945: Scientists at Los Alamos create the first plutonium–gallium alloy, which stabilizes plutonium and allows it to more easily be shaped into the hemispheres that form a weapon's pit.



"OPPIE, YOU OWE ME $10."

—George Kistiakowsky, physical chemist, to J. Robert Oppenheimer directly after the Trinity test. Kistiakowsky won a bet—a month of his salary against Oppenheimer's $10—that the Gadget would work

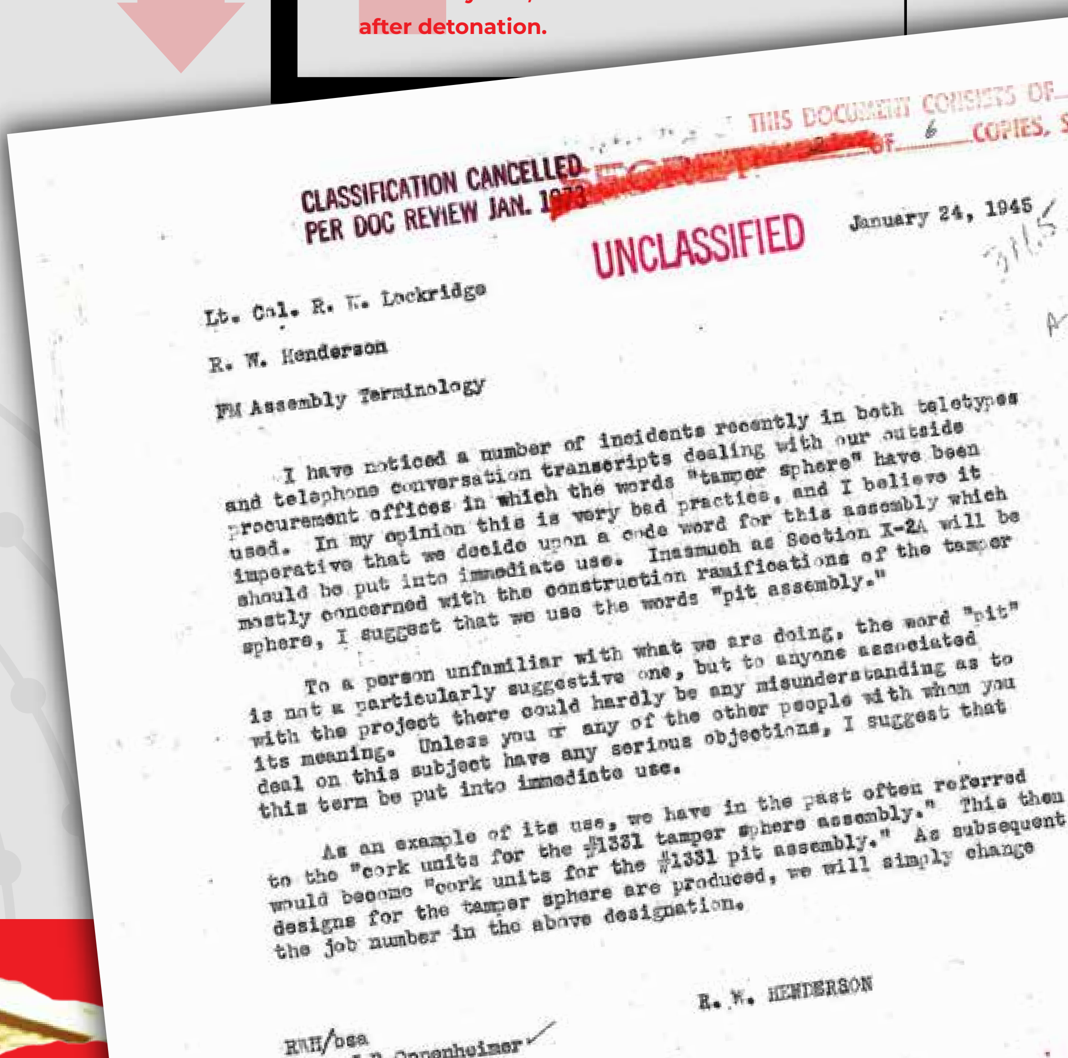
Trinity test is a success

July 16, 1945: The world's first atomic device, code-named the Gadget, is successfully tested at the Trinity site near Alamogordo, New Mexico. The Gadget employs 13 pounds of plutonium-239.

The Trinity test, 0.006 seconds after detonation.

January 24, 1945: Manhattan Project engineer Robert Henderson writes to Lieutenant Colonel Robert Lockridge, leader of the Project Y procurement group, suggesting "pit assembly" as the code phrase for the plutonium cores being developed for atomic weapons at Project Y. Over time, these cores will come to be known simply as "pits."

Pit assembly letter.



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UNCLASSIFIED

January 24, 1945

Lt. Col. R. W. Lockridge

R. W. Henderson

PM Assembly Terminology

I have noticed a number of incidents recently in both teletypes and telephone conversation transcripts dealing with our outside procurement offices in which the words "tamper sphere" have been used. In my opinion this is very bad practice, and I believe it imperative that we decide upon a code word for this assembly which should be put into immediate use. Inasmuch as Section X-2A will be mostly concerned with the construction ramifications of the tamper sphere, I suggest that we use the words "pit assembly."

To a person unfamiliar with what we are doing, the word "pit" is not a particularly suggestive one, but to anyone associated with the project there could hardly be any misunderstanding as to its meaning. Unless you or any of the other people with whom you deal on this subject have any serious objections, I suggest that this term be put into immediate use.

As an example of its use, we have in the past often referred to the "cork units for the #1331 tamper sphere assembly." This then would become "cork units for the #1331 pit assembly." As subsequent designs for the tamper sphere are produced, we will simply change the job number in the above designation.

R. W. HENDERSON

RWH/osa
J. R. Oppenheimer

On October 16, 1945, in a ceremony at Fuller Lodge in Los Alamos, the Army and Navy presented the E Flag Production Award to those whose work at Project Y had helped end World War II.

“WE HAVE NO HOPE AT ALL IF WE YIELD IN OUR BELIEF IN THE VALUE OF SCIENCE.”

—J. Robert Oppenheimer, in his farewell speech to the Association of Los Alamos Scientists, November 2, 1945

World War II ends

August 9, 1945: The plutonium implosion bomb Fat Man is dropped on Nagasaki, Japan.

The accident that resulted in the death of Louis Slotin was demonstrated using this model.

August 21, 1945: Los Alamos physicist Harry Daghlian receives a fatal dose of radiation during an accident while handling a plutonium core. He dies 25 days later. On May 21, 1946, physicist Louis Slotin is exposed to a fatal dose of radiation during an experiment accident. He dies nine days later. As a result of these criticality incidents, the types of plutonium cores involved in these accidents are nicknamed “demon cores.”

Bockscar, the B-29 Superfortress that dropped the Fat Man bomb, is now on display at the National Museum of the United States Air Force.

Photo: Flickr/Jason

A worker at Los Alamos' Technical Area 21.

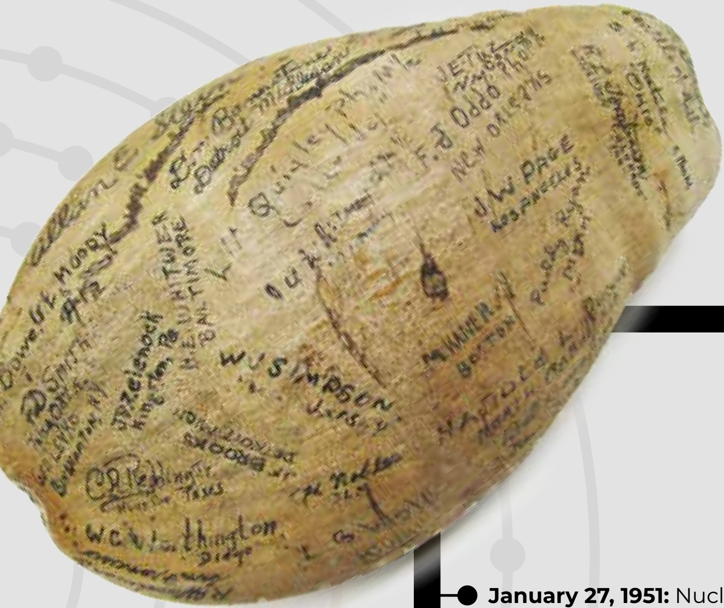
Fuel rods inside the core of Clementine, Los Alamos' fast nuclear reactor.

November 1945: Plutonium processing at Los Alamos shifts from the D-Building to the newly completed DP West Site, in what will later be known as Technical Area 21.

1946: The world's first fast plutonium nuclear reactor, code-named Clementine, achieves criticality at Los Alamos. Fast nuclear reactors are more energy efficient than reactors that rely on slower-moving thermal neutrons. In developing a fast reactor, scientists hope to design a reactor whose waste products can be recycled as fuel.

Husband and wife David and Jane Hall oversaw the construction and startup of Clementine. The reactor operated until December 1952, when it was shut down after plutonium had contaminated its mercury coolant (a coolant is necessary to remove the heat generated by fission).

First fast Pu nuclear reactor



A coconut signed by people involved in Operation Crossroads now resides at the National Museum of Nuclear Science and History in Albuquerque, New Mexico.

Photo: National Museum of Nuclear Science & History

November 1, 1952: The first full-scale test of a thermonuclear device, code-named Ivy Mike, leads to Los Alamos scientists' discovery of plutonium-244 among the debris. The discovery, which demonstrates uranium-238's capacity to absorb neutrons, will lead Lawrence Berkeley National Laboratory physicist Albert Ghioroso to seek out and discover elements 99 and 100, einsteinium and fermium, respectively, among Ivy Mike's fallout.

January 27, 1951: Nuclear testing begins at the Nevada Proving Ground (later the Nevada Test Site, now the Nevada National Security Site). The first test is the Los Alamos–designed Ranger-Able test.

1950

August 1, 1946: President Harry Truman signs the Atomic Energy Act, which transfers the control of atomic energy from the military to civilians. The Atomic Energy Commission is established to control nuclear materials and develop nuclear weapons.

June 30, 1946: The United States begins conducting atmospheric tests of nuclear weapons in the South Pacific Ocean. The first test, designed by Los Alamos, is named Crossroads-Able.

December 8, 1953: President Dwight Eisenhower delivers to the United Nations General Assembly what will become known as the "Atoms for Peace" speech. In it, Eisenhower discusses the potential non-warfare uses of nuclear energy.

July 10, 1951: Ground is broken on the Rocky Flats Plant near Denver, Colorado. From 1952 to 1989, the plant will be the United States' primary plutonium pit manufacturing facility. For more, see p. 46.

Plutonium processing equipment at the Rocky Flats Plant.

Photo: Atomic Heritage Foundation

Nevada testing begins

Craters formed by underground nuclear tests dot the Nevada National Security Site.

Seminal publications in plutonium history

1958 Bochvtar, Konobeevskii, Zaimovskii, Sergeev, Kutaitsev, Pravdiuk, and Levitskii, "Investigation of the Metallography of Plutonium, Uranium, and Their Alloys."

SCAN QR CODE WITH A SMARTPHONE CAMERA
See the complete citations for these papers.

1969 Spitsyn, Gel'man, Krot, Mefod'eva, Zakharova, Komkov, Shilov, Smirnova, "Heptavalent State of Neptunium and Plutonium."

This U.S. postage stamp was issued shortly after President Eisenhower's "Atoms for Peace" speech.

"MY COUNTRY WANTS TO BE CONSTRUCTIVE, NOT DESTRUCTIVE. IT WANTS AGREEMENTS, NOT WARS, AMONG NATIONS."

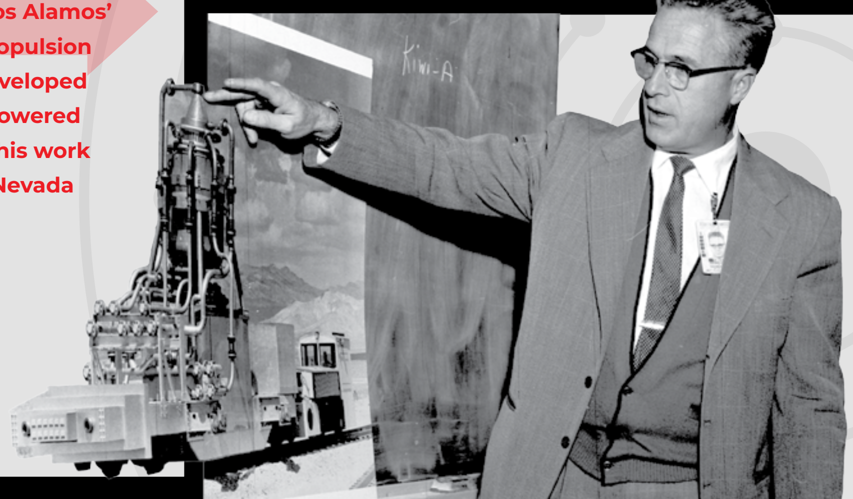
—President Dwight Eisenhower during his "Atoms for Peace" speech

1954: The PUREX (plutonium uranium reduction extraction) process is employed at the Savannah River Site to separate plutonium from spent reactor fuel. This process makes it easier to purify plutonium for use in nuclear weapons and power reactors.

1957: The International Conference on Plutonium is held in Chicago, Illinois. This is followed by other plutonium conferences in 1960, 1965, 1970, and 1975. In 1997, Los Alamos revives the concept with the "Plutonium Futures—the Science" conference, held in Santa Fe, New Mexico. This is followed by 10 more, in different locations, and an 11th planned for 2022 in Avignon, France.

1958: Construction begins on the Nevada Test Site's Nuclear Rocket Development Station, which will explore the use of atomic energy for spacecraft propulsion.

Physicist Raemer Schreiber was the head of Los Alamos' Nuclear Rocket Propulsion Division, which developed the first nuclear-powered rockets. Much of this work took place at the Nevada Test Site.



1958 Rabideau and Kline, "Kinetics of Oxidation Reduction Reactions of Plutonium. The Reaction Between Plutonium(VI) and Plutonium(III) in Perchlorate Solution."

1958 Bochvar, Konobeevskii, Kutaitsev, Men'shikova, Chebotarev, "Interaction Between Plutonium and Other Metals in Connection with Their Arrangement in Mendeleev's Periodic Table."

1960 Elliott and Gschneidner, "Behavior of Some Delta-stabilized Plutonium Alloys at High Pressures."

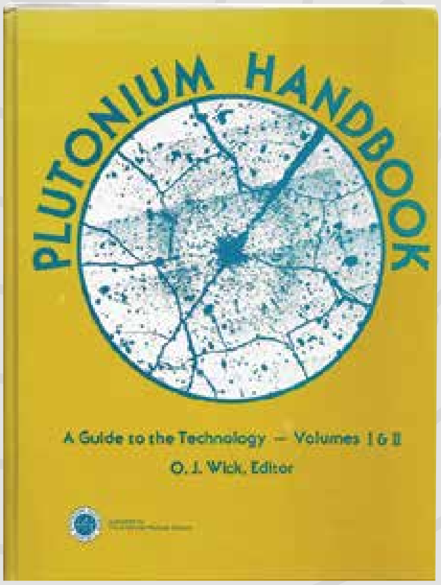
1961 Zachariasen, "Crystal-structure Studies of Plutonium Metal."

1961 Olsen, et al., "The Self-irradiation of Plutonium and its Delta Alloys."

1962 Lee, Mendelssohn, and Wigley, "Accumulation of Radiation Damage in Plutonium."

1962 Olsen and Elliott, "Effects of Impurities and Self-irradiation on the Electrical Resistivity of Alpha-phase Plutonium Below 300°K."

1965 Wigley, "Effect of Annealing on the Resistivity of Self Damaged Plutonium."



1967: The *Plutonium Handbook*, the authoritative source on plutonium science and technology edited by metallurgist O.J. Wick, is published.

January 17, 1966: During a mid-air refueling, a U.S. Air Force B-52 bomber collides with a tanker aircraft above the Mediterranean Sea. The B-52's four thermonuclear bombs land near Palomares, Spain. No nuclear explosions occur, but the area is contaminated with radioactive plutonium. The incident results in increased safety measures to ensure that no nuclear yield will ever occur in the event of an accident.

The casings of two bombs involved in the Palomares accident are on display at the National Museum of Nuclear Science and History in Albuquerque, New Mexico.

1963: Mixed uranium and plutonium oxide (MOX) fuel, recovered plutonium from used reactor fuel that is mixed with uranium, is used in a Belgian reactor. MOX fuel provides a means of repurposing weapons-grade plutonium for the production of electricity.

December 30, 1958: Chemical operator Cecil Kelley is exposed to a lethal dose of radiation while working with residual plutonium-239 at Los Alamos. He dies 35 hours later.

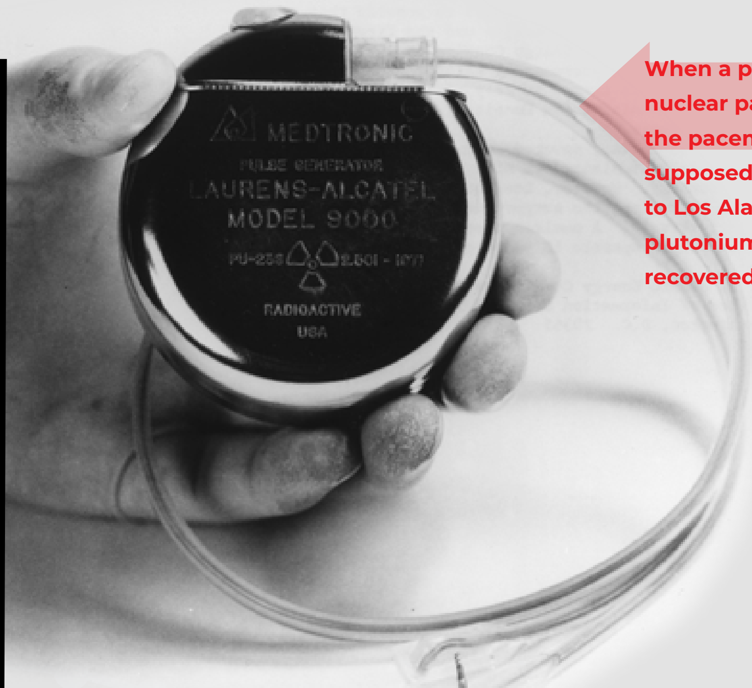
1960

Nuclear power in space

1961: Powered by plutonium-238, SNAP-3 is the first radioisotope thermoelectric generator (RTG)—a kind of nuclear battery—deployed in spacecraft. First used in U.S. Navy satellites, RTGs will power many subsequent spacecraft, including NASA's research probes *Voyager 1*, *Voyager 2*, *Ulysses*, and *Cassini*.

The Transit IV-A satellite was powered by a SNAP-3B radioisotope-powered generator that produced 2.7 watts of electrical power—about enough to light an LED bulb.

Photo: NASA/Gayle Dibiasio



When a person with a nuclear pacemaker died, the pacemaker was supposed to be returned to Los Alamos so the plutonium could be recovered.

Department of Energy created

"LOS ALAMOS STAFF MEMBERS HAVE PIONEERED MUCH OF THE TECHNOLOGY."

—O.J. Wick, editor of the *Plutonium Handbook*

April 27, 1970: The first plutonium-powered pacemaker is implanted in a human. Nuclear pacemakers are used until the mid-1980s, when improved lithium-ion battery technology renders them obsolete.

1970

1978: Los Alamos' state-of-the-art Plutonium Facility (PF-4) becomes fully operational.

August 4, 1977: The Department of Energy (DOE) is created and replaces the Energy Research and Development Administration, which had replaced the Atomic Energy Commission two years earlier.

1971: Los Alamos chemist Darleane Hoffman discovers naturally occurring plutonium-244 among a phosphate mineral deposit from the Precambrian era, a discovery that demonstrates that plutonium can be found in nature.

Darleane Hoffman at Los Alamos.

1970 Morgan, "New Pressure-temperature Phase Diagram of Plutonium."

1970 Karraker, Stone, Jones, and Edelstein, "Bis(Cyclooctatetraenyl) Neptunium(IV) and Bis(Cyclooctatetraenyl) Plutonium(IV)."

1973 Starks and Streitwieser, "Preparation of Di-.pi.-cyclooctatetraene Complexes of Uranium, Thorium, and Plutonium by Direct Reaction of the Metals with Cyclooctatetraene."

1976 Chebotarev and Utkina "Relationship Between Structure and Some Properties of Delta-Pu and Gamma-U Alloys."

1980

1983: At Los Alamos, physicists James Smith and Edward Kmetko design a binary phase diagram, charting how temperature and pressure affect the atomic structure of actinides, which are the radioactive elements with atomic numbers 89 to 103. This diagram makes plutonium's behavior more predictable for researchers and metallurgists.

1989: The FBI raids the Rocky Flats Plant amid violations of environment safety regulations. Rocky Flats stops plutonium production, and the plant closes in 1992. The site undergoes a years-long cleanup effort, after which the area is split into two areas: 1,300 acres of restricted area and the 5,237-acre Rocky Flats National Wildlife Refuge.

Workers use glove boxes at the Los Alamos Plutonium Facility in 1978.

PF-4 operational

Soviet President Mikhail Gorbachev (left) and U.S. President George H.W. Bush.

Photo: U.S. Department of State

July 31, 1991: Soviet President Mikhail Gorbachev and U.S. President George H.W. Bush sign the Strategic Arms Reduction Treaty, which eliminates approximately half of the nuclear warheads carried by ballistic missiles.

1990

July 13, 1992: President Bush announces that the United States will stop making fissionable materials for weapons. Plutonium production is suspended.

September 23, 1992: At the Nevada Test Site, the United States conducts its final nuclear test, Divider.

Preparations are made for the Divider underground nuclear test.

October 2, 1992: President Bush signs legislation that establishes a unilateral nine-month moratorium on U.S. nuclear testing. Bush's successors extend this moratorium.

January 3, 1993: President Bush and Russian President Boris Yeltsin sign the Strategic Arms Reduction Treaty (START II), which reduces each nation's arsenal of long-range nuclear weapons.

1993: DOE instructs Los Alamos to begin producing a limited number of plutonium pits.

1994: The National Defense Authorization Act, which requires a program be put in place to maintain the nation's nuclear stockpile, results in the establishment of the Stockpile Stewardship Program.

A worker uses a glove box to safely handle nuclear materials for the ARIES program.

Nuclear-Test-Ban Treaty

September 24, 1996: President Clinton signs the Comprehensive Nuclear-Test-Ban Treaty, which prohibits nuclear testing of any kind. As of 2021, the treaty has yet to be ratified by the U.S. Senate.

"IF A SCIENTIST HAS TECHNICAL KNOWLEDGE THAT IS GOING TO INFLUENCE THE DEBATE [ABOUT NUCLEAR WEAPONS], THEN HE MUST PARTICIPATE."

—Nuclear physicist Jane Hall, who, in 1955, became the first female assistant director of Los Alamos

An artist's rendering depicts the Plutonium Facility at Los Alamos in the 1970s.
Photo: Department of Energy

1995: President Bill Clinton announces that the United States will remove 200 metric tons of fissile materials from its stockpile. The announcement spurs the development of Los Alamos' Advanced Recovery and Integrated Extraction System (ARIES), which will convert surplus plutonium weapons pits to plutonium oxide—a compound of plutonium and oxygen—that can be processed into MOX fuel for use in nuclear power reactors. In 1999, the ARIES program demonstrates its feasibility, and by 2021, the ARIES program disposes of one metric ton of plutonium.

1976 Ledbetter and Moment, "Elastic Properties of Face-centered-cubic Plutonium."

1978 Lloyd and Haire, "The Chemistry of Plutonium in Sol-gel Processes."

1992 Zwick, Sattelberger, and Avens, "Transuranium Organometallic Elements."

1994 Martz, Haschke, and Stakebake, "A Mechanism for Plutonium Pyrophoricity."

Located 960 feet below ground, the U1a facility at the Nevada National Security Site comprises a series of tunnels in which subcritical and physics experiments are performed.
Photo: NNSS

1997: The United States begins subcritical experiments at the Nevada Test Site. During these experiments, nuclear materials are tested without bringing them to the point of criticality.

Subcritical testing begins

2000

1999: The Waste Isolation Pilot Plant (WIPP), near Carlsbad, New Mexico, opens. WIPP is a long-term storage facility for transuranic radioactive waste, which contains man-made elements heavier than uranium, including plutonium.

Salt deposits provide stable environments for disposal of radioactive waste. Formed about 250 million years ago, the primary salt formation at WIPP is about 2,000 feet thick, beginning 850 feet below the surface.
Photo: WIPP

A shipment of transuranic waste makes it way to WIPP.
Photo: WIPP

2000: The United States and the Russian Federation mutually agree to convert 34 metric tons of weapons-grade plutonium to MOX fuel before the end of 2019. But the agreement never reaches fruition. In 2015, Russia suspends the agreement, and, in 2016, the United States ends construction of its MOX fuel facility at Savannah River.

1999 Lashley, et al., "In Situ Purification, Alloying, and Casting Methodology for Metallic Plutonium."

2000 Haschke, Allen, and Morales, "Reaction of Plutonium Dioxide with Water: Formation and Properties of PuO_{2+x}."

2000 Savrasov and Kotliar, "Ground State Theory of δ-Pu."

“

PLUTONIUM ARGUABLY EXHIBITS THE MOST COMPLEX ELECTRONIC STRUCTURE OF ALL THE ELEMENTS.”

—David Clark, Laboratory Fellow

2000: Congress establishes the National Nuclear Security Administration (NNSA) to enhance national security through the military application of nuclear science. NNSA oversees Los Alamos and several other DOE laboratories, plants, and sites.

NNSA established

2003: The Joint Actinide Shock Physics Experimental Research (JASPER) facility is used as part of the Stockpile Stewardship Program to test the effects that changing temperature and pressure can have on aging plutonium.

2000s: The Los Alamos Neutron Science Center (LANSCE) measures plutonium’s cross-sections, which dictate the probability that a reaction will occur under certain circumstances—in this case, the likelihood that plutonium-239 will convert to plutonium-238 when bombarded with neutrons. These measurements allow researchers to better understand how plutonium pits will perform when detonated.

In addition to national security research, LANSCE provides researchers with intense sources of neutrons and protons to perform experiments supporting civilian research and the production of medical and research isotopes.

JASPER experiments help scientists understand important properties and behaviors of plutonium.

2002 Sarrao, Morales, Thompson, and Scott, “Plutonium-based Superconductivity with a Transition Temperature Above 18K.”

2003 Wong, Krisch, Farber, Occelli, Schwartz, Chiang, Wall, Boro, Xu, “Phonon Dispersions of fcc δ-Plutonium-Gallium by Inelastic X-ray Scattering.”

2003 Lashley, et al., “Experimental Electronic Heat Capacities of Alpha- and Delta-plutonium: Heavy-fermion Physics in an Element.”

2004 Fluss, Wirth, Wall, Felter, Caturla, Kubota, and Rubia, “Temperature-dependent Defect Properties from Ion-irradiation in Pu(Ga).”

A scale weighs more than 100 grams of plutonium-238.

Plutonium is heated by coils at PF-4.

2000–2004: Los Alamos leads a series of experiments, in collaboration with Lawrence Livermore National Laboratory, that artificially age plutonium 60 years. The results indicate that plutonium pits change over time, which might necessitate their eventual replacement.

May 2003: Los Alamos completes Qual-1, the first nuclear weapons pit that meets or exceeds the quality of the pits produced at Rocky Flats. Unlike Rocky Flats' pits, which were produced by rolling plutonium flat and pressing it into shape, Qual-1 is created by casting molten plutonium.

2005: A study of plutonium compounds at Lawrence Berkeley National Laboratory, conducted using scanning transmission x-ray microscopy (STXM), opens the door to further investigations using STXM. STXM helps researchers study very small quantities of substances such as plutonium dioxide, which can be produced from dismantled weapon pits and used in MOX fuel.

March 23, 2005: The Jason group, a panel of experts that advises the U.S. government on scientific matters, stresses the importance of quantification of margins and uncertainties (QMU) for plutonium aging and weapons systems. QMU helps those working in the post-testing era make informed risk assessments when evaluating the stockpile.

PF-4 employees work in a glove box.

2006: The Jason group concludes there isn't enough proof to support a plutonium pit aging issue.

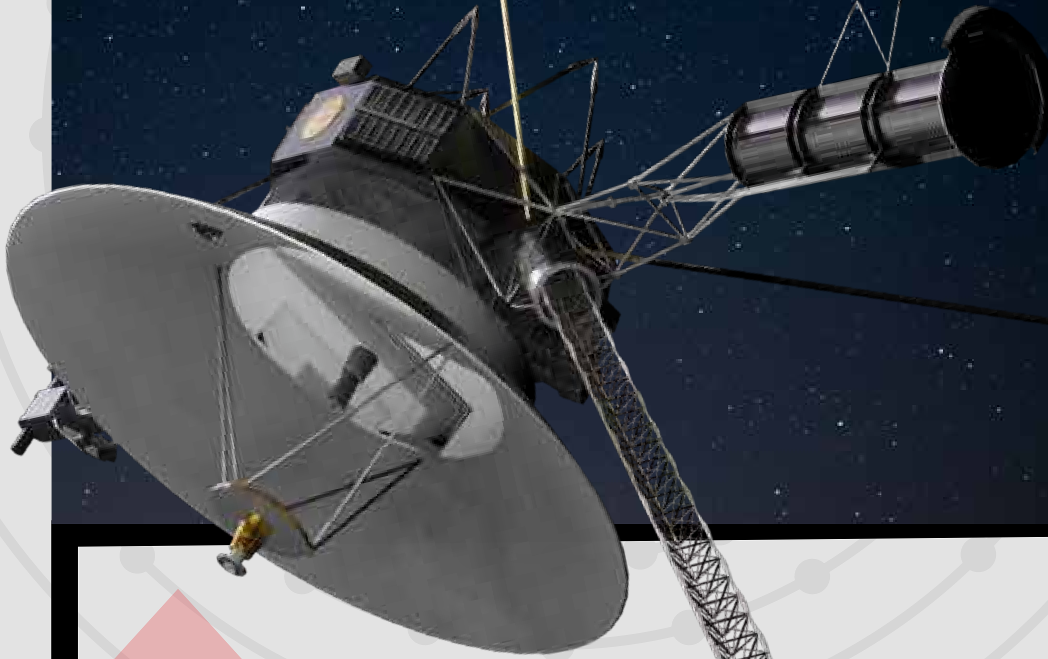
2007: Los Alamos reaches the ability to produce 10 pits per year, a requirement handed down by NNSA and Congress.

2007: Los Alamos completes Prod-1, the first of 31 replacement pits for W88 warheads. All 31 will be delivered by 2011.

2009: NNSA designates Los Alamos National Laboratory as the Nation's Plutonium Center of Excellence for Research and Development.

2010

March 11, 2011: The Tōhoku earthquake and tsunami begin a sequence of events resulting in the meltdowns of three nuclear reactors at the Fukushima Daiichi Nuclear Power Plant in Ōkuma, Japan. One of the reactors used a MOX core, and small amounts of plutonium are released from the damaged reactor. The disaster is the worst nuclear accident since the meltdown of a uranium-fueled reactor at the Soviet Chernobyl Nuclear Power Plant in 1986.



From 1979 to 1989, the *Voyager 2* flew by Jupiter, Saturn, Uranus, and Neptune. In 2021, 44 years after its launch, the space probe is collecting data about interstellar space.

Photo: NASA

Interstellar space is reached

August 25, 2012: *Voyager 1*, launched by NASA in 1977 and powered by plutonium-238, becomes the first man-made object to reach interstellar space, the space between the Milky Way galaxy and other star systems.

August 6, 2012: The *Curiosity* rover, which is powered by a plutonium heat source designed at Los Alamos, lands on Mars.

2012: Los Alamos conducts the first nuclear magnetic resonance measurement of plutonium-239. This measurement allows for the detection of plutonium's magnetic resonance signature, which is produced when a magnetic field perturbs the element's nucleus.

“SPACE. THE FINAL FRONTIER.”

—John Grunsfeld, NASA's associate administrator of science missions, quotes *Star Trek* after *Voyager 1* reaches interstellar space

2006 McCall, et al., “Emergent Magnetic Moments Produced by Self-damage in Plutonium.”

2007 Migliori, Mihut, Betts, Ramos, Mielke, Pantea, Miller, “Temperature and Time-dependence of the Elastic Moduli of Pu and Pu-Ga alloys.”

2011 Suzuki, Fanelli, Betts, Freibert, Mielke, Mitchell, Ramos, Saleh, Migliori, “Temperature Dependence of Elastic Moduli of Polycrystalline Beta Plutonium.”

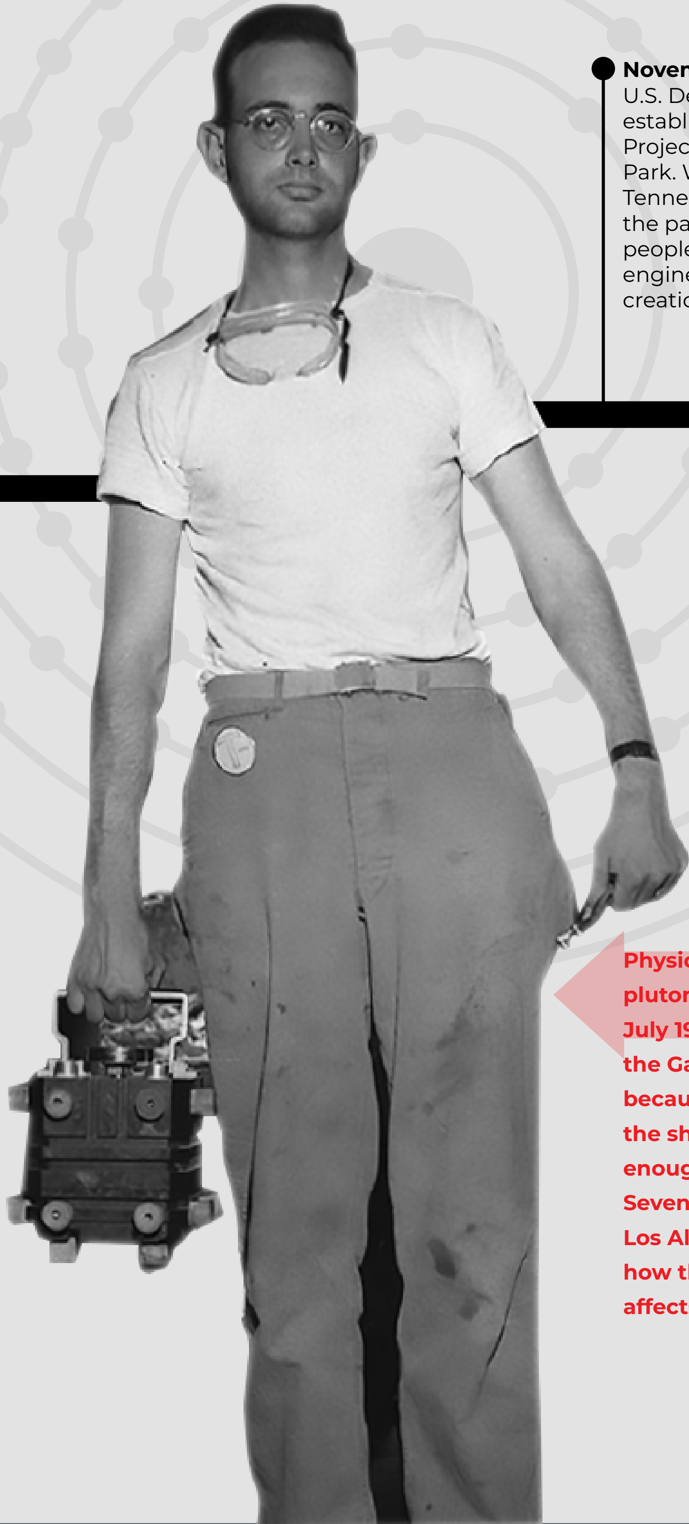
2012 Yasuoka, Koutroulakis, Chudo, Richmond, Veirs, Smith, Bauer, Thompson, Jarvinen, Clark, “Observation of 239Pu Nuclear Magnetic Resonance.”

November 2015: DOE and the U.S. Department of the Interior establish the Manhattan Project National Historical Park. With sites in New Mexico, Tennessee, and Washington, the park tells the story of the people, events, science, and engineering that led to the creation of the atomic bomb.

2015: A team of scientists led by Los Alamos' Marc Janoschek confirm plutonium's long-theorized magnetism. Because plutonium's magnetic field is in a state of constant flux, its magnetism—a quality that arises from the interaction of its electrons—had previously been impossible to measure. This breakthrough helps explain how small changes in temperature and pressure affect plutonium's volume.

Collaboration in 2015 between Los Alamos and Oak Ridge National Laboratory provided an explanation for the missing magnetism of plutonium.

Photo: ORNL



Physicist Herb Lehr carries the plutonium core for the Gadget in July 1945. Before being placed in the Gadget, the core swelled because of heat and was placed in the shade so it would shrink enough to fit inside the device. Seventy years later, in 2015, Los Alamos pioneered research on how the temperature of plutonium affects its volume.

2012 Booth, Jiang, Wang, Mitchell, Tobash, Bauer, Wall, Allen, Sokaras, Nordlund, Weng, Torrez, and Sarrao, "Multiconfigurational Nature of 5f Orbitals in Uranium and Plutonium Intermetallics."

2017 Windorff, Chen, Guo, Cross, Evans, Filipp, Gaunt, Janicke, Kozimor, Scott, "Identification of the Formal +2 Oxidation State of Plutonium: Synthesis and Characterization of $\{Pu^{II}[C_5H_3(SiMe_3)_2]_3\}^-$."

During the Manhattan Project, Emilio Segrè conducted plutonium research in Pond Cabin. "It could be reached only by a jeep trail that passed through fields of purple and yellow asters and a canyon whose walls were marked with Indian carvings," Segrè said. "The cabin-laboratory, in a grove shaded by huge broadleaf trees, occupied one of the most picturesque settings one could dream of." The cabin, built in 1914, is now part of Manhattan Project National Historical Park.

"THE MANHATTAN PROJECT LAID THE GROUNDWORK FOR OUR NATIONAL LAB SYSTEM, WHICH HAS LED TO COUNTLESS SCIENTIFIC BREAKTHROUGHS THAT BENEFIT HUMANITY."

—Secretary of Energy Ernest Moniz upon the establishment of Manhattan Project National Historical Park

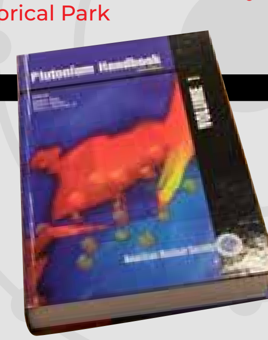
Secretary of the Interior Sally Jewell addresses a crowd shortly after the creation of Manhattan Project National Historical Park, which is the 409th park in the National Park System.

Photo: NPS/Anthony DeYoung

February 2018: The Department of Defense's Nuclear Posture Review states that by 2030, the United States will produce no fewer than 80 plutonium pits per year. The NNSA directs that 30 pits per year will be produced at Los Alamos, starting in 2026. Fifty pits per year will be produced at the Savannah River Site, starting in 2030.

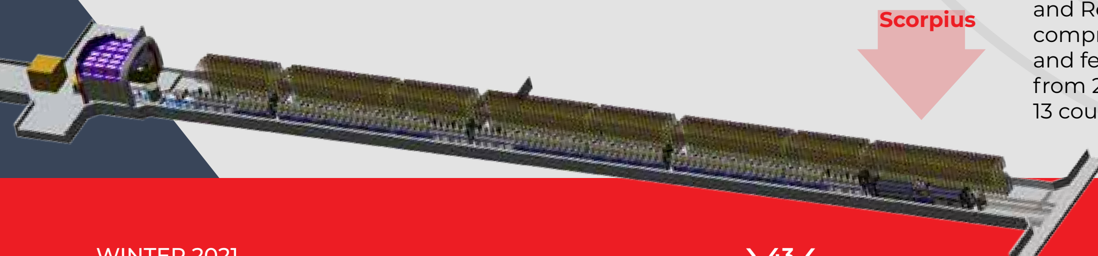
2018: Los Alamos leads a multiagency portfolio that will include the development of Scorpius, a 20 megaelectronvolt linear accelerator, at the Nevada National Security Site. The accelerator will allow for the subcritical study of plutonium's behavior during the final stages of implosion. Scorpius is expected to be operational by 2025.

2019: The Jason group releases a study that assesses plutonium pit lifetimes. In the unclassified summary, the authors "urge that pit manufacturing be re-established as expeditiously as possible in parallel with the focused program to understand Pu [plutonium] aging, to mitigate against potential risks posed by Pu aging on the stockpile."



2019: The American Nuclear Society publishes a second edition of the *Plutonium Handbook*. The update, coordinated by a team at Los Alamos and edited by David Clark, David Geeson, and Robert Hanrahan, comprises seven volumes and features contributions from 215 authors from 13 countries.

Scorpius



Welding is one of many steps in plutonium pit production at Los Alamos' PF-4.

Pit production ramps up at Los Alamos

August 19, 2020: Much of the Rocky Flats archive arrives in Los Alamos. The archived documents will aid the Laboratory's pit production mission. For more, see "Raiders of the lost archive" in the summer 2020 issue of this magazine.

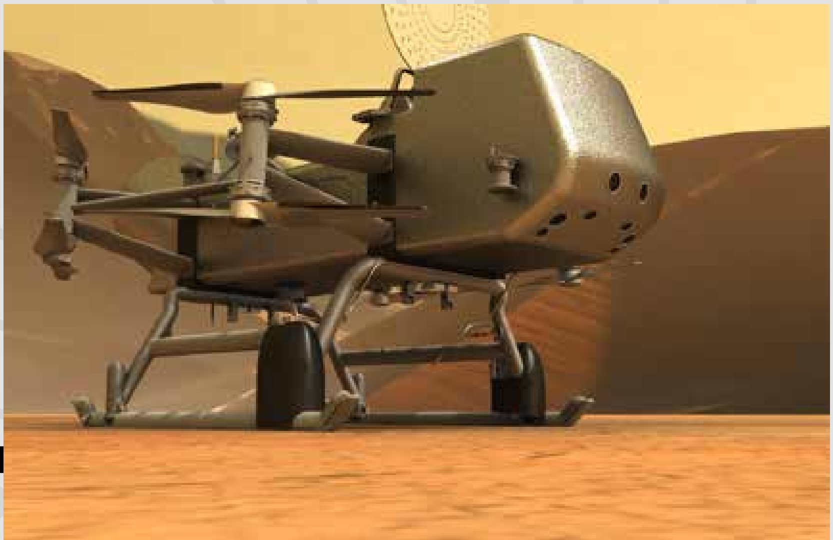
July 30, 2020: The *Perseverance* rover is launched; it lands on Mars nearly six months later. The rover is powered by a Los Alamos–manufactured multi-mission radioisotope thermoelectric generator that contains plutonium-238.

The *Perseverance* rover's multi-mission radioisotope thermoelectric generator is powered by plutonium-238 oxide produced at Los Alamos.

Photo: NASA/JPL-Caltech

2019: Los Alamos produces five research and development pits, kicking off the 30-pits-per-year mission. At the same time, Los Alamos delivers its official plan to reach that level of production.

> "WE CAN MAKE A NUCLEAR-POWERED BATTERY THAT KEEPS INSTRUMENTATION RUNNING LONG ENOUGH TO REALLY BE ABLE TO EXPLORE."
>
> —Jackie Lopez-Barlow, Los Alamos radioisotope program manager



Plutonium headed to Saturn

May 2021: Los Alamos provides eight plutonium-powered heat sources for NASA's Dragonfly, which will fly to Titan, one of Saturn's moons, in 2026.

The nuclear-powered Dragonfly is expected to arrive on Titan 2034.

Photo: NASA/Johns Hopkins APL

July 2021: Nightshade, a series of subcritical experiments, begins at the Nevada National Security Site.

PF-4 at Los Alamos today.

> "IT IS ESSENTIAL TO CAPTURE AND DOCUMENT THE SCIENCE AND TECHNOLOGY OF PLUTONIUM TO HELP TRAIN A FUTURE GENERATION OF SCIENTISTS AND ENGINEERS."
>
> —Former Laboratory Director Siegfried Hecker in his foreword to the second edition of the *Plutonium Handbook*.

2022

Pu TODAY

Subject matter expertise was contributed by David Clark, Franz Freibert, and Bob Putnam.

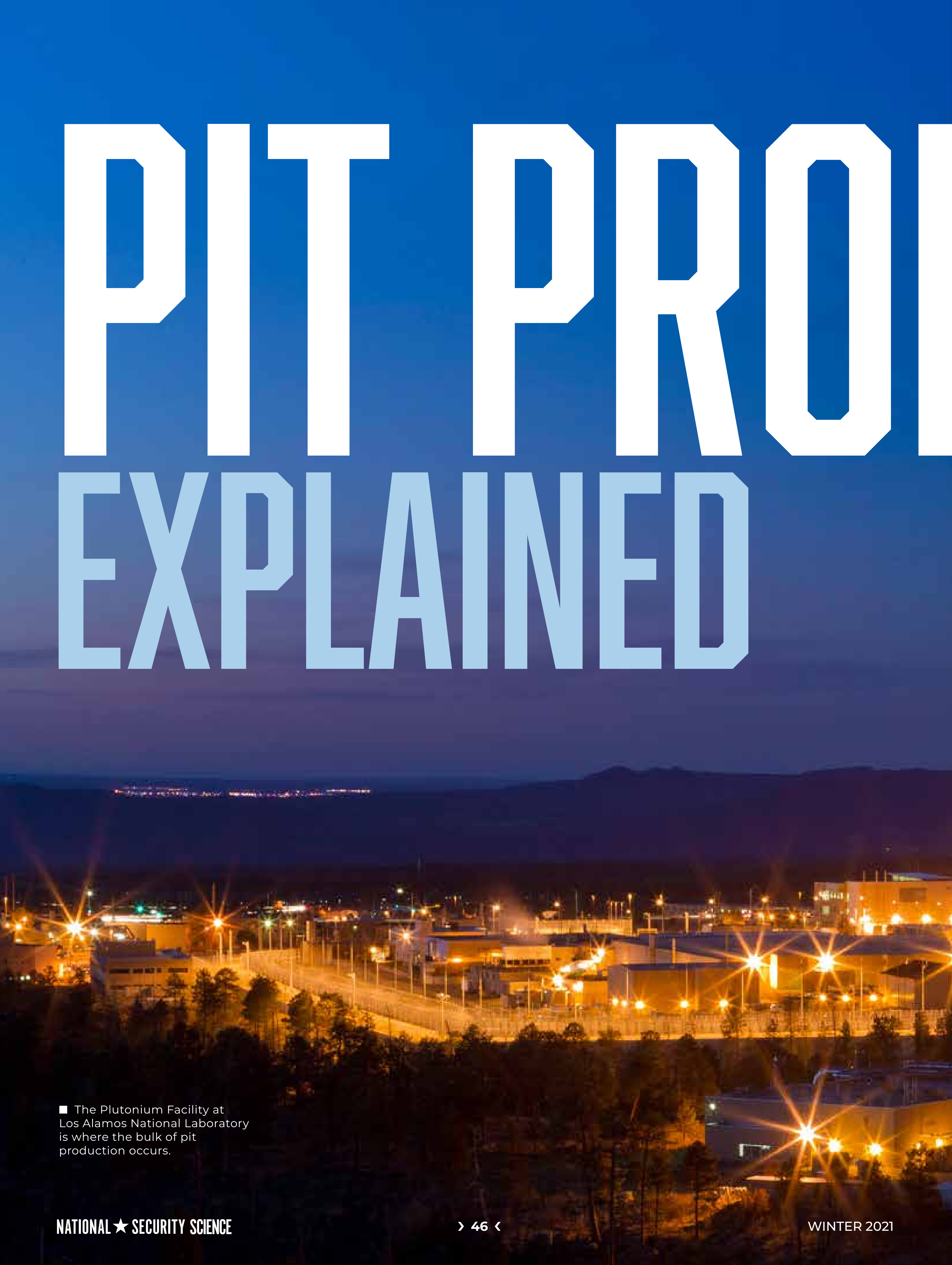
Jake Bartman, Brenda Fleming, and Sierra Sweeney contributed to this feature.

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

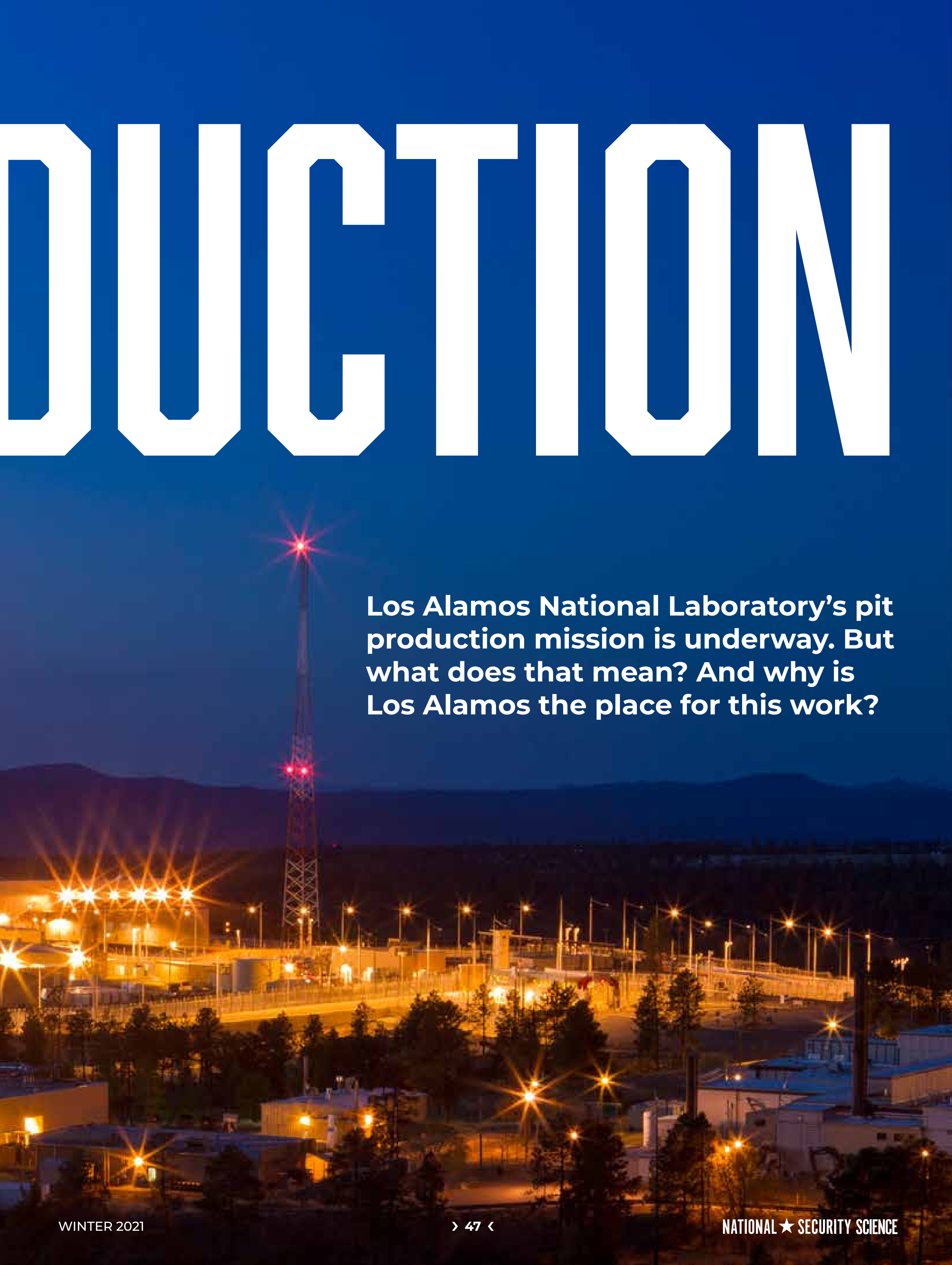
The history of plutonium is closely aligned with the history of the Laboratory. Los Alamos is responsible for much of what is understood about plutonium today.

PIT PRO
EXPLAINED



■ The Plutonium Facility at Los Alamos National Laboratory is where the bulk of pit production occurs.

DUCTION



Los Alamos National Laboratory's pit production mission is underway. But what does that mean? And why is Los Alamos the place for this work?

■ A vacuum induction furnace safely melts and casts molten plutonium metal. In the furnace's upper chamber (pictured), molten plutonium is mixed with alloys before being released to flow via gravity into a casting mold.

ACCORDING TO *MERRIAM WEBSTER*, A "PIT" can be a cavity in the ground, the stone of a drupaceous fruit, or the name of a river in northern California.

Employees at Los Alamos National Laboratory are most familiar with a definition of pit that's not in the dictionary. To this workforce, a pit is a hollow sphere of plutonium that, when uniformly compressed by explosives inside a warhead or bomb, causes a nuclear explosion.

Los Alamos produced the first plutonium pits in 1945, during the Manhattan Project. These pits were used in the atomic bombs detonated in the Trinity test and above Nagasaki, Japan. Since the end of World War II, Los Alamos has done limited pit production for research purposes and, from 2007 to 2011, to replace the pits in 31 W88 warheads (these warheads are carried on submarine-launched missiles).

From 1952 to 1989, the majority of plutonium pits for U.S. nuclear weapons were manufactured at the Rocky Flats Plant near Denver, Colorado. During that time—the throes of the Cold War—the nuclear weapons stockpile was constantly evolving; new weapons with new pits were designed, manufactured, and tested one after another. At its height in 1967, the stockpile comprised 31,225 weapons, each with a plutonium pit inside.

While pits were produced by the thousands per year in Colorado, Los Alamos was becoming the nation's Plutonium Center of Excellence for Research and Development (an official title bestowed by the National Nuclear Security Administration [NNSA] in 2009). In other words, the Laboratory was making every effort to learn and understand plutonium's complexities and the effects of its aging. Because plutonium, a man-made element, had been around only since 1940, a lot was still unknown about its behavior. Los Alamos became the place where scientists went to find out more.

What scientists discovered over the years is that plutonium is unstable and radioactively decays over time. This means that, in an effort to reach a more stable state, plutonium emits alpha particles, neutrons (through spontaneous fission), beta particles, and gamma rays. Plutonium can also absorb neutrons. Eventually, the loss or gain of these particles causes the plutonium to transform into daughter products, such as uranium, neptunium, and americium.

In plutonium pits, these daughters start to build up as impurities. They don't perform or behave the way plutonium does, and they can even react with the original plutonium. Over decades, as more of the plutonium in the pit is transformed, the total mass of plutonium decreases.

Plutonium decay can also break down molecular bonds in neighboring materials and cause helium bubbles that change the characteristic properties of the plutonium.

But do these changes matter? Do aging plutonium pits pose a risk to the nuclear stockpile?

Analyzing aging

The most obvious way to learn if aging plutonium pits are less reliable is to test one—to detonate it and study the resulting effects and data. However, the Comprehensive Nuclear-Test-Ban Treaty, signed (but not ratified) by the United States in 1992, prohibits nuclear testing of any kind.

Instead, scientists rely on surveillance (pulling weapons from the stockpile for nonnuclear testing and monitoring, see p. 53) and applied research consisting of nonnuclear experiments, computer simulations, and data from historical nuclear tests.

For example, starting in the early 2000s, Los Alamos' Franz Freibert led plutonium-aging experiments in collaboration with Lawrence Livermore National Laboratory in which plutonium was aged 60 years in 4 years. These and other experiments offered scientific proof that the material properties of plutonium pits *do* change over time in ways that could affect the performance of nuclear weapons, even if a pit's "best before" date is beyond the reach of our current scientific understanding.

In 2019, the independent scientific advisory group Jason released a study that assessed plutonium pit lifetimes. The study, a follow up to the 2006 Jason report that concluded there *wasn't* enough proof to support a plutonium aging issue, stated that plutonium aging might in fact eventually impact the reliability of U.S. nuclear weapons. In the unclassified summary, the authors "urge that pit manufacturing be re-established as expeditiously as possible in parallel with the focused program to understand Pu [plutonium] aging, to mitigate against potential risks posed by Pu aging on the stockpile."

With this sudden paradigm shift, concern about aging pits has become more palpable in recent years. How much longer will pits last?

"We don't have an immediate concern with aging," says Los Alamos Director Thom Mason. "Up to this point, the plutonium pits in America's nuclear weapons have been very robust. But the pits we have today were largely manufactured in the 1980s, and we don't have the predictive ability to say with certainty that our current, 40-year-old pits will be good until any particular date. It's sort of glass half full, glass half empty; we can't prove that they will fail, but we also can't prove that they will work."

The best way to deal with this dilemma is to "take it off the table," Mason explains. "We do that by making new pits, immediately."

To do this, the Department of Defense (DOD) and NNSA (which oversees Los Alamos) turned to the only facility in the country where this type of work could be immediately restarted—the Plutonium Facility (PF-4)

"It's sort of glass half full, glass half empty; we can't prove that [pits] will fail, but we also can't prove that they will work."

—THOM MASON


Plutonium Pit Manufacturing
AT LOS ALAMOS
Receive from Pantex
Receipt and packaging
Receive and unpack pits from the Pantex Plant near Amarillo, Texas
Pit disassembly
Disassemble old pits to recover the plutonium to feed new pit manufacturing
Old metal
Metal preparation
Remove stable and radioactive impurities from the feed plutonium
Spec metal
Foundry
Melt, alloy, cast, and anneal pure plutonium into a blank for machining
Machining blanks
Machining & inspection
Machine cast plutonium and inspect using radiography, dimensional inspection, and density
Machined hemishells
Assembly & joining
Assemble plutonium and nonnuclear shells and perform welding to seal the pit against the environment
Finished assemblies
Post assembly
Perform final inspection and nondestructive testing of the pit
Finished assemblies
Pit quality acceptance
Remove stable and radioactive impurities from the feed plutonium
Ship to Pantex
Storage
Securely store plutonium-bearing items, including residues, oxides, metals, components, and pits
Solid waste management
Stage, characterize, and ship low-level and transuranic waste (which primarily contains tools, gloves, and other items that have been in contact with hazardous materials) to the appropriate disposal site
Liquid waste management
Remove radioactive elements from liquid waste streams so that effluent can be discharged to the environment
Nitrate & chloride recovery
Dissolve plutonium by-products and residues in acid to recover plutonium from the residue stream
Materials characterization
Analyze plutonium metal samples for physical properties, such as grain size, surface chemistry, and strength
Analytical chemistry
Analyze plutonium samples to ensure chemical and isotopic constituents are within specifications

> “Pit production today is more of a craftsman activity. It’s very exacting work.”
>
> —THOM MASON

at Los Alamos. NNSA has tasked the Lab with developing a pit production process and delivering a minimum of 30 pits per year by 2026. PF-4 is the right-size solution for a right-now problem, Mason explains. “Waiting any longer would put us behind the curve in terms of production schedule, which would translate to needing a larger production facility with higher throughput.”

Another facility, the Savannah River Site, in South Carolina, has also been tasked with producing pits. Using the Los Alamos process, Savannah River is planning to deliver 50 pits per year by 2030.

Salvaging plutonium

Pits were historically manufactured using new plutonium, but the United States stopped producing fissionable plutonium for nuclear weapons in 1992, when President George H.W. Bush suspended production. So how can new pits be made from old plutonium, especially if aging plutonium is the problem?

On paper, the answer is simple: Los Alamos will salvage usable plutonium from old pits to make new pits.

In reality, this is a long and complex process that begins at the Pantex facility near Amarillo, Texas, where an aging pit is removed from a weapon, packaged, and shipped to Los Alamos. Upon arrival at PF-4, the pit is disassembled.

First, impurities—daughter products—are separated from the plutonium through pyrochemistry, or chemical activity at high temperatures. “This generates purified plutonium metal as a product, while the impurities are separated into a fused salt,” explains David Kimball of the Lab’s Materials Recovery and Recycle group. “These salts and other impure by-products become feed for further purification via aqueous chloride or aqueous nitrate processing. After dissolving the impure salts in acid, the remaining plutonium that was not converted to metal in pyrochemistry operations is recovered and purified into an oxide suitable for storage or conversion back to metal.”

The waste generated from this process is radioactive and requires proper disposal. Both Los Alamos and Savannah River will send this waste to the Waste Isolation Pilot Plant near Carlsbad, New Mexico, for safe, long-term geologic disposal in deep salt beds 2,150 feet underground. "Waste disposal is critical to the ramp-up of pit production," Mason says, "and it has to be done in real time—keeping up with the production—so that we don't build a backlog."

Salvaged plutonium from multiple old pits is necessary to make one new pit. Once enough plutonium has been salvaged, it is sent to be cast into a mold at the PF-4 foundry. The plutonium is inspected at this stage, and samples are sent to the Analytical Chemistry group, where they undergo tests to ensure that the chemical and isotopic properties of the plutonium are within predetermined parameters.

Pieces of cast plutonium are then welded together to form a pit. Pits are carefully examined using a variety of processes and technologies. Computed tomography, for example, is a digital imaging capability similar to a medical CT scan that provides a detailed characterization of a final pit assembly.

Once a pit has passed inspection, it is diamond stamped—literally stamped with a diamond shape—as a visual indicator it has met all design, manufacturing, and quality requirements and that it is ready to be used in the stockpile. Karen Haynes leads the Lab's Production Agency Quality division, which, upon delegation from NNSA, performs the diamond stamping. "Our division is comprised of quality analysts, engineers, and inspectors," she says. "We provide the evidence and level of confidence that products meet the exacting quality requirements necessary, such as ensuring there aren't any defects in a product and that it will function as intended."

The plutonium's journey comes full circle as the pit is shipped back to Pantex, where it is placed back into a stockpiled weapon.

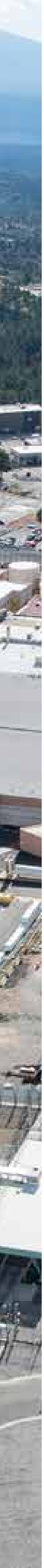
Mason describes the whole process as "kind of artisanal," especially when compared to mass production of pits at Rocky Flats. "Pit production today is more of a craftsman activity," he says. "It's very exacting work."

Bob Webster, deputy Laboratory director for Weapons at Los Alamos, agrees. "We're talking about making in a year what Rocky Flats could have made in a week," he says.

Redundancy and relationships

Los Alamos and Savannah River must succeed independently and together to reach the goal of 80 pits

■ The Plutonium Facility at Los Alamos, with the Rio Grande valley and the Sangre de Cristo mountains in the background.



WEAPONS SURVEILLANCE

Careful inspection of nuclear weapons in the stockpile ensures their safety, reliability, and performance.

BY KATHARINE COGGESHALL

Because the United States does not detonate its nuclear weapons to ensure reliability, weapons must be surveilled—inspected inside and out to ensure they will work. Surveillance is a critical part of the Stockpile Stewardship Program, which—through nonnuclear experiments and computer simulations—gives scientists and engineers the confidence they need to ensure the safety, security, and effectiveness of the nuclear weapons in the U.S. stockpile.

"All U.S. weapon components are surveilled using both nondestructive and destructive techniques," explains Sheldon Larson, Los Alamos Weapons Systems Surveillance group leader. "That begins with disassembling each weapon at the Pantex Plant near Amarillo, Texas."

Nondestructive techniques leave the weapon fully functional and ready to go back into the stockpile, if needed. These techniques involve everything from visually inspecting the exterior of each component to using advanced imaging systems to examine the interior. A great deal can be learned from nondestructive techniques, such as how a weapon is aging and whether it has obvious defects.

"We think of it as a health checkup," says Los Alamos surveillance engineer Miguel Santiago Cordoba.

From there, a down-selection process happens, and a small number of weapons are chosen for further testing, which involves destructive techniques. Some questions can be answered only by cracking open a weapon—and all of its parts and pieces. Destructive surveillance offers a more complete picture of a weapon's health, but with the caveat that those components cannot return to the stockpile.

"We can't destructively surveil all the weapons in the stockpile," Cordoba explains. Not only would it be impractical to destroy and then rebuild the entire stockpile, but it would also be costly. Instead, destructively surveilling a small sample of weapons allows scientists and engineers to extrapolate the reliability of the larger population of weapons. "This sampling is enough to detect a 10 percent defect in the stockpile with 90 percent probability within two years," Cordoba says.

"At Los Alamos, we surveil detonators and pits of nuclear weapons," Larson says. Los Alamos has been a detonator production facility since the closure of the Mound Plant in 2003, in addition to its designation as a pit production facility. Whichever institution produces a specific weapon component is typically also the institution that performs the destructive surveillance. "Surveillance spans the nuclear weapon enterprise," Larson explains. "It involves all of the National Nuclear Security Administration's sites and all of the weapons systems. It's a very interactive and collaborative partnership."

Surveillance is also an ever-changing field because technology is advancing at a rapid pace. The surveillance tools and techniques available now were impossible at the time these parts were made, back in the Cold War. "We are always looking to improve our technologies," Larson says. "For example, now we can see inside components in 3D, something we couldn't do back when these pits were originally made. We have a lot of tools in our toolbox now, and we have to know when to use what."

Surveillance is a complicated task, especially when anomalies are detected. There isn't a one-size-fits-all approach to test and mitigate an anomaly. New techniques, methods, and assessments are constantly being added to the surveillance repertoire as new situations are observed—the aging nuclear enterprise is not without surprises.

Even those who have been working in surveillance for more than 25 years, such as Patrick Rodriguez, a seasoned surveillance engineer, say they still learn something new every day. "We are at the intersection of many sciences, involved with everyone at all different levels with all different needs." By this, Rodriguez is referring to the physicists and engineers who rely on surveillance data, the technicians and technologists who help acquire that data, and the managers and directors who use the interpretation of that data to guarantee the stockpile.

The culmination of annual surveillance (along with weapon simulations and subcritical experiments, which round out the Stockpile Stewardship Program) is the Annual Assessment Letter—a letter to the president from the directors of Los Alamos, Sandia, and Livermore national laboratories that certifies the safety and reliability of all the weapons in the stockpile. Making that guarantee takes the ingenuity, dedication, and critical thinking of many people across the Laboratory. ★

per year by 2030. But collaboration is tricky because of the physical distance between the sites—1,500 miles—and because of the need to update facilities at both institutions.

Neither Los Alamos nor Savannah River is currently set up for large-scale pit production.

Los Alamos' PF-4 was designed for R&D (research and development) and surveillance; the facility at Savannah River was designed for mixed-oxide fuel fabrication (which never happened). Changes—such as new equipment, updated buildings, new employees, and 24-hour operations—are necessary to turn these facilities into functional pit production facilities. Processes and equipment at both sites must be exactly the same so all pits produced are identical. This concept of being able to create a specific product at more than one production facility is called redundancy.

"The level of cooperation and integration across multiple sites that I have witnessed in the first years of this effort has been outstanding," says Dave Olson, director of the Savannah River Plutonium Production Facility mission. "There is truly a shared vision and commitment to the national plutonium pit production mission."

In 2018, NNSA completed an engineering assessment and workforce analysis of the sites and found that both locations can meet the needed requirements—and meet them safely. No one wants a repeat of Rocky Flats, which was raided in 1989 after the FBI and other agencies caught wind of environmental crimes. Large-scale pit production came to a sudden halt. The plant was declared a Superfund (hazardous waste) site by the Environmental Protection Agency and was officially shut down in 1992.

Today, scientists know more about plutonium handling and hazards (much of it curated by Los Alamos in the 2019 seven-volume second edition of the *Plutonium Handbook*). "Since the United States last did pit production in any sustained way, a lot of the technology has changed, our understanding of plutonium science has advanced, and the world has changed," says Dave Eyler, associate Laboratory director for Weapons Production at Los Alamos. "PF-4 was built and operated until relatively recently as a facility for R&D or surveillance activities that are relatively episodic as opposed to a sustained cadence of production. We're still putting a lot of things in place and learning how to do production while still doing all the R&D and surveillance, too."

In addition to renovating parts of PF-4 to meet production needs, the Laboratory has also been making improvements to the facility to mitigate all types of potential unexpected events. For example, even though large earthquakes are not common in Northern New Mexico, the columns in PF-4 have been rigorously tested to ensure they'll withstand a seismic event.

"Since the United States last did pit production in any sustained way, a lot of the technology has changed, our understanding of plutonium science has advanced, and the world has changed."

—DAVE EYLER

The facility's fire suppression system has also been upgraded, and empty nuclear material containers have been fire tested and drop tested to help ensure no hazardous material will be released in the unlikely event of an accident.

In short, "PF-4 is probably one of the safest places in New Mexico," says Matt Johnson, who leads the Lab's Pit Technologies division. "We want to protect our workers, and we also realize that sustaining public trust and confidence that we can do this safely is priority number one."

When it comes to actually making pits, all plutonium at Los Alamos is handled inside a glove box—a sealed compartment that is accessed through two holes to which gloves are attached. Technicians insert their hands into the gloves and are able to handle the plutonium with no exposure to the element. Glove boxes are located inside secure rooms, inside a secure building, on a secure road in the middle of a secured Laboratory campus.

"We don't do the work if we can't do it safely," Mason says. "We have to get this work done in order to support the nuclear deterrence mission. So being able to operate safely in a complex environment is a prerequisite."

The workforce

Approximately 2,500 people will eventually support the pit mission at Los Alamos. That number includes a handful of people who used to work at Rocky Flats (see p. 58). "But a lot of that expertise is walking out the door as people retire," Mason says. "We need to transfer that knowledge to younger employees now."

Finding new employees who meet stringent hiring qualifications is a challenge, but one that the Laboratory is addressing in specific ways. "We have pipeline programs starting or continuing with Northern New Mexico and Santa Fe Community College," says David Dooley, chief operating officer for Weapons Production at Los Alamos. "And we have plans to provide funding to New Mexico colleges and universities to assist in workforce development."

All PF-4 employees are part of the Human Reliability Program, which is specific to those who work with nuclear materials. Anything that can cause an employee to be distracted—a stressful life event, for example—is closely monitored so that employees can be removed from contact with nuclear materials for a period of time if that is deemed necessary for safety and security. Employees also undergo yearly physicals, yearly psychological evaluations, random drug testing, and random polygraph tests. "There are a lot of additional demands on this workforce, all of which are designed to keep PF-4 as safe and secure as possible," Johnson explains.

Mission focused

Los Alamos is currently developing the processes for producing pits for the W87, which is the warhead that tops Minuteman III intercontinental ballistic missiles. The first W87 pit will be delivered in 2023. From there, production will ramp up quickly to 30 pits per year. Down the road, other types of pits for other U.S. nuclear weapons—the B61 gravity bomb, and the W76, W78, and W88 warheads—will be produced at Los Alamos.

These new pits and their corresponding weapons will comprise the future U.S. nuclear deterrent. Maintaining the safety and reliability of the deterrent has always been Los Alamos' primary mission. "That has been true since 1943 when we made the first pit," Mason says. "We've shown, and will continue to show, that Los Alamos is the right place to lead this effort to support the national security mission." ★

Katharine Coggeshall, Virginia Grant, and Whitney Spivey contributed to this article.

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

Replacing the plutonium pits in America's nuclear weapons will result in a safer, more secure, and more reliable deterrent.

"Unfortunately, the nuclear deterrent is as relevant as it has ever been. There are certainly people who wish that we didn't have nuclear weapons. In fact, there are a lot of people who work at Los Alamos who wish we didn't have nuclear weapons. But we recognize that we do, and as long as we do, the weapons have to be safe and reliable.

Plutonium pits have become almost iconic in the discussion of whether we should have nuclear weapons. What is really an argument against nuclear weapons has become an argument against pit production because, if we don't have pits, we don't have nuclear weapons, which is true.

So, the question is: Do you believe that the world as it currently exists would be safer and more stable if the United States unilaterally disavowed nuclear weapons? If so, you wouldn't make pits. But if you think that the deterrent is important for maintaining stability in an environment in which other states are prone to using coercion if they can get away with it, then we're going to need to manufacture pits."

—THOM MASON
LOS ALAMOS NATIONAL LABORATORY DIRECTOR

WHO INVENTED THE FIRST PLUTONIUM PIT?

New documents from Los Alamos National Laboratory help clarify the role of theoretical physicist Robert Christy.

**BY THOMAS CHADWICK,
NATIONAL SECURITY RESEARCH CENTER**

Canadian scientist Robert Christy worked in the Theoretical Implosion group at Los Alamos during the Manhattan Project. This group was tasked with designing a weapon in which explosives would compress a plutonium pit (see p. 46), which would result in a nuclear explosion. But the group's original pit design just wasn't working as intended. So, in late 1944, Christy proposed a new design.

Christy's design was adopted and used during the Trinity test—the detonation of the world's first atomic weapon. Thus, the Trinity device was nicknamed as the "Christy Gadget." However, in the years since, many sources have given credit for this invention to other scientists—most often to Theoretical Implosion group leader Rudolf Peierls, who does in fact share credit with Christy on the official patent.

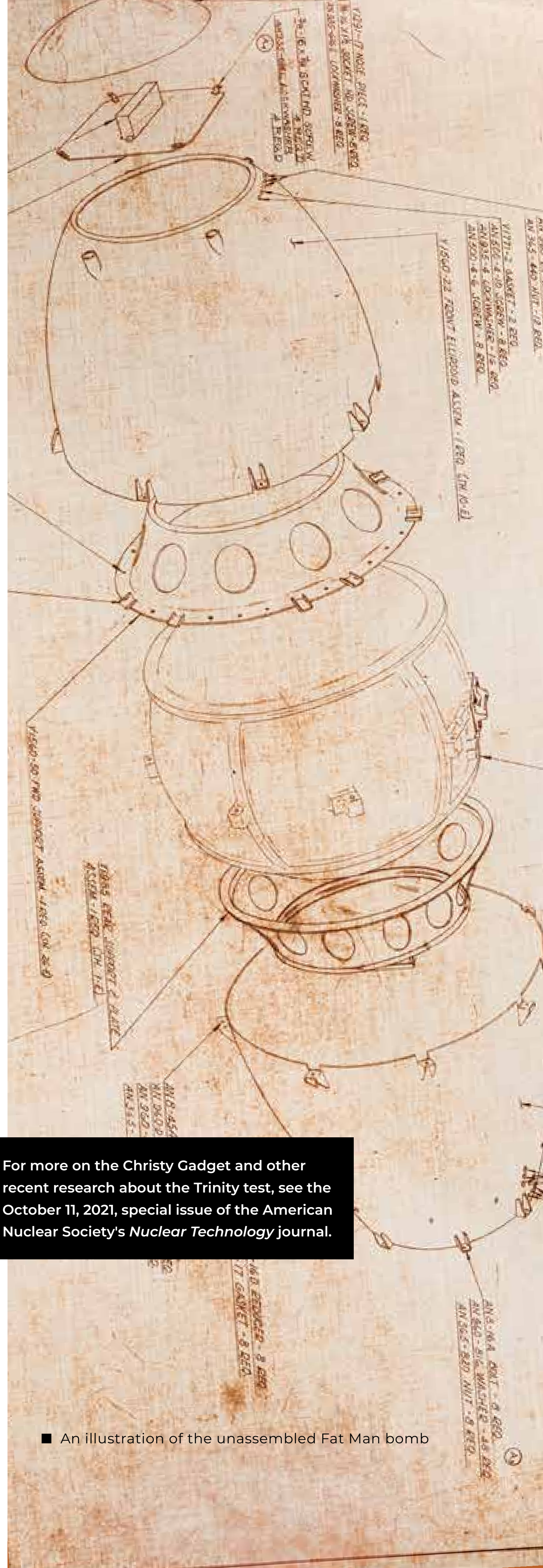
"Prominent historians have challenged that the basic design of the wartime implosion system's pit was largely conceived by physicist Robert Christy," says Alan Carr, senior historian for the National Security Research Center (NSRC), which is the classified library at Los Alamos National Laboratory. "However, recently uncovered records demonstrate that Christy is, in fact, the primary architect of the design."

Even though the finalized patent, titled "Method and Apparatus for Explosively Releasing Nuclear Energy," is filed jointly under Peierls and Christy, NSRC Archivist Danny Alcazar and Chief Scientist Mark Chadwick discovered that the original handwritten draft of the patent was in Christy's name alone. The NSRC is also home to an early typed copy of the patent that was edited by Peierls, on which Peierls made the handwritten addition "and Rudolf Peierls." Additionally, the NSRC has recordings from a 1986 interview with both Peierls and Christy that offer implicit credit to Christy for inventing the pit design of the Trinity device.

"This case is the perfect example of how valuable the Lab's national security collections are to verifying history," Carr says. ★

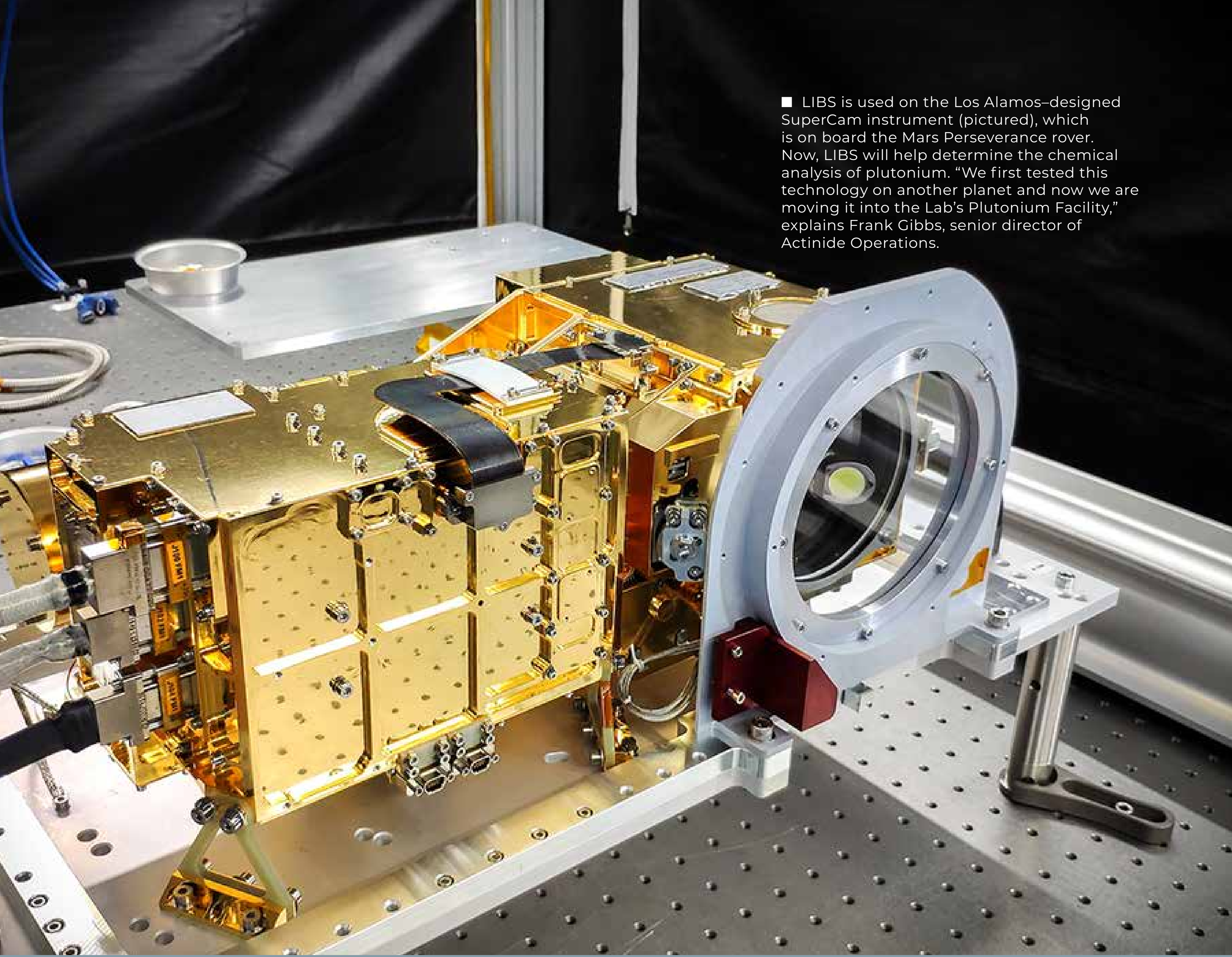
■ Robert Christy

■ Rudolf Peierls



For more on the Christy Gadget and other recent research about the Trinity test, see the October 11, 2021, special issue of the American Nuclear Society's *Nuclear Technology* journal.

■ An illustration of the unassembled Fat Man bomb



■ LIBS is used on the Los Alamos–designed SuperCam instrument (pictured), which is on board the Mars Perseverance rover. Now, LIBS will help determine the chemical analysis of plutonium. "We first tested this technology on another planet and now we are moving it into the Lab's Plutonium Facility," explains Frank Gibbs, senior director of Actinide Operations.

FASTER PIT ANALYSIS

Laser-induced breakdown spectroscopy will help characterize pits quickly and accurately.

BY KENNY VIGIL

Currently, characterizing—studying the chemical composition of—plutonium pits involves sampling small amounts of plutonium at Los Alamos National Laboratory's Plutonium Facility and then sending the samples to various other Lab facilities to be analyzed—a process that can take weeks.

But a recent collaboration between the Laboratory and the United States Air Force Institute of Technology (AFIT) resulted in an experiment and machine learning studies that determined laser-induced breakdown spectroscopy (LIBS) can be used to characterize pits in just seconds.

LIBS works by focusing a highly energetic laser pulse onto the surface of the plutonium. A micro-plasma of electronically excited atoms and ions is created on the sample surface. As these atoms decay back into their ground states, they emit characteristic wavelengths of light, or unique "fingerprints" that allow researchers to get an immediate characterization of the plutonium sample.

"LIBS can raise confidence in each step of the pit production process and change how we do pit manufacturing," says John Auxier II, of the Lab's Actinide Material and Processing Power division. LIBS is expected to help the Laboratory meet its goal to manufacture at least 30 pits per year starting in 2026.

Analysis of LIBS data takes only minutes. AFIT applied machine learning techniques to the data, which had never been done before. Machine learning uses models to understand patterns and make predictions, in this case, about the chemical analysis of plutonium. "The machine learning allowed us to get quantification of impurities in plutonium," explains Auxier, noting that in the future, additional machine learning technology developed at the Laboratory will also be used for data analysis.

"We can't do pit production without the entire Lab behind us. It really requires the technical engine that is Los Alamos to support it," Auxier says. "The science piece of this is really driving some exciting stuff." ★

KNOWLEDGE TRANSFER

Former Rocky Flats employees bring decades of experience to Los Alamos.

BY JAKE BARTMAN

From 1952 to 1989, almost all of the plutonium pits for U.S. nuclear weapons were manufactured at the Rocky Flats Plant near Denver, Colorado. Although Rocky Flats was shut down due to violations of environmental law, the expertise of many who worked there is an important resource for Los Alamos National Laboratory as it prepares to produce 30 plutonium pits per year by 2026.

National Security Science spoke with five former Rocky Flats employees who are now employed by Los Alamos about the ways in which their time at Rocky Flats informs their current work. ★

■ The Rocky Flats Plant is now the Rocky Flats National Wildlife Refuge, home to a large elk herd.
Photo: U.S. Fish & Wildlife Service/ Ryan Moehring

Frank Gibbs

SENIOR DIRECTOR OF ACTINIDE OPERATIONS

ACTINIDE OPERATIONS OFFICE

Frank Gibbs took a job at Rocky Flats in 1984 and worked there until 1998. During that time, he manufactured components for underground weapons tests, served as lead plutonium development engineer on the W88 warhead, and even earned his PhD from the Colorado School of Mines, just 10 miles up the road from the plant, in Golden, Colorado.

Gibbs worked at Los Alamos from 1998 to 2000, then returned to Rocky Flats to help shutter the facility. "I was there until the day we closed the gate in 2005," he says. He was proud to have helped close the plant "in record time and with a fantastic safety record." He returned to Los Alamos in 2018 as a member of the Laboratory's senior leadership team.

"The pit manufacturing experience from Rocky Flats was key for me," Gibbs says. "And as we decommission old equipment in PF-4 to replace and upgrade, the cleanup and waste experience when we closed Rocky Flats has been invaluable."

After 37 years in the nuclear industry, Gibbs retired from Los Alamos in October 2021. "Frank provided tremendous leadership and dedication to improving overall performance of our plutonium missions at Los Alamos," says Dave Eyler, associate Laboratory director for Weapons Production. "His combination of technical knowledge, organizational skill, and humor will be missed, and we congratulate and thank him for his years of service to our country and the Lab."

David Olivas

PLUTONIUM METALLURGIST

ACTINIDE OPERATIONS OFFICE

In 1978, after earning a degree in metallurgical engineering from the University of Texas at El Paso, David Olivas was hired by Rockwell International, which at that time operated Rocky Flats. During his 12 years there, Olivas was promoted to manager of plutonium metalworking. "The plutonium components for all of the weapons that are currently in the stockpile came through the shop I ran," Olivas remembers. "I am very proud of this contribution to our nation's security."

Olivas left Rocky Flats for Los Alamos in 1989, shortly after earning his PhD from the Colorado School of Mines. As plutonium fabrication section leader, he led the Laboratory's fabrication of prototype pits for use at the Nevada Test Site prior to the United States' 1992 testing moratorium. He retired in 2006 after 17 years at the Laboratory but has since returned as a contractor. "My focus in my current position is passing along as much of the knowledge that I garnered over the years to the next generation," he says.

Julie Geng

CRITICALITY SAFETY ANALYST

NUCLEAR CRITICALITY SAFETY GROUP

In 1990, Julie Geng was unhappy in graduate school. When her mother—who lived in Colorado—asked Rocky Flats to send Geng a job application, Geng decided to humor her mother by applying. When she was selected for an interview that coincided with Thanksgiving, "I got Rocky Flats to pay for a trip home for the holiday," Geng remembers. "Then, when they offered me a job in 1991, I couldn't pass up the opportunity to come back home to Colorado."

Geng worked at the plant for 14 years, helping to develop the Criticality Safety group and bring documentation of criticality safety limits up to a newer standard. Geng now works at Los Alamos as a contractor and says that criticality safety standards at the Laboratory are being developed to a higher level than they were at Rocky Flats.

"Although I never got to see Rocky Flats in full production mode, we did still have to handle a lot of items that were produced during the Cold War and disposition them," Geng says. "I've been able to use some of those experiences to help me understand the processes performed in PF-4 and relate those experiences to my coworkers."

John Guadagnoli

SENIOR SUPERVISORY WATCH

BUSINESS SYSTEM INTEGRATION GROUP

A New Mexico native, John Guadagnoli earned his bachelor's degree from New Mexico Highlands University. In 1982, while studying at the Colorado School of Mines, he was hired by Rockwell International to work as a metallurgical operator in foundry operations, where he learned how metals are blended for pit manufacturing. Guadagnoli remained at Rocky Flats for 23 years, acquiring numerous titles and supporting various projects. He also helped decommission the site—including Building 771, which ABC's *Nightline* described as "the most dangerous building in America" due to its radioactive contamination.

Having worked at Los Alamos at various points over the years, Guadagnoli returned to Los Alamos in 2012. In his current role, he mentors and coaches a new generation of Laboratory employees and supports the implementation of Conduct of Operations principles—a "philosophy of working in a formalized, disciplined manner with an aim to achieving operational and programmatic excellence" that applies to all Laboratory endeavors.

Cameron Freiboth

WEAPONS PRODUCTION SUPPORT

CHIEF OPERATIONS OFFICE

A native Boulderite, Cameron Freiboth started working part-time as a union laborer at Rocky Flats in 1985. After earning his undergraduate degree from the Colorado School of Mines, he joined the plant full-time in 1988.

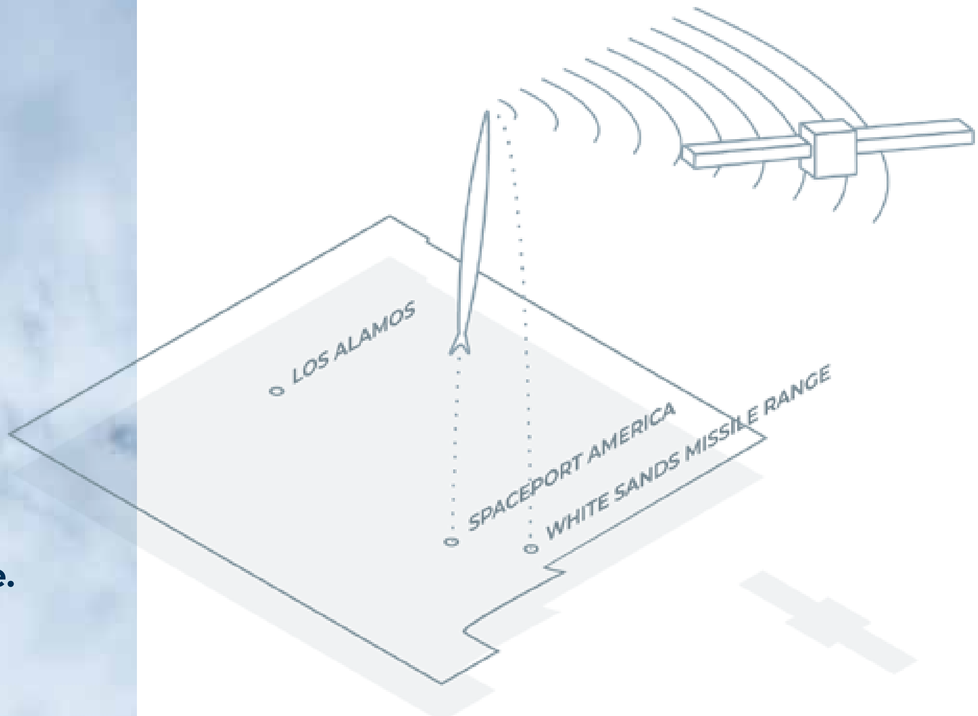
During the 18 years Freiboth spent at Rocky Flats, he supported production of the B83 bomb and the W80, W87, and W88 warheads. He also served as development engineer on the W82 and W89 warheads. As Rocky Flats was cleaned up in the mid-1990s, he was responsible for the demolition of more than 100 nonnuclear facilities and structures at the site.

Freiboth most recently worked at Los Alamos as a contractor supporting the Pit Technologies division. Freiboth says Rocky Flats helped him gain experience in nuclear facility operations and nuclear materials production in a Department of Energy environment—all great preparation for a second career at Los Alamos.

LAU
PAR

■ On August 11, Los Alamos partnered with Up Aerospace to perform a suborbital flight experiment involving a Los Alamos–developed diagnostic and communications payload.

Collaborating with private companies allows Los Alamos National Laboratory to launch payloads more affordably, more conveniently, and more often than ever before.



NCHING RTNERSHIPS

BY J. WESTON PHIPPEN

THE WEATHER ON THE morning of August 11, 2021, was sunny and warm, with a slight but steady wind blowing through the desert that surrounds southern New Mexico's Spaceport America (yes, the same Spaceport America from which Richard Branson launched toward space on July 11, 2021). Just east of the glassy, modern Spaceport headquarters, a blue rocket was positioned vertically on a launchpad, ready to be blasted 60 miles high, to the edge of outer space.

Inside mission control—a retrofitted trailer about half a mile from the rocket—Los Alamos National Laboratory mechanical engineer Justin McGlown manned several phones. In intervals, he spoke with ground monitoring stations across the state that would track the rocket's flight and eventual crash into White Sands Missile Range, just miles east of where he sat.

McGlown spends most of his time at the Lab engineering small satellites, called CubeSats, for the Lab's Agile Space program. But this launch was different from anything he'd done before. In fact, it was different from anything the Lab had done before.

The August 11 launch would mark several "firsts" for Los Alamos. It would be the first collaboration between Los Alamos and the state of New Mexico–owned Spaceport America.

It would be the first time the Lab partnered with a private company—Up Aerospace, based in Denver, Colorado—to launch a rocket carrying a Los Alamos–designed and assembled payload. It would also be the first time an in-flight payload would send information to a nearby, orbiting satellite.

Inside the control room, Jerry Larson, president of Up Aerospace, spoke into a microphone that broadcast his voice to the crowd of observers gathered outside on bleachers. "Launch crew has successfully completed all pre-launch procedures," he said. "Request permission to proceed with terminal countdown operations."

This was the moment that McGlown, and dozens of Lab scientists and engineers, had waited on for more than a year.

Stockpile responsiveness

The weapons in the U.S. nuclear stockpile were designed and built in the 1960s, '70s, and '80s. These weapons remain safe and reliable, largely because of various updates over the years by Los Alamos and other national laboratories. This general maintenance of nuclear weapons is called the Stockpile Stewardship Program, and in 2016 the National Nuclear Security Administration (NNSA) created a parallel program called the Stockpile Responsiveness Program to "fully exercise the workforce and capabilities of the nuclear security enterprise," according to its Fiscal Year 2021 Stockpile Stewardship and Management Plan Biennial Plan Summary. The program engages "the technical capabilities required for all stages of the design, testing, and production of nuclear weapons, as well as working in concert with DOD [Department of Defense] to recruit, train, and retain the next generation of weapon designers and engineers."

"The Stockpile Responsiveness Program is allowing our new staff to learn and develop the experience they will need to meet the Lab's national security mission requirements," explains Matthew Tucker, a program manager with the Lab's Office of National Security and International Studies. "We need to significantly decrease the amount of time it takes to go from concept to prototype in order to be prepared to respond to emergent threats."

So what does stockpile responsiveness have to do with rockets? Well, new technical capabilities for the stockpile require testing, specifically flight testing, which involves launching

■ Up Aerospace President Jerry Larson, (second from left) sits in mission control before the launch. "We are very proud that as a small company we executed this complicated mission in less than 11 months from contract start," Larson says. "This mission demonstrated that a small company like Up Aerospace is capable of meeting complex stringent requirements in a very short period of time, at low cost, enabling new technologies to be developed in a very rapid cadence."

systems on rockets to see how the systems behave in extreme conditions, such as zero gravity, very high or low temperatures, and varying accelerations, velocities, and pressures. A rocket launch can produce environments relevant to those a system would need to survive on an intercontinental ballistic missile launch. In other words, flight tests help ensure systems will perform as expected on the "real thing."

In the past, flight tests were conducted over the Pacific Ocean and required very specific telemetry data to meet DOD test requirements, which also meant relying on a large contingent of DOD assets (such as U.S. Navy ships and ground-monitoring stations) to support each test. Lots of people, resources, and vessels were needed for each test to aid with everything from data collection to tracing the impact location and even for recovering the rockets. Given all of this, these experiments were very expensive—roughly $100 million per flight—which limited the ability to do iterative design, to test new ideas, or to provide the training required for teams to take a system from concept to reality.

But things have changed. From SpaceX and Virgin Galactic, to dozens of smaller companies, private industry is doing what was once reserved for governments: launching rockets. In this 21st-century space race, entrepreneurs are jockeying to reach beyond Earth's atmosphere, quicker and cheaper than ever before.

"There's been a revolution in commercial launches—you just contract with a company and bring your satellite or whatever your payload is, and they send it to space," Tucker says. "We thought, why can't we do the same for our flight tests?"

As Tucker and others began to discuss this possibility, they realized that it was not only totally doable but also faster to coordinate and significantly less expensive.

The three things they had to figure out, however, were—without the DOD—who would launch their payload, who would collect the flight diagnostics, and who would recover the rocket?

The solutions for two of these things, it turned out, were pretty close to home.

Making it work

About 270 miles south of the Laboratory is Spaceport America. Adjacent to the Spaceport, just over a mountain range, is White Sands Missile Range. At nearly 3,200 square miles, the Army-operated testing range is the largest military installation in the United States.

"When we looked at that combination it became obvious," Tucker says. "If we found a private company to launch out of Spaceport, we could then use White Sands to help coordinate with tracking and for the recovery of the rocket and payload. We knew it could save a lot of money, and we knew it was achievable. It's just that this had never been done before, so for the next year we set about figuring out how to make it work."

As the Lab looked around for a private company with which to partner, it found Up Aerospace, a family-owned business lead by Larson, a former Lockheed Martin employee who conducted suborbital flight experiments for NASA. "I worked at Lockheed Martin for 20 years launching rockets," Larson says. "I loved it there, but when the opportunity came 15 years ago for me to start my own company, I took a chance. We've been able to work with the U.S. Air Force, NASA, a lot of other organizations, and now Los Alamos. It's been a really fun ride."

The company designs and assembles rockets itself; currently, it has three models from which to choose. Cesaroni Technologies, based in Florida, manufactures motors for the rockets. Once a rocket is ready for launch, Up Aerospace coordinates with all involved parties, including Spaceport America and the Federal Aviation Administration.

> "We need our new staff to learn and develop the experience they will need to meet the Lab's national security mission requirements."
>
> —MATT TUCKER

For the Los Alamos flight test, which was named ReDX-1 (pronounced like "FedEx" and short for Responsive Development Experiment), Larson's Up Aerospace used its SpaceLoft rocket, which weighs 800 pounds and can fly 60 miles into the atmosphere, reaching Mach 6 in 12 seconds. "You can watch it lift off, and within seconds it will be at about 45,000 feet, pulling 15 Gs [15 times the force of gravity]," Larson says. "The fins are canted with an angle, which allows the rocket to spin, kind of like a bullet, and that makes it much more accurate."

Accuracy was important for the third piece of the puzzle—collecting the flight diagnostics. "Using a satellite to upload the flight diagnostic data seemed

■ The Lab's payload was launched from a SpaceLoft rocket, which is capable of flying 60 miles into the atmosphere and reaching the edge of space.

STOCKPILE RESPONSIVENESS PROGRAM OBJECTIVES

- Identify, sustain, enhance, integrate, and continually exercise all of the capabilities, infrastructure, tools, and technologies across the science, engineering, design, certification, and manufacturing cycle required to carry out all phases of the joint nuclear weapons life cycle process*, with respect to both the nuclear security enterprise and relevant elements of the Department of Defense.

- Identify, enhance, and transfer knowledge, skills, and direct experience with respect to all phases of the joint nuclear weapons life cycle process from one generation of nuclear weapon designers and engineers to the following generation.

- Periodically demonstrate stockpile responsiveness throughout the range of capabilities as required, such as through the use of prototypes, flight testing, and development of plans for certification without the need for nuclear explosive testing.

- Shorten design, certification, and manufacturing cycles and timelines to minimize the amount of time and costs leading to an engineering prototype and production.

- Continually exercise processes for the integration and coordination of all relevant elements and processes of the [National Nuclear Security] Administration and the Department of Defense required to ensure stockpile responsiveness.

- The retention of the ability, in coordination with the Director of National Intelligence, to assess and develop prototype nuclear weapons of foreign countries if needed to meet intelligence requirements and, if necessary, to conduct no-yield testing of those prototypes.

* The process developed and maintained by the Secretary of Defense and the Secretary of Energy for the development, production, maintenance, and retirement of nuclear weapons.

The Lab's ReDX-1 team stands in front of the launch pad at Spaceport America in New Mexico.

like the easiest option," explains McGlown, noting that for this to happen, the rocket's payload—which would be ejected in space—would have to "talk" to an already orbiting Lab-designed DOD satellite. These very fast-moving objects would have a four-minute-long window to speak to each other while flying in different directions. It would be like tossing a ball from a moving car and expecting someone driving in the opposite direction to catch it.

"The Lab has extensive background building and designing satellites, so we knew it was possible," McGlown says. "Accomplishing that, however, meant we'd need to design the communications and diagnostic payload from the ground up."

A younger generation

McGlown became vital in this process, not only because of his technical skill set, but also because of his age. At just 35 years old, McGlown was among the youngest engineers working on the project.

"For the ReDX-1 test, we wanted someone who could not only help lead the current launch, but someone who could then become a leader on future missions. Immediately, Justin McGlown's name was brought up," Tucker says. "It was very important to us to partner some of our veteran scientists with early and mid-career employees."

This type of knowledge transfer is also an objective—and crucial to the success—of the Stockpile Responsiveness Program. In fact, 50 U.S. Code 2538b, which legislates the program, specifies one of the program's objectives is to "identify, enhance, and transfer knowledge, skills, and direct experience with respect to all phases of the joint nuclear weapons life cycle process from one generation of nuclear weapon designers and engineers to the following generation."

McGlown became fascinated with space because of his father, an amateur astronomer. After earning a master's in nuclear engineering from the University of Tennessee and then working at the Naval Surface Warfare Center in Virginia, McGlown landed at Los Alamos in 2015.

"When I saw the Lab was hiring someone to help work with satellites on the Agile Space Program, I applied right away," McGlown remembers. "I was actually leaving the theater after watching the film *Interstellar* when I got the call offering me the job. So it was kind of a coincidence."

▲ A Black Hawk helicopter is on standby to retrieve the payload after the launch.

McGlown develops CubeSats, tiny satellites that are generally 10 centimeters-square. These small satellites typically "piggyback" into space, meaning they catch a ride on a shared rocket system. This background with small orbital systems built for rideshare applications made McGlown a natural fit for the ReDX-1 test.

Up Aerospace's payload requirement meant that Los Alamos engineers had to develop a cone-shaped structure to hold the payload that was 12 inches high, 10 inches wide, and included an antenna, diagnostic equipment, a power source, and other electronics. After two months, McGlown—who had initially been brought on to help design the payload's inner workings—was appointed team leader and charged with overseeing each group's design, as well as testing all the components individually and as a whole.

For the next year, McGlown checked in with the teams as they engineered every aspect of the communications and diagnostic device. "I learned a lot along the way," McGlown says. "I also received a lot of helpful guidance because this was so new to me. Not only had I not led a team before, but all of the work I'd done in the past was designed to go one way—into space and into orbit. I'd never worked on a project that would return to Earth."

For example, one of the first problems McGlown and his team had to solve was how to protect the payload's electronics from the intense aerodynamic heat the payload would encounter upon reentering the atmosphere. The solution? A silicon-based heat

> "The ReDX-1 flight test is just the first example of a unique collaboration that will enable us to train a whole new generation of scientists and engineers."
>
> —BOB WEBSTER

SCAN QR CODE WITH A SMARTPHONE CAMERA
Watch a video of this rocket launch.

■ Within 12 seconds of launch, the rocket reached Mach 6.
Photo: Up Aerospace

shield, designed by members of the Lab's Materials Science and Technology division, that coated the entire payload and was capable of withstanding temperatures of the thousands of degrees Fahrenheit.

One of the last problems the team had to solve was how to make the payload fall back to Earth and land in a very precise location. A spinning, uncontrollable object hurling 60 miles toward earth could land anywhere. The team turned to tungsten. A 17-pound cube of the element, no larger than a coffee cup, was milled to fit at the top of the payload and would act as a ballast to force the payload to fall nose down.

"That was a really exciting moment—once we figured out how to make everything fit, and we tested it sufficiently," McGlown says. "Then we realized we still needed to launch it all on a rocket, and we begin to worry all over again."

Ready to launch

Around 8:40 a.m., the Los Alamos employees who weren't in mission control gathered on bleachers. Many of them had brought their families, and children eagerly craned their necks to see the rocket in the distance.

"T-minus 30 seconds," Larson's voice sounded from the loudspeaker.

The crowd hushed as the countdown reached its final moments, "Five... four... three... two..." and the last word was cut off by a massive boom. In a second, the rocket became a white streak slicing through the clouds. The rumble from its motor grew increasingly faint.

But the flight test wasn't complete just yet. The week before, the team decided it would be helpful—perhaps mostly to relieve their anticipation—to receive a live download of flight diagnostics relayed from the payload to the satellite to a makeshift monitoring station. Now, some of the Los Alamos team gathered around the station, set up on a plastic folding table.

> There's nothing like an encounter with reality to focus the mind."
>
> —BOB WEBSTER

"How long do you think it will take until we hear something back?" Tucker asked.

"Probably a few minutes," someone in the crowd replied.

But then, as if on cue, the blank laptop screen began to fill with numbers. One line, then two lines, then half a page. The payload had successfully communicated with the satellite, and the team was receiving live flight information.

"We nailed it," said McGlown, walking out of mission control.

"We received a lot more information than we anticipated, and we're just beginning to go through it," Tucker said a few days after the launch. "But already, we know we have some really interesting data."

With ReDX-1 a success, Los Alamos plans to carry out two of these flight tests per year for five years. The potential cost savings of these tests, compared with how they were once conducted, will

■ The payload is extracted from the desert at White Sands Missile Range.

be at least hundreds of millions of dollars, probably more. Going forward, these flight tests will become more complicated and technical until researchers are ready for full-scale tests in rockets that more closely simulate an actual missile launch.

"The ReDX-1 flight test is just the first example of a unique collaboration between the Laboratory, Up Aerospace, and Spaceport America," says Bob Webster, deputy Laboratory director for Weapons at Los Alamos. "By exploiting the revolution in commercial space flight, we can give our staff the chance to learn and innovate at a high rate and in a cost-effective manner. And there's nothing like an encounter with reality to focus the mind."

Back on earth

After some of the excitement had died down, members of the ReDx-1 team stepped onto a Black Hawk helicopter, which then soared over the mountains to White Sands Missile Range to recover the payload. It took some time, but eventually the payload was found—buried two feet underground but almost completely intact. ★

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

By partnering with private industry, Los Alamos can more quickly and less expensively test components and systems that are essential for national security.

■ The Lab's RedX-1 team and their family members watch the rocket launch.

NOT YOUR AVERAGE ZOOM MEETING

U.S. Secretary of Energy Jennifer Granholm virtually visited Los Alamos to give kudos and encouragement to Laboratory workforce.

BY WHITNEY SPIVEY

By the time U.S. Secretary of Energy Jennifer Granholm said, "I hope I'm not blasted across a screen at the front of the auditorium," it was too late—her face was already projected above the stage in the National Security Sciences Building at Los Alamos National Laboratory.

There, 200 vaccinated employees were gathered for a two-hour Zoom meeting. The date was June 14, and the secretary beamed clearly into the auditorium from her Washington, D.C., office. Before she participated in a virtual tour of the Laboratory to learn more about how Los Alamos' national security mission enables other types of science—including climate studies, cancer research, and space exploration—Granholm addressed Laboratory employees. Here's what she said. (The following has been edited for length and clarity.)

Science is foundational to America's success

What a treat to be able to visit you all. I'm excited to learn more about the incredible work that you do, and I want to take this opportunity to share how much I respect and admire and believe in everything that you're doing at Los Alamos. This complex is where all of DOE's [the Department of Energy's] core missions converge—nuclear security, fundamental science, applied science, clean energy innovation, environmental clean up, cyber security, the whole nine yards. You do it all, and it makes the scope and the reach of your work truly something to behold.

You make the plutonium pits (see p. 46) that are critical to maintaining a safe and effective nuclear deterrent. You work with another isotope of plutonium that helps power NASA missions to Mars. You spearhead the R&D for all kinds of energy technologies, including the ones that are going to be instrumental in our clean energy future. You're developing complex modeling that helps us track how diseases move and spread, including COVID-19. And what's really amazing to me is how all of these efforts really complement and accelerate one another—the supercomputers you use to certify the nuclear stockpile also map climate impacts; the accelerators you use for weapons diagnostics also help to treat cancer.

The bottom line is that no matter what the mission is that you work on, you are what DOE is, what I like to call, "America's solutions department." Because with every new technology, every new innovation, every new boundary that you push and you break through, you're helping us to build a safer and healthier and more prosperous nation and clearing the way for America to win the 21st century, and that never fails to make me feel more energized and more inspired and more hopeful about the future.

I do not want to get political, but I do know that, in the past few years, some people in our DOE family have felt that maybe their projects have been ignored or slighted or even attacked because of the "war on science." Some of you may have had studies blocked or delayed or felt the integrity of your work was put into jeopardy. Some of you may have felt pressure not to follow the science. The suspension of diversity, equity, and inclusion training efforts may have made some people feel unwelcomed. Many of you have watched dear colleagues maybe even decide to leave. I don't know if that's true at Los Alamos, but I know it's true at some labs. Whether or not any of this has been your experience, I want you to know that President Biden and I and everyone in our leadership ranks are here to support you and to fight for you every step of the way. We believe that science—and I mean science that reflects the incredible diversity of ideas and viewpoints that this country has to offer—is foundational to the success of America.

The national labs are really the crown jewels of this agency, and we have every intention of treating you as the jewels that you are. I hope you'll be able to see that commitment in the president's 2022 proposed budget for DOE, which requests a very large increase in funding for our science programs and national labs, as well as our support for nuclear security and environmental cleanup, and I hope you can see it in the American jobs plan that the president is hoping to get through congress. That plan aims to cement our nation's spot as a global leader in science and innovation. The point is, we are putting a big bet on research and development. We are putting a big bet on the sheer power of American ingenuity, and that means we're putting a big bet on each and every one of you. We can't do these things—we can't tackle the climate crisis, we can't protect the American people, we can't compete in the global economy—any other way.

Granholm watched prerecorded videos about the Laboratory's plutonium, accelerator, and supercomputing facilities and then interacted in real time with employees who work in each of these areas. "Today you'll learn about a handful of our programs in areas like nuclear nonproliferation, fundamental science, and R&D," Laboratory Director Thom Mason told her before the first video. "We hope after this virtual tour, you'll want to come back in person and get a deeper dive into our work."

Granholm also took questions, including the following, from employees.

Los Alamos is engaged in a wide range of missions. How would you frame the role of our national labs and Los Alamos in particular in today's world?

I know that when most people think of Los Alamos, they think of the nuclear security mission, but what really amazes me is your leadership in energy, research, and technological innovation. The work that you do on everything from materials and concepts for clean energy to developing safe and sustainable nuclear energy is so

Nominated by President Joe Biden to lead the Department of Energy (DOE) and confirmed as a member of his cabinet in February 2021, Granholm is the nation's 16th secretary of energy. Prior to her nomination, Granholm was the first woman elected governor of Michigan, where she served two terms from 2003 to 2011. Granholm, who has a history of pursuing programs that support clean energy, was particularly interested in the ways the Laboratory supports strategic national interests, including climate solutions.

▲ "I'm a political scientist," Granholm told Los Alamos employees. But after hearing about some of the Lab's cutting-edge science, technology, and engineering work, she joked, "I'll just throw that out the window."

important to this administration's climate and clean energy goals. As you know, the president has laid out the boldest climate agenda in our nation's history, which includes the ambitious goals of 50 to 52 percent reductions in our carbon emissions below 2005 levels by the end of this decade, by 2030, 100 percent clean electricity by 2035, and net zero emissions by 2050. Pulling that off is really going to require the power of science and innovation at a scale the world has never seen before. And that's where Los Alamos and the rest of DOE's national labs come in. You're already on a significantly impressive streak—Los Alamos has won 170 R&D 100 awards for the development of exceptional technologies that help us, and that number continues to grow. That is just phenomenal, and it certainly bodes well for our ability to research, develop, and deploy the technologies that we're going to need to secure that clean energy future. Our energy security and our national security are utterly intertwined. And we're going to need to maximize the full scope and breadth of the research agendas at all our national labs to advance both.

What can the national labs contribute to further hardening our security posture against sophisticated cyberattacks?

These cyberattacks on our critical infrastructure only continue to get more aggressive and more frequent. We are going to need to use every tool that we have to better predict and mitigate risks and the scientific and technological power of our national labs is going to be absolutely critical in those efforts.

One of the most important tools that our labs are already bringing to bear in our cybersecurity efforts is complex modeling. For example, Los Alamos has been working with other national labs and our Office of Electricity on the North American Energy Resilience Model—an analytic tool to help us to identify major vulnerabilities in our energy infrastructure and invest in effective solutions.

Will you and the Biden administration support continued investments in the pit mission (see p. 46) while also investing in cleanup of World War II and Cold War nuclear sites?

The Biden administration continues to support that 80 pits-per-year commitment, and we're really glad that Los Alamos is leading the way and that you are on track to meet your 30-pit production milestone by 2026. I also want to recognize that Los Alamos is working very closely with DOE and the Savannah River Site to make sure that the two-site strategy for pit production is successful.

We have to address plutonium aging to keep the stockpile safe, secure, and reliable, and at the same time, we're absolutely committed to making progress in environmental cleanup work. The environmental cleanup work is about more than restoring the land; it's about keeping promises to our people and lifting this burden from communities that have shouldered the burden of our safety, including tribal nations. It's about making sure that families can breathe clean air and drink clean water and raise their children in safe homes. We need to build strong relationships with the community. You guys have done that really well with tribes and stakeholders around all of our project sites. Strong outreach leads to safer and faster clean up.

Ultimately, these two missions [pit production and environmental cleanup] are critical to our national and economic security. The goal is to do both with the utmost regard to safety and inclusivity while taking into account the needs of local communities every step of the way. ★

■ Although Liz Miller "Everested" using a stationary bike trainer in the comfort of her own home, she also enjoys cycling outdoors on New Mexico's scenic roads.
Photo: Minesh Bacrania

■ Liz Miller swims, bikes, and runs to train for triathlons. Photo: Minesh Bacrania

WHAT'S SHAKING?

Whether she's studying earthquakes at work or logging miles on her bike, geologist Liz Miller is on the move.

BY JAKE BARTMAN

In 2020, the COVID-19 pandemic put a hold on Liz Miller's triathlon plans but not on her competitive nature. So, instead of swimming, cycling, and running her way to a medal, the Los Alamos National Laboratory geologist decided to "Everest"—to climb the elevation (29,032 feet) of Mount Everest—during a single bike ride.

On August 8, 2020, Miller, together with friend Lani Seaman of the Lab's Surveillance Oversight group, completed the challenge virtually, which allowed them to undertake the effort using stationary bike trainers inside their own homes. Miller started at 4:30 a.m. and wrapped up just under 12 hours and 6,000 burnt-calories later. "You've got to be prepared for some very dark moments," she says. "There were definitely some tears, and definitely some questions of 'Why am I doing this?'"

BACK AT WORK

Meanwhile, in her job at the Laboratory, Miller never asks herself, "Why am I doing this?" As part of the Lab's Earth Systems Observations group, she is involved in monitoring the globe for underground nuclear explosions.

"As you can imagine, a bad actor who wants to hide a nuclear test isn't going to volunteer a lot of information regarding its size or whereabouts," she says. However, by studying the seismic, acoustic, and chemical signatures generated by an explosion, scientists can learn more about it. As a geologist, Miller is most interested in understanding how rocks and subsurface features, such as faults, affect the signatures generated by an explosion, since the presence and magnitude of these signatures depends on the types of rocks they move through.

"Seismic monitoring stations are often positioned great distances from where a blast occurs. Gathering and integrating geologic information helps us figure out how far and how fast the signal traveled to determine where the blast originated," Miller explains. "My job is to help build computer models of geographical areas of interest so that when seismic monitoring stations detect an event, we can use the seismic data and the geologic model to estimate an event location."

Miller starts by asking what is known about the rocks in the area. Are they porous? How hard are they? How much water do they contain? What is the fracture network like? With that knowledge, she builds a framework model of the subsurface structure. "I like to equate my work to going grocery shopping," Miller explains. "You start with an empty shopping cart and then, as you walk through the store, you pick different items off the shelf to fill it, which you then combine when you get home to make a recipe. Similarly, in building these computer models, I'm using a variety of 'ingredients' such as geologic maps and drilling data to best feed the computer model."

Seismic waves will create very different signals depending on whether they're moving through hard rock (such as granite) or softer rock (such as sandstone). "So when we create a model for a certain region of the world, we look at the topography of the location and use publicly available maps, GPS satellite data, and other open-source information to determine what type of rock lies underneath," Miller explains. "We also look at clues such as nearby water sources, past earthquake data, and other seemingly minor details that can make a big difference in the accuracy of a model."

Scientists then use these models to help pinpoint the location of the blast. The better the models are, the better the analyses of explosions can be, and the better informed leaders will be on what's happening in remote locations around the world. All of this helps researchers monitor global nuclear weapon activities, thus giving them the information to make the world safer.

HALL OF FAME

Miller's Everest ride was formally verified by the Hells 500 organization, which maintains an Everesting Hall of Fame. Miller is one of nearly 6,000 people who have completed the challenge. Will she ever try to do it again? No, she says, but then seems to reconsider. "You always forget the bad part," she says. "You're always like, 'That was horrible.' But then the next day you're like, 'Where do I sign up?'" ★

THE DISTINGUISHED 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.

Piotr Zelenay, of the Lab's Materials Synthesis and Integrated Devices group, was appointed an International Society of Electrochemistry fellow in recognition of his contributions to electrochemical science. Zelenay's research focuses on fundamental and applied aspects of polymer electrolyte fuel cell science and technology, electrocatalysis, and electrode kinetics.

Mark Chadwick, chief scientist and chief operating officer of Weapons Physics, and **Stuart Maloy**, deputy group leader for Materials Science at Radiation and Dynamic Extremes, were named fellows of the American Nuclear Society. Chadwick was recognized for his contributions to modeling of plutonium fission and his leadership in nuclear cross-section evaluations. Maloy was recognized for his accomplishments in radiation materials science and engineering and his expertise in microstructural analysis and interpretation.

D.V. Rao, program director for the Laboratory's Civilian Nuclear Program, earned an award from the American Nuclear Society for making advanced nuclear energy systems a reality. Rao's work is focused on advancing small reactor deployment opportunities by designing new space reactors, microreactors, and moderating material for low-enriched uranium fuel.

Miles Beaux, of the Engineered Materials group, and **Matt Durham**, of the Nuclear Particle Physics and Applications group, are among 83 scientists who will receive a total of $100 million through the Department of Energy's Early Career Awards Program. See p. 9 for more on Beaux's work.

Rian Bahran, who is on assignment in Washington, D.C., received the Secretary of Defense Medal for Exceptional Public Service. Bahran was recognized for his contributions as a senior science and policy adviser for nuclear deterrence policy and as a special assistant to the Under Secretary of Defense for Policy.

Eric Brown, of the Lab's Office of Experimental Sciences, was named president of the Society for Experimental Mechanics, a professional society for scientists and engineers in that field.

David Chavez, deputy group leader of the High Explosives Science and Technology group, is now a fellow of the American Chemical Society. Chavez was recognized for distinguished contributions to the field of energetic materials chemistry, particularly the development of highly energetic, fundamentally novel, and environmentally friendly materials important to national security.

Travis Sjostrom received the 2021 John Dawson Award for Excellence in Plasma Physics Research from the American Physical Society. Sjostrom has researched warm dense matter for more than 10 years, with the goal of providing theoretical understanding and accurate characterization of materials in extreme conditions.

Meghan Gibbs, a research and development engineer in the Nuclear Materials Science group, received the 2021 ASM Bronze Medal Award, awarded by ASM International, the world's largest materials science and engineering society. ASM International cited Gibbs for "excellence in process modeling, manufacturing science, and professional service impacting the U.S. steel industry and product qualification for the U.S. nuclear deterrent."

Upon his recent retirement, Los Alamos program director **Kerry Habiger** was honored with the Deputy Undersecretary for Counterterrorism and Counterproliferation Meritorious Service Award.

The Laboratory's Sustainability Manager **Monica Witt** received a 2021 Department of Energy Sustainability Award for being a Sustainability Champion. Under her leadership, the Lab has reduced energy use by 8.3 percent since 2015 and water consumption by more than 20 percent since 2007.

Siddharth Komini Babu, of the Materials Synthesis and Integrated Devices group, received an Electrochemical Society Toyota Young Investigator Fellowship for Projects in Green Energy Technology. The $50,000 fellowship supports young electrochemical researchers as they develop battery and fuel cell technology.

Los Alamos National Laboratory made the 30th annual "Top 20 Government Employers" list by ***Woman Engineer*** magazine. This year, Los Alamos, tenth on the list, is the highest-ranked Department of Energy national laboratory.

Baolian Cheng, of the Plasma Theory and Applications group, **Elizabeth Hunke**, of the Fluid Dynamics and Solid Mechanics group, **David A. Smith**, of the Space and Remote Sensing group, and **Blas Uberuaga**, of the Materials Science in Radiation and Dynamics Extremes group have been named 2021 Los Alamos National Laboratory Fellows. "To be a Fellow at the Laboratory is to be a leader in our workplace and within the scientific community at large," says Lab Director Thom Mason.

Writer **Virginia Grant**'s feature article on early computer programmer Mary Tsingou in the winter 2020 issue of this magazine received an honorable mention in the long-form category of the National Association of Science Writers Excellence in Institutional Writing Awards.

For the fourth year in a row, ***Latina Style*** named Los Alamos National Laboratory as one of the Top 50 Best Companies for Latinas to Work in the U.S. The Lab ranked 30th out of the 50 companies on the 2021 list.

Bill Daughton, **Andrew Gaunt**, and **Cristiano Nisoli** received Laboratory Fellows Prizes for Research. These awards go to individuals for outstanding research performed at Los Alamos within the past 10 years.

Eva Birnbaum received the Laboratory Fellows Prize for Leadership. This award honors individuals for outstanding scientific and engineering leadership at the Laboratory and recognizes the value of such leadership that stimulates the interest of talented young staff members in the development of new technology.

James Owen, associate Laboratory director for Weapons Engineering, received the 2021 Distinguished Alumni Award for the College of Engineering from the New Mexico State University Alumni Association.

Vania Jordanova, of the Lab's Space Science and Applications group, was named a fellow by the American Geophysical Union. Jordanova specializes in theoretical, numerical, and observational studies of the Earth's magnetosphere and geomagnetic storm dynamics. ★

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YEARS AGO

On December 7, 1962, President John F. Kennedy and Vice President Lyndon B. Johnson traveled to New Mexico for a briefing on the details of Project Rover, Los Alamos Scientific Laboratory's program to develop nuclear rocket engines for space travel.

Kennedy addressed Los Alamos residents at the high school football field. "There is no group of people in this country whose record over the last 20 years has been more preeminent in the service of their country than all of you here in this small community in New Mexico," he said. "We want to express our thanks to you. It's not merely what was done during the days of the second war, but what has been done since then, not only in developing weapons of destruction which, by an irony of fate, help maintain the peace and freedom, but also in medicine and in space, and all the other related fields which can mean so much to mankind if we can maintain the peace and protect our freedom."

After his speech, Kennedy rode down Central Avenue in a motorcade on his way to the Los Alamos airport. ★

SCAN QR CODE WITH A SMARTPHONE CAMERA

Watch a 1962 documentary on this presidential visit.

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THEN & NOW

In 1994, construction began on Los Alamos National Laboratory's Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility. Each of DARHT's axes contains a very large and very fast machine that produces radiographs (x-ray images) of materials that implode at more than 2.5 miles per second. Such radiographs allow scientists to "see" inside a mock-nuclear weapon as it detonates inside a spherical confinement vessel.

The location where that confinement vessel sits is called the firing point, and until recently, the firing point was outside, at the intersection of the two axes. Because of this exposure to the elements, DARHT tests were sometimes delayed because of weather.

But in July 2020, a weather enclosure (pictured at right) was completed around the firing point, creating a predictable and consistent environment for experiments. At the same time, the enclosure shields the facility's high-tech camera system and other complex diagnostics equipment from poor weather conditions. ★

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Watch a video about DARHT.