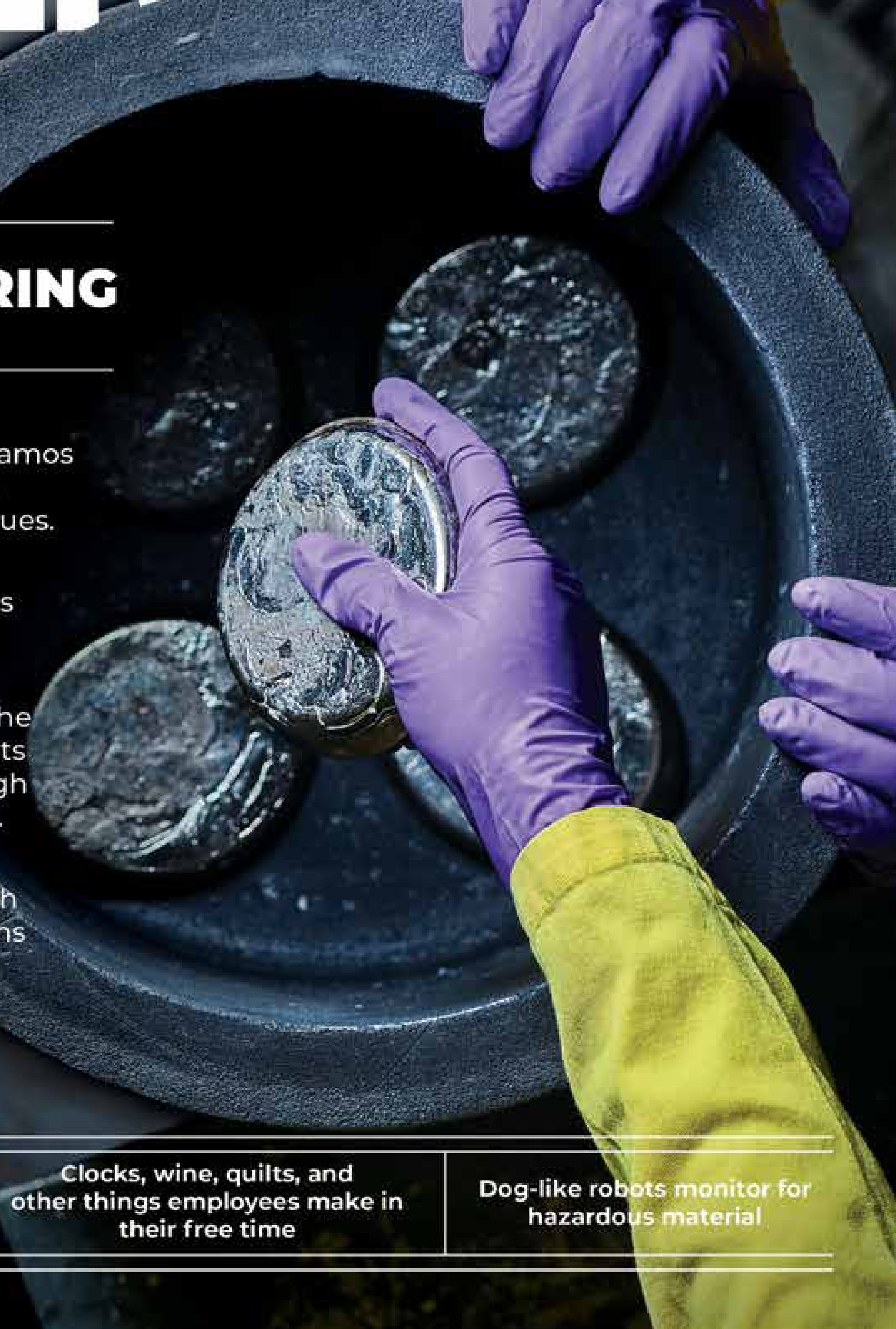
LOS ALAMOS NATIONAL LABORATORY ◆ WINTER 2024

NATIONAL ★ SECURITY SCIENCE



THE MANUFACTURING ISSUE

- **The future of manufacturing:** Los Alamos advances cutting-edge manufacturing techniques.
- **People-powered prototypes:** Los Alamos employees fabricate one-of-a-kind parts.
- **Quality guaranteed:** The Sigma Complex supports national security through manufacturing science.
- **Sparking success:** High explosives research and development booms at Los Alamos.

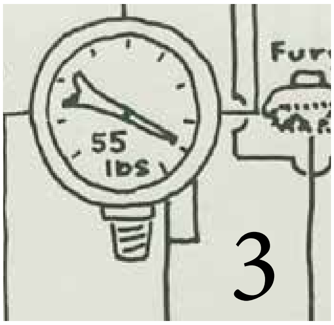
+PLUS:

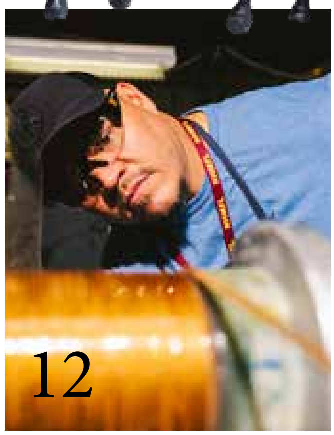
War-reserve pit production is underway	Clocks, wine, quilts, and other things employees make in their free time	Dog-like robots monitor for hazardous material

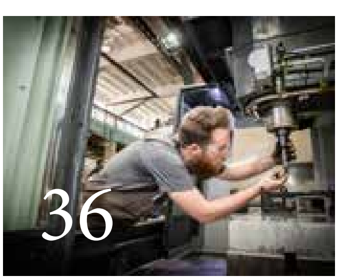
PHOTOBOMB

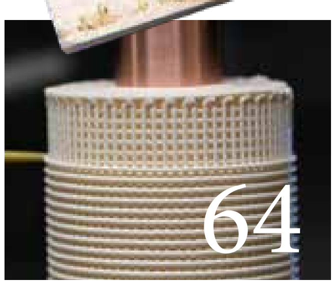
▼

Research technologist Sean Raybon operates the Bliss rolling mill at Los Alamos National Laboratory's Sigma Complex. The mill, which can thin metal plates into foils, dates to the early 1940s. "Knowing the Bliss mill made parts for the Manhattan Project gives me a sense of pride in the work I do and the American history it continues to create," Raybon says. "Long live the Bliss mill—she's 80 years young and still making great progress here at Sigma." Learn more about Sigma on p. 48. ★









IN THIS ISSUE

FEATURES

About the cover: Uranium alloy pucks are placed into a vacuum furnace at Los Alamos National Laboratory's Sigma Complex. Inside the furnace, the pucks become liquified by heat. The molten alloy is then poured into a graphite mold. When the alloy cools, the molds are removed and the cast alloy is further machined. Sigma is collaborating with the Y-12 National Security Complex to implement this direct casting process at a larger scale. Learn more on p. 48. ★

THE MANUFACTURING ISSUE

In its many machine shops and specialized work areas, Los Alamos National Laboratory produces parts to support national security.

BY ELLEN CERRETA

ASSOCIATE LABORATORY DIRECTOR FOR PHYSICAL SCIENCES

Welcome to the winter issue of *National Security Science*, in which I am excited to introduce a focus on manufacturing science at Los Alamos National Laboratory. Manufacturing at Los Alamos plays a vital role in ensuring our nation's security, combining cutting-edge research with precision engineering to produce some of the most advanced technologies in the world.

Throughout this issue we explore how the Laboratory leads the way in several key areas of this rapidly evolving field—and the people behind that work, each contributing to our mission to safeguard the nation.

Staff in the Lab's Sigma Complex, a manufacturing science cornerstone of the nuclear security enterprise, continue to be at the forefront of materials engineering in support of national security needs. On p. 48, learn more about the innovative parts and processes developed at Sigma, including a direct casting method developed in partnership with the Y-12 National Security Complex.

Similarly, the work being done by dedicated polymer researchers across the Lab reflects our commitment to advancing materials research to meet modern challenges. On p. 25, read more about how Los Alamos scientists work with experts at the Kansas City National Security Campus to develop polymers that can be produced in large quantities.

This issue also highlights, on p. 14, our efforts in low-enriched fuel fabrication, a crucial aspect of ensuring the future of nuclear energy in a way that aligns with global nonproliferation goals, and our efforts in isotope production (p. 15), which not only serve national security interests but also have far-reaching applications in medicine and industry.

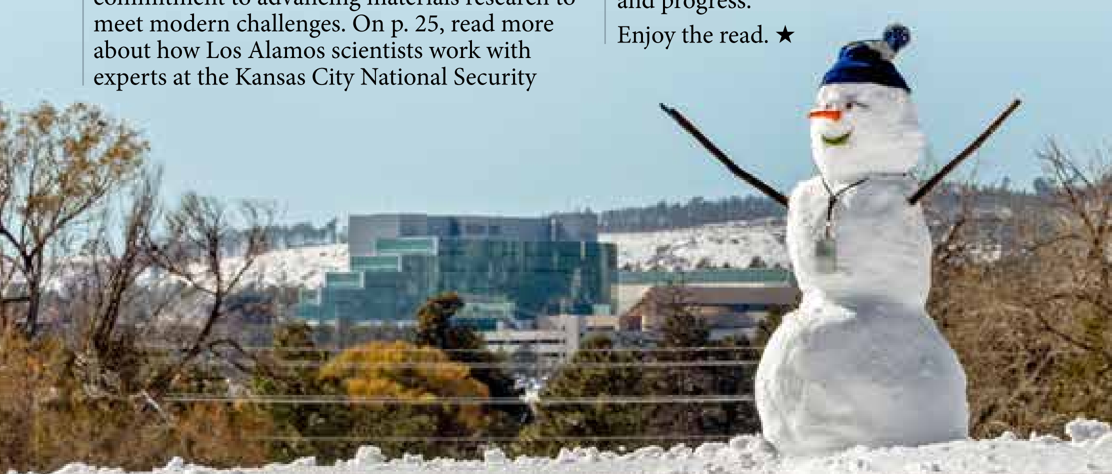
I encourage you to explore the article on pit production (p. 66), which discusses the challenges and triumphs of producing a key component of the nation's nuclear stockpile. Additionally, on p. 36, the deep dive into our Prototype Fabrication (PF) division showcases how our teams are innovating the production of high-precision parts. Some of those parts—the ones made in PF's Mark Quality Manufacturing Center (p. 44)—are war-reserve quality, which means they are approved for use in nuclear weapons.

Finally, on p. 56, explore how high explosives are synthesized and, in some cases, even 3D printed in support of national security. One of our explosive chemists also shares her perspective on risk assessment—in everything from swimming with sharks to eating raw cookie dough.

Having spent much of my career in the Lab's Materials Science and Technology division, I have seen firsthand the impact of advanced manufacturing on our ability to meet the nation's security challenges. The work we do at Los Alamos National Laboratory is not just about producing materials—it's about pushing the boundaries of what's possible, creating solutions that will shape the future. Learn more about advanced manufacturing efforts on p. 26.

I hope this issue inspires you as much as it has inspired us to share the exceptional work happening at the Laboratory. Our continued focus on manufacturing science is a testament to our commitment to innovation, security, and progress.

Enjoy the read. ★



MASTHEAD

EDITOR Whitney Spivey
ART DIRECTOR Brenda Fleming
WRITERS Jake Bartman, Jill Gibson, Ian Laird
COPY EDITOR Anne Jones
3D ARTIST Margaret Doebling
PHOTOGRAPHERS Ethan Frogget, Ignacio Perez, David Woodfin
EDITORIAL ADVISOR Kimberly Scott
CONTRIBUTORS Ellen Cerreta, Virginia Manner, Kevin Robinson-Avila

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 office of the deputy Laboratory director for Weapons. 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.

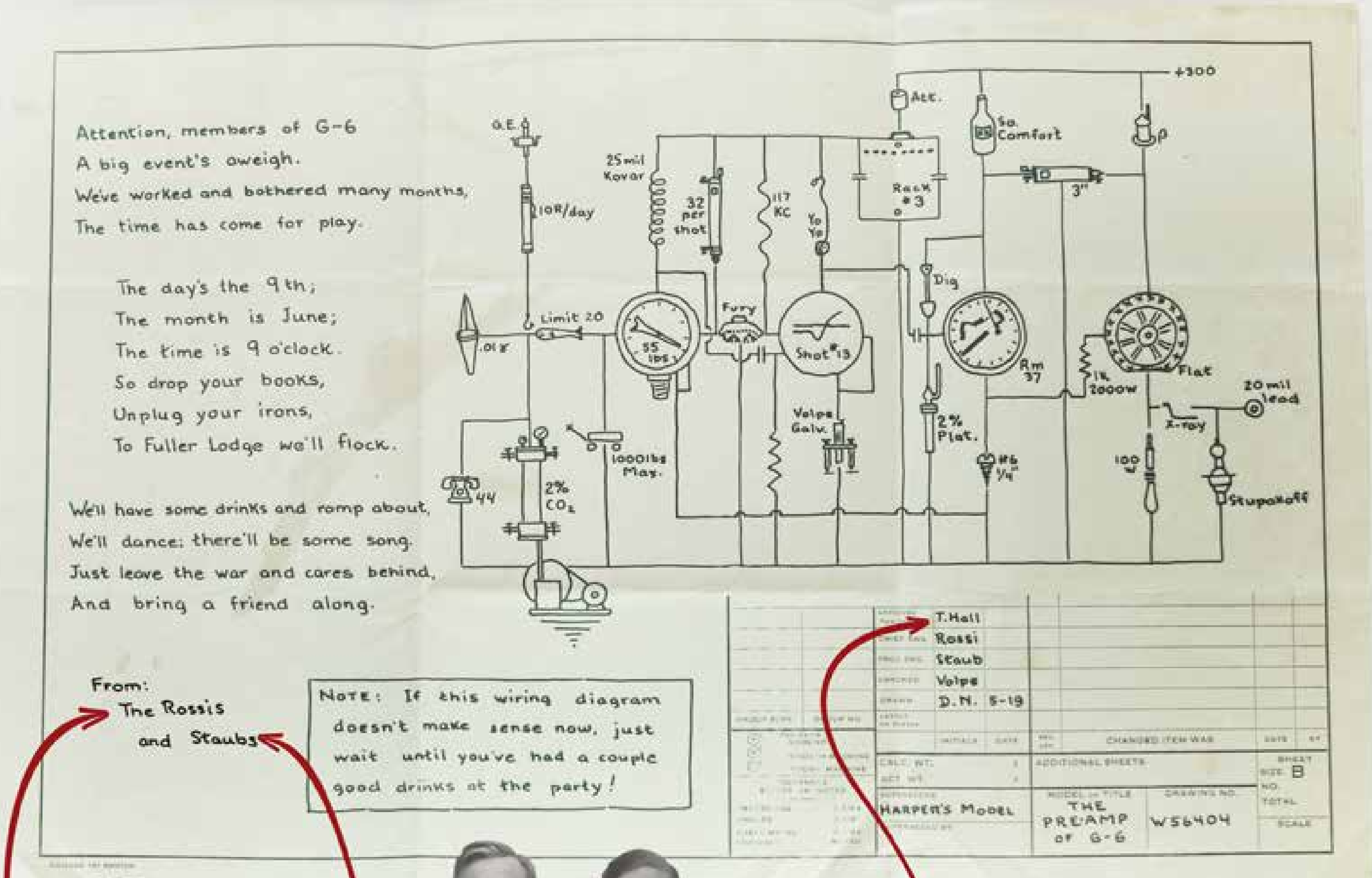
To subscribe, email magazine@lanl.gov, or call 505-667-4106.

LA-UR-24-32521

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC, for the National Nuclear Security Administration for the U.S. Department of Energy under contract 89233218CNA000001.

NSS STAFF SPOTLIGHT

Writer Jill Gibson says that ever since she started working at Los Alamos National Laboratory, she's been hearing about pits. Recently, she decided it was time to get a pit of her own—a pit bull, that is. Hopper, a pit-bull mix adopted from Albuquerque's Cross my Paws rescue, has little in common with the pits (the cores of nuclear weapons) that Los Alamos is manufacturing. To learn more about the Lab's pit mission, turn to page 66. ★



On June 9, 1945, physicists Bruno Rossi and Hans Staub hosted a party for members of G-6, a group in the Experimental Physics division at Project Y—the Los Alamos branch of the Manhattan Project. The invitation (pictured) features a comical wiring diagram and the drawing number W56404, which was also the license plate for the group's vehicle. Physicist Ted Hall, who "approved" the diagram, was later revealed to be a spy for the Soviet Union. ★

Photo: Los Alamos Historical Society

From left: Marvin Adams, head of Defense Programs at the National Nuclear Security Administration (NNSA); General Anthony Cotton; NNSA Administrator Jill Hruby; and Los Alamos Director Thom Mason.

QUOTED

"General Cotton's personal visit to our Laboratory signifies the tremendous importance of our deterrence mission and the continued confidence America's military leaders have in our ability to steward the nation's stockpile."

—Los Alamos Director Thom Mason, shortly after General Anthony Cotton toured the Laboratory on July 16. General Cotton is the commander of U.S. Strategic Command, which integrates and coordinates the strategic capabilities of the military to deter attacks and to plan and execute nuclear military missions. ★

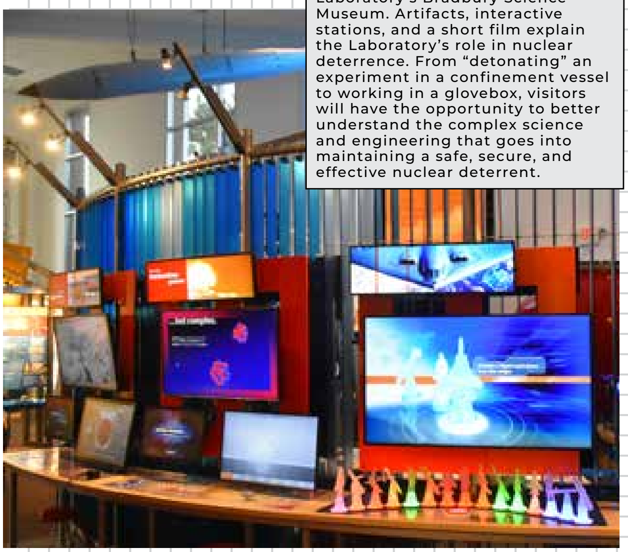
ABSTRACTS Notes and news from around the Lab

THE INTERSECTION

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

SCIENCE

CULTURE



If you find yourself in downtown Los Alamos, check out the new exhibit in the Defense Gallery of the Laboratory's Bradbury Science Museum. Artifacts, interactive stations, and a short film explain the Laboratory's role in nuclear deterrence. From "detonating" an experiment in a confinement vessel to working in a glovebox, visitors will have the opportunity to better understand the complex science and engineering that goes into maintaining a safe, secure, and effective nuclear deterrent.

Every July, Los Alamos County hosts ScienceFest, a multiday celebration of science, technology, and engineering. Attendees geek out over all types of interactive displays, but they especially enjoy controlling the Laboratory's Boston Dynamics Spot robots. To learn more about how these animal-like machines are used at the Lab, see p. 20.

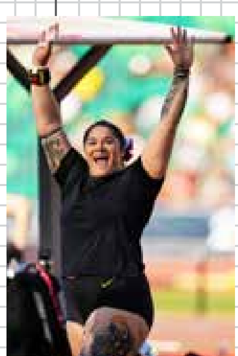
1663, the Laboratory's science and technology magazine, has gone digital! Check it out online and subscribe using the QR code.

According to *U.S. News & World Report*, Los Alamos County is No. 2 on the list of 2024 Healthiest Communities. Ranked No. 1 in 2023, Los Alamos scored high marks in the housing and population health categories. Photo: Los Alamos County

When the Program Project Interface division's Halloween party was announced, operations support specialist Amanda Vigil knew she wanted to enter the pumpkin decorating contest. "I spent some time browsing Instagram for inspiration and saw a carousel," she said. "I bought the supplies and enlisted the help of my daughter to glue on the gems—it took 3 hours to get them all on." Vigil said her pumpkin turned out even better than she expected, and she enjoyed seeing her coworkers' reactions.

Secundino Sandoval, known for his paintings of northern New Mexico, was employed as a draftsman and industrial artist at the Laboratory's Sigma Complex (see p. 48) starting in 1952. In 1974, Sandoval asked for a three-month leave of absence so he could focus on painting. According to his obituary (he died in January 2022), "at his first art show that summer he sold out all of his paintings. He promptly retired from [the Laboratory] and, like the saying goes, the rest is history."

Lab scientist Jeff Favorite founded the Hill Stompers jazzy street band in 2000. Twenty-four years later, the troupe is still going strong. Here, Favorite performs in the WinterFest Light Parade in downtown Los Alamos. Photo: Los Alamos County



Los Alamos High School graduate and two-time world shot put champion Chase Ealey Jackson represented the United States in the shot put at the 2024 Olympic Games in Paris. During her years competing as a LAHS Hilltopper, Jackson won several state championships. Jackson's mother, Michelle Naranjo-Martinez, also grew up in Los Alamos and worked for the Laboratory's Fire Protection Office for 25 years. Photo: Nathan Limback

MANUFACTURING FOR NATIONAL SECURITY

From coast to coast, specialized parts, technology, and strategic materials help make the world safer.

The National Nuclear Security Administration's labs, plants, and sites work together and with industry partners to produce America's nuclear weapons and other technology with national security applications. Here's a high-level look at where some items are produced and manufactured across the nuclear security enterprise. ★

Los Alamos National Laboratory

- Detonators (p. 8)
- Graphite molds (p. 48)
- Heat sources (p. 16)
- Isotopes (p. 15)
- Magnets (p. 12)
- Nonnuclear weapons components (p. 44)
- Plutonium pits (p. 66)
- Prototypes (p. 36, 48)
- Space instruments (p. 16)
- Targets (p. 10)

Sandia National Laboratories

- Electronics
- Neutron generators

Y-12 National Security Complex

- Uranium components (p. 48)

Pantex Plant

- High explosives (p. 56)

Kansas City National Security Campus

- Nonnuclear weapons components, including
  - fiber optics
  - firing systems
  - gas transfer systems
  - polymers (p. 25)
  - radar systems

Savannah River Site

- Plutonium pits (future)

ENTERPRISE ASSISTANCE:

Holston Army Ammunition Plant

- High explosives (p. 56)

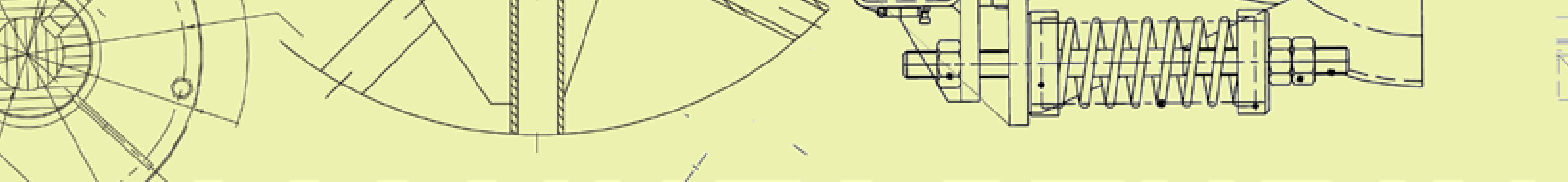
Tennessee Valley Authority

- Tritium

**For a deeper dive into the nuclear security enterprise—the National Nuclear Security Administration's network of labs, plants, and sites—see the spring 2023 issue of this magazine.*

LISTEN

The *National Security Science* podcast is a spin-off of *National Security Science* magazine. Listen to stories from Los Alamos National Laboratory's Weapons Programs—stories that show how innovative science and engineering are key to keeping America safe. Check out the latest episode to hear *National Security Science* magazine interview Los Alamos National Laboratory historian Nic Lewis about the Lab's longest serving director, Norris Bradbury. Learn about how Bradbury impacted the evolution of the Lab. You'll also hear historical audio clips from Bradbury himself. ★

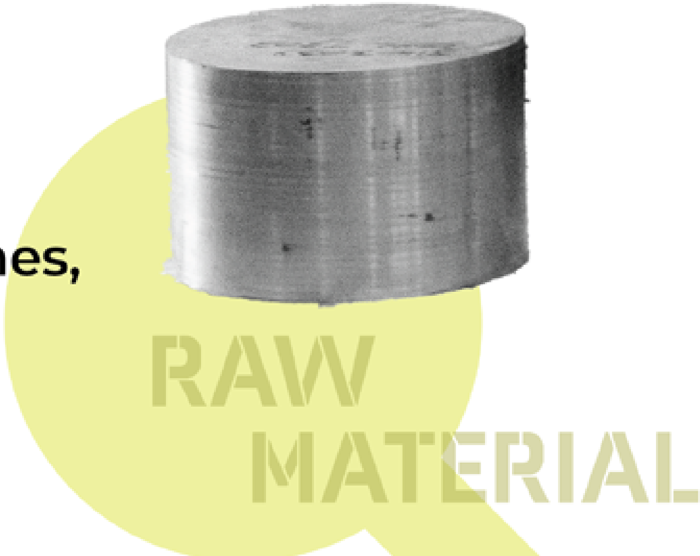


MANUFACTURING

Useful terms to know before diving into this issue.

MANUFACTURING:

The process of converting raw material to a finished part through labor, machines, tools, and chemistry.



TECHNIQUES

(just a few of many)

Casting: The process of pouring molten material into a mold to form a specific shape upon solidification. See p. 48.

Computer numerical control (CNC) machining: A manufacturing process that uses pre-programmed software to control the movement of tools and machinery to shape materials.

Welding: Processes that join metals by melting and fusing them using different methods.

Turning: A machining process that uses a cutting tool to remove material from a rotating workpiece to create cylindrical or other desired shapes.

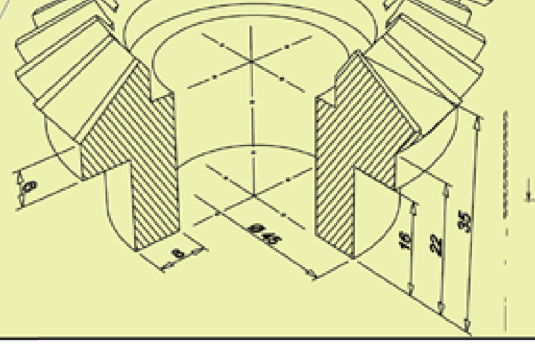
Electron-beam additive manufacturing (EBAM): An additive manufacturing process using an electron beam to melt metal powder or wire into a desired shape.

Forming: A manufacturing process where a material's shape is altered by applying pressure or force without removing any material.

Roll forming: A process of continuous bending of a metal sheet or strip using rollers.

Forging: The process of heating a piece of metal and then beating or hammering it into a desired shape.

G MANUAL



ADVANCED MANUFACTURING:

Innovative production technologies that improve products and processes, often involving automation, robotics, and smart systems. See p. 26.

ADDITIVE MANUFACTURING

The process of creating objects by adding material layer by layer, often using 3D-printing technologies.

SUBTRACTIVE MANUFACTURING

The process of creating objects by removing material from a solid block through machining processes such as milling or turning.

MACHINING: A type of subtractive manufacturing that involves removing portions of a larger piece of raw material to create a desired shape or part. Machining uses tools such as lathes, mills, routers, grinders, and drill presses.

FABRICATING: The process of assembling, cutting, and shaping materials into a finished product.

TOOLS

Lathe: A machining tool that rotates a piece of raw material around a stationary cutting tool to create a desired shape.

Mill: A machining tool that rotates a cutting tool around a stationary piece of raw material to create a desired shape.

Router: A machining tool similar to a mill that's used to carve or engrave a piece of raw material.

Grinder: A machining tool that uses an abrasive rotating wheel to wear down the surface of an object.

Drill press: A stationary machining tool that drills holes in objects.

CNC laser cutter: A CNC machine used to precisely cut materials.

CNC press brake: A CNC machine used to bend sheet metal with high precision.

Coordinate-measuring machine (CMM): A device that measures the geometrical characteristics of an object.

Multi-axis 3D printer: A 3D printer that uses a robotic arm (rather than a frame structure) to move a tool head, allowing the fabrication of complex shapes.

FINISHED GOODS

A modern detonator (left) is much smaller than a 1940s-era detonator.

SMALL BUT MIGHTY

Los Alamos serves as the production agency for all detonators.

BY JILL GIBSON

"Extremely small and extremely important." That's just one of the ways Los Alamos National Laboratory's Detonator Manufacturing Office leader Jim Shipley describes the detonators that the Lab builds. Los Alamos is the only place in the country that manufactures detonators for nuclear weapons.

Because different weapons use different types of detonators, Los Alamos currently manufactures seven different types of detonators simultaneously. Five of these types were designed at Los Alamos, and the other two were designed by scientists at Lawrence Livermore National Laboratory.

In 2023, the Lab delivered more than 3,000 detonators to the National Nuclear Security Administration, which oversees all aspects of nuclear weapon design, maintenance, and production. "The detonators are built in lots of a few hundred and it typically takes about a year to build a full lot of detonators," Shipley says.

After building a lot, the team pulls a certain number of detonators out to test them. "The tests ensure they meet the specifications, which are highly exacting as we are a production agency building parts for the nation's nuclear stockpile," Shipley says.

Shipley describes the products his division makes as "crucial."

"Without detonators, you don't have a nuclear weapon that will operate," he says. "It's a key thing that has to work. Not that it's more important than any other component in the weapons system, but you must have detonators for the system to work."

A nuclear weapon detonates in a carefully choreographed sequence in which detonators trigger the high explosives surrounding the plutonium pit at the core of the weapon. The resulting explosion causes the pit to implode, initiating a nuclear reaction.

The first step of this process begins when an electrical charge or a laser (depending on the type of detonator) within the detonator produces a shockwave that triggers a small amount of included explosive material. This detonator explosive then triggers the larger quantity of high explosives surrounding the pit.

"The way detonators work is fascinating," says Shipley. "The physics is so complex, and the timescales are so short."

The Lab is exploring the merits of using detonators that use optical energy instead of electricity to set off the internal explosion. By using radiation at a specific wavelength, an optical detonator removes the hazard posed by electrical initiation and reduces the risk of accidental detonation.

■ Technician Daniel Byers solders components together to build a detonator.

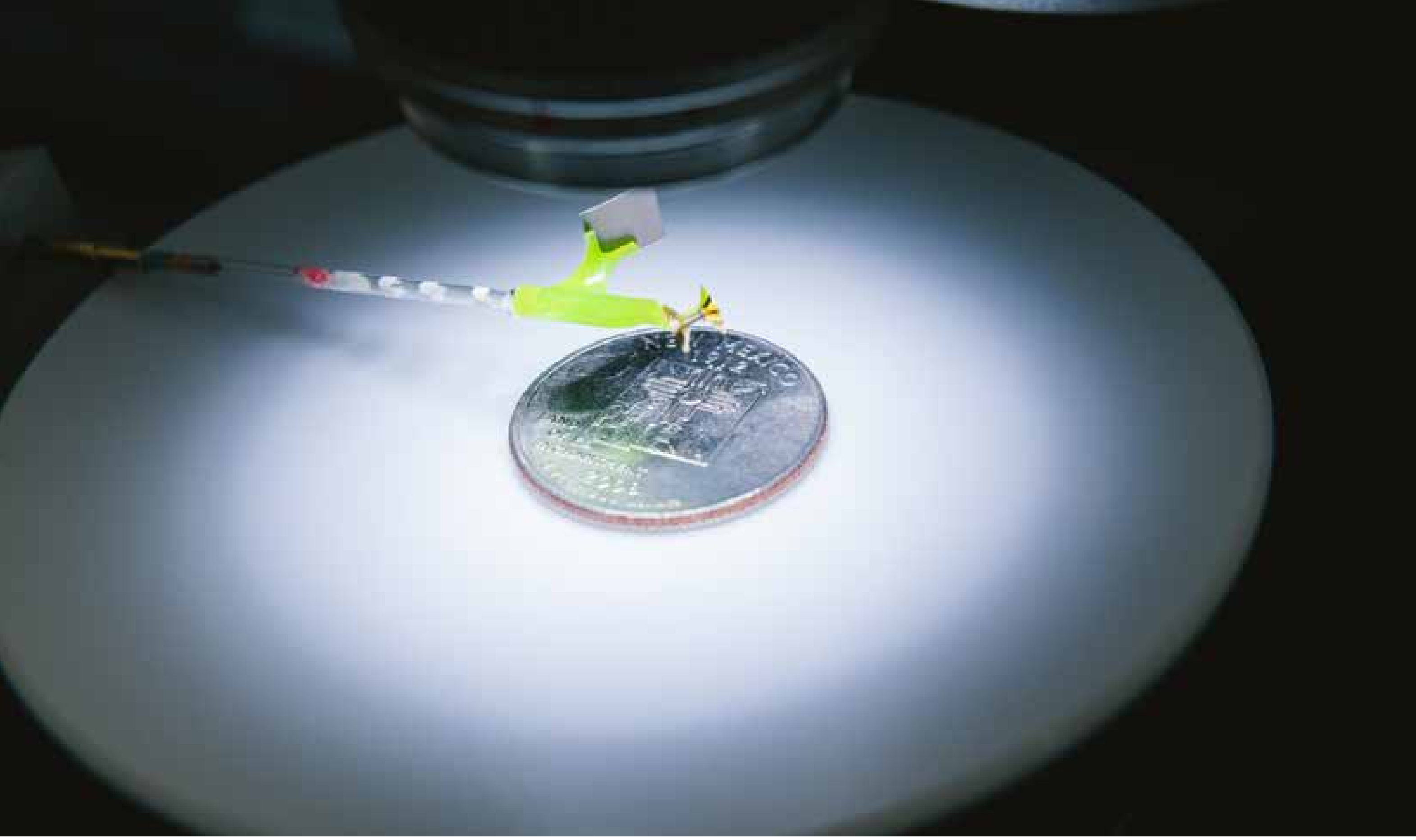
However they are initiated, the detonators, the explosives inside them, and the explosives surrounding the pit must all work together to ensure a successful nuclear reaction. Because of this, the scientists who design and produce detonators work closely with the scientists who design and produce explosives. Conveniently, those scientists work at Los Alamos as well, which makes collaborating easier for everyone involved, according to Margo Greenfield, High Explosives Sciences and Technology group leader.

“We collaborate closely with the Detonator Production team,” Greenfield says. “We provide the explosive, we conduct studies of how the detonators and the explosives are aging, and we work together to solve problems.”

One way detonator and explosive aging are assessed is through a process called surveillance. 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. During destructive surveillance, weapons are disassembled and detonators are removed, examined, and tested by initiating a detonation and analyzing the result.

Shipley says many people are surprised to learn how tiny yet powerful the detonators are. “We work on such very small things, but we have a very large sense of pride,” Shipley says. “The employees in Detonator Production are invested in the national security mission. We are proud of our contributions manufacturing this small but essential part.” ★

■ Control specialist Angela Trujillo glues and crimps together parts.



To demonstrate its small size, a target is shown next to a quarter.

ON TARGET

A Los Alamos team's tiny creations are key to fusion experiments and more.

BY JILL GIBSON

What do you think of when you hear the word "target"? A bullseye, a large retail chain, a goal or aim? The most basic definition of a target is something at which someone aims, which is an appropriate description of the targets Los Alamos National Laboratory engineer Derek Schmidt makes.

Schmidt's targets vary in size, but many are tiny: smaller than a person's pinky nail. Targets are used in physics experiments, where they are bombarded (or targeted) by particles (such as electrons, protons, or radiation). Los Alamos–built targets often are used at Lawrence Livermore National Laboratory's National Ignition Facility (NIF), where scientists are achieving fusion ignition, meaning the experiments create more energy than was put in. In addition to NIF, scientists use targets in tests at the OMEGA Laser Facility at the University of Rochester and Sandia National Laboratories' Z machine. Los Alamos makes as many as 700 targets a year.

"We precision-machine the targets," Schmidt explains. "The components inside the targets are so small they look like dust. They are smaller than the diameter of a human hair."

Before target engineers build a target, they meet with scientists to discuss the overall concept of an experiment and what data the scientists want to obtain. Physicist Liz Merritt describes members of the Los Alamos target fabrication team as artisans who play an integral role in her ability to create fusion experiments to explore the physics of nuclear implosions.

Merritt recently executed a series of experiments that used a double-shell target. The target consists of an inner metal capsule filled with deuterium and tritium. The capsule, which is a couple hundred microns in radius, is surrounded by two foam hemispheres and an aluminum outer shell. The double shell target was assembled using a custom-designed and -programmed robot that Schmidt invented.

"Double-shells are the most complex targets we make in the Department of Energy," Merritt says. "They take advantage of all of the strengths of the Los Alamos target fabrication team."

Scientist Brian Patterson uses 3D tomographic x-ray imaging to examine the double-shell assembly to assess and measure any imperfections down to submicrometer resolution. "We can create 3D rotating images to make measurements and look for flaws," he says. "It's all about identifying defects that could affect the performance of the target and checking accuracy." He adds that rarely are any two targets exactly the same.

"We have to measure every little idiosyncrasy on these targets," Schmidt says. He holds up a miniscule clear plastic container. "Do you see the tiny disc in there?" He points to a flat circle about half the size of a small sequin. "It has 100 sine waves machined across it." Those sine waves help scientists compare computer codes to the outcome of the experiment.

Despite their small size, targets are essential to producing large amounts of data—as long as they make it into experiments. Machinist Casey Blough says it took him a while to get the hang of micromachining targets. He likes to joke that, "once, I exhaled and lost what I was working on." ★

MODELING MICROSTRUCTURES

A new open-source code improves safety and performance of manufactured parts.

BY IAN LAIRD

How a part is made determines its microstructure, which determines its behavior. Scientists at Los Alamos National Laboratory have developed an open-source code that allows researchers to "see" into a part's microstructure and determine how it might perform under certain conditions. The code, called Fierro, is particularly useful for additive manufacturing, in which microstructures are not always well understood. Fierro evaluates the unique microstructures of additively manufactured parts and simulates how those microstructures impact performance—things like strength, safety, and durability.

"Codes such as these are essential to understanding the relationship between manufacturing processes and part performance," says Fierro co-developer Nathaniel Morgan. "Adjusting manufacturing processes to give a superior microstructure yields a stronger product. The need to better understand the impact of microstructure on part performance is critical and creates pathways to adopt modern manufacturing methodologies."

Along with evaluating the microstructures of additively manufactured items, Fierro can design and optimize additively manufactured products. Out of millions of different options, the code autonomously finds the optimal design that meets the requirements set by the user.

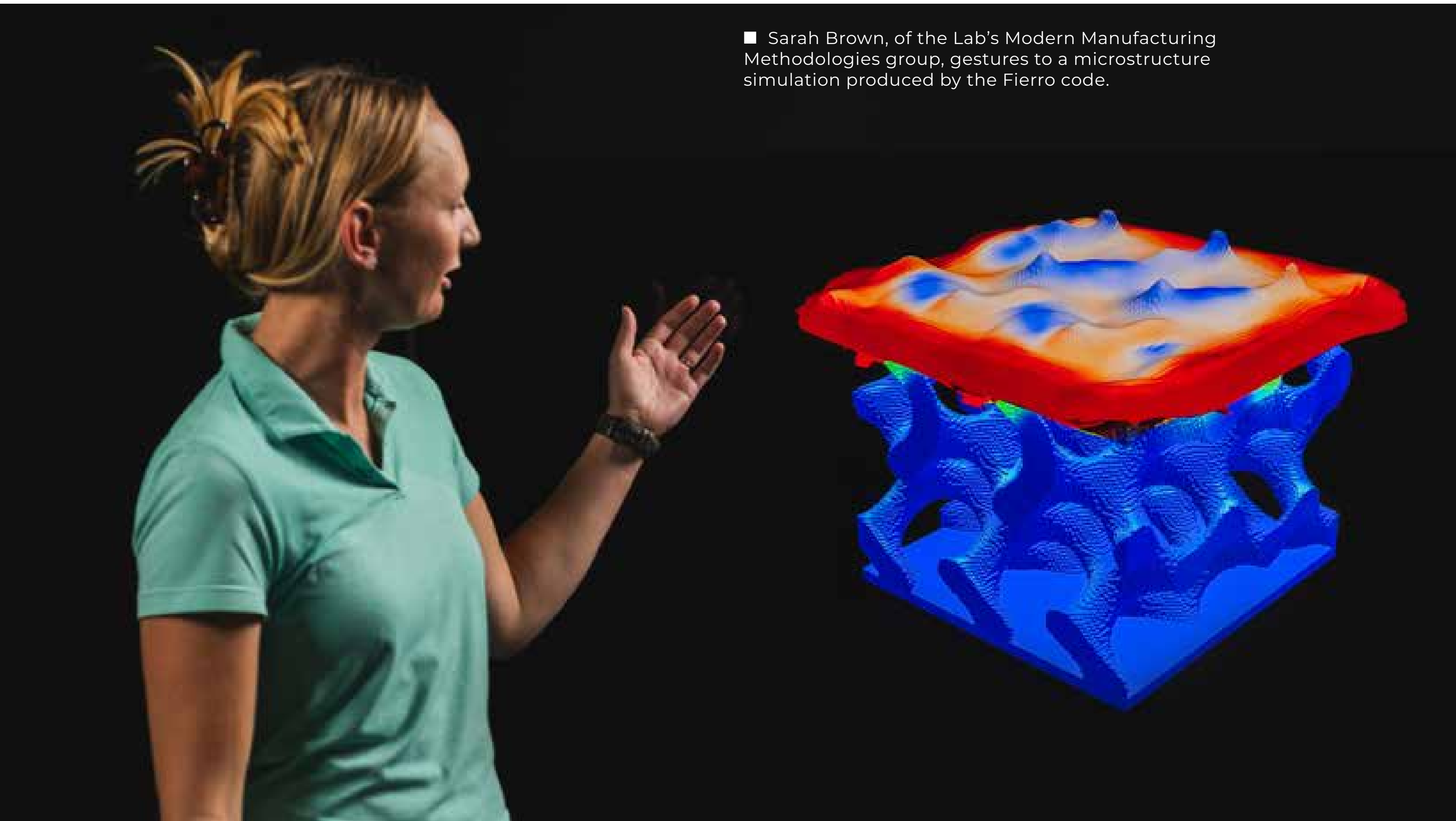
Fierro can also design and model items for stress wave dissipation, which is important for energy-absorbing products such as helmets and car bumpers. "With the advent of additive manufacturing, energy-absorbing structures can be produced with intricate lattices that deliver superior safety and reduced weight," Morgan says. "Fierro uniquely can identify the optimal lattice to dissipate stress waves, maximizing the efficacy of an energy-absorbing structure."

Leveraging the power of supercomputers, Fierro processes problems faster and allows users to develop higher quality simulations with higher levels of accuracy. As Morgan explains, slower running software often forces engineers to make concessions on things like fidelity and physics, which could lead to errors in evaluating performance.

"Efficiency, which in this case refers to shorter computing times to solve a problem of specific size, is paramount when using Fierro for material design," says Fierro co-developer Ricardo Lebensohn. "Finding an optimized design requires running expensive models many times over as part of an optimization loop."

Morgan and Lebensohn hope Fierro, which is openly available on GitHub, can eliminate, or at least reduce, poorly made parts that could pose serious safety risks.

"Fierro is one of many success stories from the Laboratory Directed Research and Development program," Morgan says. "This is a high-value research project that we hope can have an impact not just on academia and our profession but the world as a whole." ★



■ Sarah Brown, of the Lab's Modern Manufacturing Methodologies group, gestures to a microstructure simulation produced by the Fierro code.

Jason Lucero and Abran Valdez use special tooling to coil wires around a magnet body.

MAKING MAGNETS

At Los Alamos National Laboratory's MagLab, magnets are designed and built for research in high magnetic fields.

BY IAN LAIRD

The magnets at the MagLab—the Los Alamos National Laboratory branch of the National High Magnetic Field Laboratory—are some of the strongest in the world, capable of reaching 100 tesla. (For comparison, a refrigerator magnet is about 0.005 tesla, and the Earth's magnetic field is about 0.00005 tesla).

Currently, the MagLab operates five kinds of magnets, including multiple 65-tesla short-pulse magnets (dubbed the "workhorse" magnets because of their frequent use) and a prized 100-tesla magnet, which is the strongest non-destructive magnet in the world.

Scientist Doan Nguyen is responsible for the design and production of these magnets. "To generate the highest magnetic fields possible, our magnets are designed and operated to fail," he explains. "Once a magnet fails, some components are damaged and cannot be reused."

Magnets typically last a few months to a few years, and failure can occur after repeated exposure to high stress, general wear and tear, or overheating.

"Magnets have a limited lifetime, and so we are constantly building new magnets here," says Nguyen, gesturing around a warehouse filled with machinery. "We have coil-winding stations and machines—like lathes and hydraulic presses—to make our different magnets."

The central body of a magnet is composed of layers of conductor reinforced with coils of high-strength metal and polymer fibers.

The coils of the 100-tesla magnets, for example, are made out of copper-niobium wire, which has high tensile strength and is conductive—a rare combination. "Typically, high strength and high conductivity don't go together," Nguyen says.

The coiled wire is then wrapped in zylon, a polymer that resembles threads of golden-blonde human hair and has exceptionally high tensile strength, which helps resist the radial force of the magnetic field. Then, layers of a thin nickel-cobalt alloy are applied over the zylon to help resist the magnetic field's compression force.

Some of these materials are difficult to come by. Zylon, for example, is produced by only one company in Japan, and copper-niobium wire is produced by one company in Russia. After Russia's invasion of Ukraine, import bans have prevented Nguyen from ordering more wire. "We have some stocked, and we are saving that for our 100-tesla magnet," he says. "Before, we used that same wire for some smaller magnets, but we've had to stop that and find new routes."

Across the country, both government and industry organizations are testing new materials and trying to produce copper-niobium wire, but so far, none of the materials or production facilities have replicated the strength and conductivity of the stocked wire.

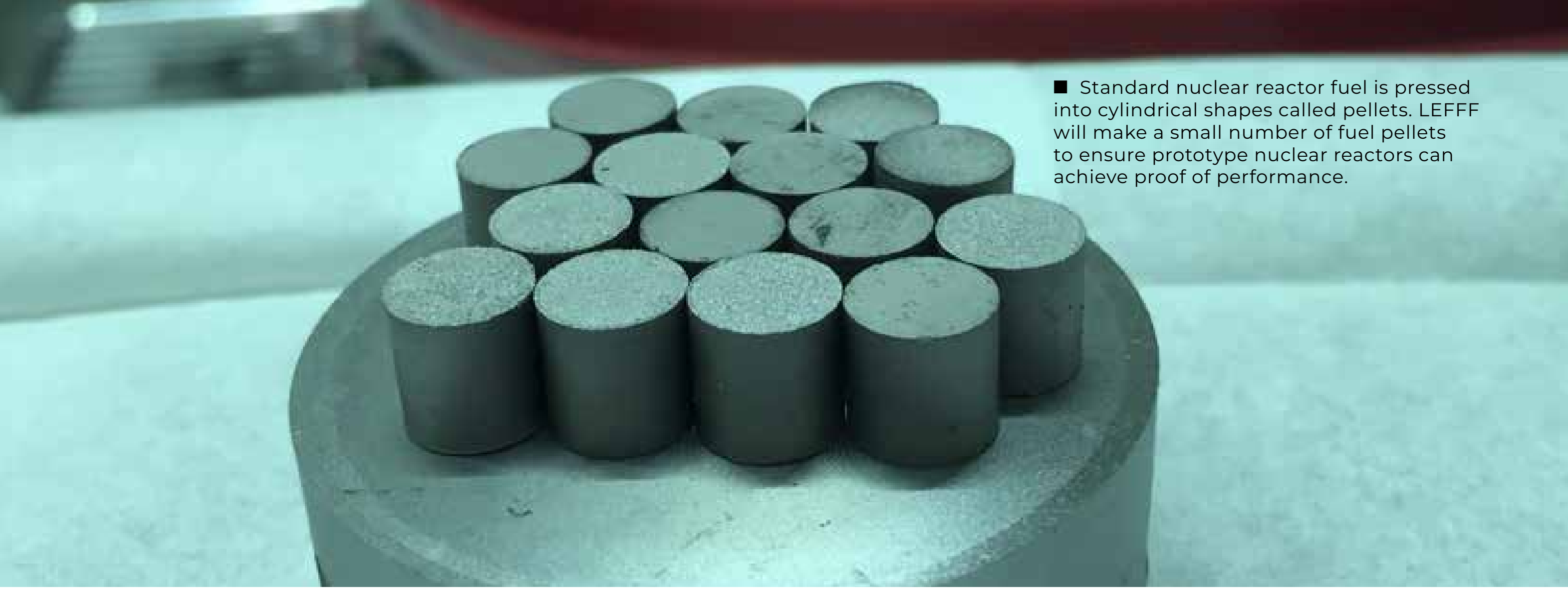
In the meantime, "we are limiting our users on the number of max-tesla tests they do on the 100-tesla magnet in an effort to extend the life of the magnet," Nguyen says. "We are instead conducting experiments in the 80-tesla and 90-tesla range, which place less stress on the materials."

While simultaneously maintaining and building the MagLab's current suite of magnets, Nguyen must think about the future. An 85-tesla magnet is set to enter service by the end of 2024, and a 2024 report published by the National Academy of Science strongly recommended investment in developing and building a 120-tesla magnet.

"My main task is to meet what the MagLab users ask for," Nguyen says. "The 120-tesla magnet is ambitious, but I intend to do everything I can to deliver it." ★

■ Doan Nguyen helped with the design and production of the five kinds of magnets at the MagLab.

■ James Michel winds zylon fibers around a 100-tesla magnet.



■ Standard nuclear reactor fuel is pressed into cylindrical shapes called pellets. LEFFF will make a small number of fuel pellets to ensure prototype nuclear reactors can achieve proof of performance.

FUELS OF THE FUTURE

A new Los Alamos National Laboratory facility will manufacture advanced nuclear reactor fuels.

BY JILL GIBSON

At Los Alamos National Laboratory, construction is underway on an advanced nuclear-reactor fuels manufacturing hub. The Low-Enriched Fuel Fabrication Facility (LEFFF) is expected to be fully operational by 2026.

LEFFF will make a variety of fuel types, collaborating with partners ranging from small businesses to Fortune 500 companies, the Department of Energy, the National Aeronautics and Space Administration, and the National Criticality Research Center. “We will be a national tool to facilitate the maturation of new fuels,” says Tim Coons, LEFFF team leader.

Why this need for different fuels? It stems from the development of prototype nuclear reactors that require small fuel amounts to achieve proof of performance.

Scientists are developing advanced reactor designs that have the potential to improve the safety and operation of nuclear plants. Each new reactor design can require a slightly different fuel formulation. The new reactor designs are advanced, but so are the fuels. These fuels can be more resistant to radiation, corrosion, or high temperatures.

“LEFFF will bridge the gap between research and development and commercial production,” Coons says. “The facility will serve as a launching pad for these advanced reactor companies to move to the commercial stage of reactor development.”

Nuclear reactors operate by splitting atoms (nuclear fission) to produce heat. That heat generates steam, which then spins a turbine. The turbine is connected to an alternator that releases energy. The initial energy to split atoms comes from the reactor fuel, which generally consists of uranium processed into small ceramic pellets and stacked together in sealed metal tubes called fuel rods. Typically, more than 200 of these rods are bundled together to form a fuel assembly.

One of the advantages of LEFFF will be its ability to use low-enriched uranium for fuel fabrication, including high-assay, low-enriched uranium (HALEU), which contains an increased concentration of uranium-235 (the fissile uranium isotope). Using HALEU to manufacture novel fuels allows researchers to design new types of reactors that can operate for decades without refueling, which increases safety and reduces waste. Currently, Los Alamos National Laboratory is one of the few places in the country with the ability and authority to work with HALEU, which is produced in limited quantities and requires a high level of expertise, safety training, and special authorization to use. “This will be a major advantage for the customers that partner with LEFFF,” Coons says.

Coons says LEFFF will draw upon Los Alamos and Department of Energy expertise to ensure all safety measures are in place and approvals documents are implemented. This facility will also be included in the Lab’s new Site-Wide Environmental Impact Statement, and the general public will be able to comment on the facility’s environmental impact.

Coons describes LEFFF as agile. “This is an intermediate place where we want to fail fast and learn what the challenges are,” he says. He points out that LEFFF will be flexible and multidisciplinary. “Partners both large and small need this fuel fabrication facility.”

When complete, LEFFF will contain equipment for chemical testing and processing of fuels; mechanical pressing and machining; high-temperature processing; and analysis, characterization, and qualification of fuels. The goal is to fabricate around 200 kilograms of fuel per year, Coons says. “The main mission is to take an advanced concept and run it through its paces before going into full production,” he notes. “That way you actually learn the process and determine if it makes business sense or if anything needs to be changed.”

LEFFF will work with one customer at a time, targeting the customer’s demonstration of technology and requirements. The 3,500-square-foot facility will also conduct research to assist the Lab’s nuclear nonproliferation teams to improve their ability to detect signatures from fuel fabrication facilities.

“When LEFFF is finished, it will be an adaptable radiological facility that will allow us to do a variety of things that serve the Lab’s mission,” Coon’s says. “Los Alamos is the place to take an advanced manufacturing concept and run with it. We embrace challenges. Making a safe, deployable, and reliable energy source is the type of extreme challenge this Lab was made for.” ★

Inside a shielded chamber, robotic arms are used to handle radioactive medical isotopes.

ACCELERATING SOLUTIONS

Isotopes produced at Los Alamos National Laboratory are saving lives, advancing cutting-edge research, and keeping the United States safe.

BY WHITNEY SPIVEY

What's the difference between sodium-22 and sodium-23?

One is edible (sodium-23) and the other is radioactive. Such differences are the superpowers of isotopes—variants of an element that have the same number of protons but differ in the number of neutrons. Chemical properties of isotopes of the same element are generally similar, but their physical properties can vary.

Some isotopes, such as sodium-23, occur naturally, but others are created using nuclear reactors or accelerators. In an accelerator, particles (such as protons) are accelerated to high speeds and used to bombard a target, which causes a nuclear reaction that produces isotopes. Scientists can tailor the type of particles and the type of target to create specific isotopes.

One such accelerator, located at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory, is used to produce isotopes for a range of scientific, medical, and industrial applications.

At LANSCE's Isotope Production Facility, scientists make isotopes to order for the Department of Energy (DOE) Isotope Program, which coordinates with hospitals and companies around the country to determine what to produce and when. DOE's national laboratories work together under the Isotope Program's direction to ensure a steady supply of critical isotopes. These isotopes are used for medical, national security, environmental, and industrial applications. ★

Los Alamos–produced isotopes (some of many):

- **Americium-241: used in smoke detectors and for oil and gas exploration (p. 21)**
- **Arsenic-73: used for environmental research**
- **Cadmium-109: used to calibrate instruments that monitor air quality**
- **Sodium-22: used as a source for positron emission tomography**
- **Additional isotopes are produced on demand**

Los Alamos designs and builds specialized space instruments for national security and scientific missions. Here, JP Martinez, Vernon Vigil, and Fabio Da Rocha prepare the NASA IMAP-Hi qualification unit for vibration testing to ensure the instrument design survives the launch environment.

OUT OF THIS WORLD

Los Alamos makes myriad technologies for space.

BY WHITNEY SPIVEY

Before there was the National Aeronautics and Space Administration (NASA), there was Los Alamos Scientific Laboratory, which kicked off Project Rover—an effort to develop a nuclear-powered rocket—in 1955.

In the years since, Los Alamos (often partnering with NASA and other organizations) has continued to apply science, engineering, and manufacturing expertise to basic space science and space-based nuclear detonation detection.

Past research and discovery highlights include the ChemCam and SuperCam instruments on the Mars rovers, the Two Wide-angle Imaging Neutral-atom Spectrometers instrument, the Van Allen Probes, and NASA's Interstellar Boundary Explorer. Present highlights include the NASA Interstellar Mapping and Acceleration Probe IMAP-Hi and Solar Wind Electron instruments and the Advanced Ion Mass Spectrometer Sentry instrument.

"These research and discovery instruments are exciting both because of the groundbreaking data they deliver and because they allow us to experiment with and mature innovative scientific, engineering, and manufacturing techniques," explains Jessica Wood, who leads the Space Instrument Realization group within the Lab's Intelligence and Space Research (ISR) division. "The technologies developed for and lessons learned from science are often directly applicable to our national security missions."

Global security is also a key focus of ISR. Since Los Alamos built and launched the first Vela satellites in 1963, the Lab has designed, built, and operated instruments to monitor international compliance with the Limited Test Ban Treaty, which prohibits nuclear detonations in space, the atmosphere, and underwater. The first Vela satellites were equipped with x-ray, neutron, and gamma-ray detectors, as well as charged particle and plasma sensors. In addition to their global security applications, these instruments provided some of the first measurements of Earth's space-radiation environment and the discovery of gamma ray bursts. The Laboratory continues to build and launch similar suites of instruments today.

Wood highlights the Space and Atmospheric Burst Reporting System (SABRS) instruments, which detect prompt gamma rays (the initial burst of gamma rays in a nuclear explosion), delayed gamma rays (found in radioactive decay after the initial burst), neutrons, and high- and low-energy charged particles. All SABRS development and fabrication work takes place at Los Alamos, and each SABRS payload takes about

four and a half years to build, test, and deliver for integration with its host satellite. “They hold a special place for those of us in the mechanical and manufacturing engineering discipline because they are so interesting and complex to design and build,” Wood says. “Colleagues frequently refer to the staff who build such instruments as having ‘magic hands’ because they have the skills and dexterity to fabricate these delicate, sophisticated assemblies with the quality and robustness to operate in the harsh space environment.”

In addition to ISR, the Lab’s Actinide Material Processing & Power (AMPP) division also manufactures parts for space. For more than 50 years, AMPP has manufactured heat sources, which are power sources made from plutonium-238. The radioactive isotope of plutonium generates heat as it decays. This heat is converted to electricity by a generator and can power a device in deep space for a very long time. In addition to powering the Mars rovers, heat sources manufactured at Los Alamos have powered the Galileo mission to Jupiter and the Cassini mission to Saturn. In 2027, plutonium-238 will power the Dragonfly mission to Saturn’s largest moon, Titan.

From satellite instruments to heat sources, Los Alamos is “staffed with incredibly creative problem-solvers and individuals with highly valuable and specialized skills,” Wood says. “Designing and fabricating these intricate, multi-component instruments to operate over long mission lifetimes in the extreme environment of space is both challenging and thrilling.” ★

■ Director Thom Mason

QUOTED

▼

“Along with our partners at Lawrence Livermore National Laboratory, the Kansas City National Security Complex, and the National Nuclear Security Administration, we have brought to bear our laboratories’ scientists and engineers; our manufacturing experts; and our weapons, safety, and operations workforce to ensure the pits met rigorous design requirements. This mission is an example of big science at work—an effort Oppenheimer established when Los Alamos was first founded more than 80 years ago and a legacy that our nation’s laboratories and plants continue today.”

—Los Alamos National Laboratory Director Thom Mason on the first production unit of the plutonium pit for the W87-1 warhead. Learn more about the pit mission on p. 66. ★

Intern Minhtet Hoon developed the code that automates the robotic arm responsible for moving samples into and out of the load frame.

Scientist Jesse Callanan opens the target chamber door on a gas gun. Gas gun testing allows researchers to test the shock response of materials.

SEARCHING FOR SUPERIOR MATERIALS

Scientists use automation and AI to find element combinations with optimal properties.

BY IAN LAIRD

The process of developing a new material sounds simple: Just combine different ratios of different elements until you come up with something that meets your specifications. In reality, the process is much more tedious and complex—that's why scientists at Los Alamos National Laboratory are turning to automation and artificial intelligence (AI) for a hand.

"Traditionally, humans mix and match elements to try and make materials, but it's too much for a human to do manually," says Saryu Fensin, leader of the Lab's Quasi-static and Dynamic Behavior of Materials team. "If you pick just nine elements on the periodic table and think about the combinations to generate binary (two-element), ternary (three-element), quaternary (four-element) alloys (mixtures of two or more elements), there are 300 unique compositions."

Through robotic automation and AI, however, Fensin aims to reduce the time it takes to manufacture and characterize new alloys from hours to minutes.

Fensin is developing a continuous automated production cycle for alloys that starts with melting specific amounts of two elements together. The cooled combination is shaped into a thimble-sized pellet. From there, a robotic arm takes the pellet and places it into a load frame—a device used to test the mechanical properties of materials, including their strength, stiffness, and displacement.

The data generated from the load frame goes into a database that trains an AI model. Each new alloy is a new data point. The goal is a model that can distinguish patterns across those data points, extrapolate patterns to unknown alloys, and ultimately propose a ranked list of known and unknown alloys optimized for specified properties.

However, developing such a model requires a significant amount of data. "The biggest issue we have is we are data poor, and the way AI works is you train it on data where variables are systematically changed until it learns the patterns," Fensin says. "So, we're going to try brute force and generate lots of data to find trends."

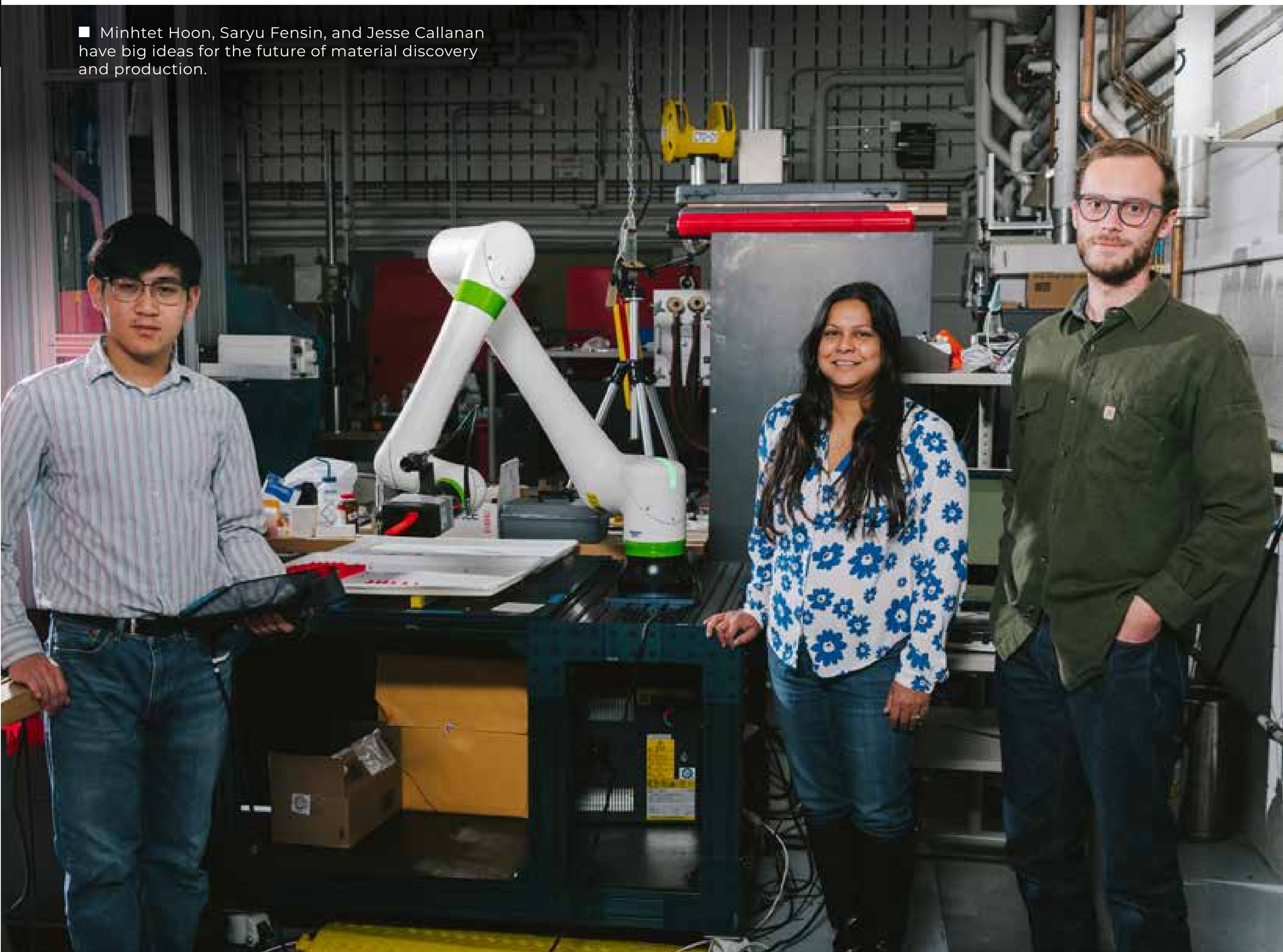
Fensin says that testing hundreds of millions of possible combinations is unrealistic even with an automated process. More realistically, she expects to produce and evaluate hundreds of thousands of combinations. "Tweaking compositions by a single percentage point will be too much, so in the first round we might change elemental compositions by 20 percent and see if properties change," she says. "If we see changes, then we can zoom in and do a smaller change."

Fensin is quick to note, however, that "there's always an exception to the rule, and there could be some composition that doesn't follow the patterns. So, the challenge is going to be gathering enough data and validating predictions. If the model predicts a composition in a microstructure that would give us certain properties, we need to go make it. It can't just be a computer exercise."

This gets at another point Fensin is passionate about: the role of humans in this process. She believes that repetitive work should be automated so that people are free to support, utilize, and expand on that automated work. She refers to this as "collaborative robotics," in which humans and automatons work together to maximize what each does efficiently.

Fensin sees three primary use cases for her team's work: providing data to customers about existing alloys, fundamental research and development of new alloys in general, and designing new alloys for specific applications, including for stockpile stewardship—the maintenance of America's nuclear weapons.

"This investment in fundamental research will be beneficial for stockpile stewardship," Fensin says. "We can build a scientific foundation and start doing research so that we can be responsive to any issues that arise." ★



■ Minhtet Hoon, Saryu Fensin, and Jesse Callanan have big ideas for the future of material discovery and production.

A Boston Dynamics Spot robot can conduct radiation surveys and other tasks.

Four-legged robots can go all sorts of places that wheeled robots can't.

SNIFFING OUT RADIATION

Dog-like robots monitor for hazardous material.

BY JAKE BARTMAN

In the most-viewed YouTube video for the month of November 2017, a Boston Dynamics Spot robot—which is bright yellow and about the size and shape of a golden retriever—uses a clawlike arm mounted atop its back to turn a doorknob before prancing through a doorway.

Viewers of the video were fascinated both by Spot's door-opening abilities and by the way that the robot moved. With its four legs, Spot sauntered with a smoothness that didn't call to mind the jerky motions of R2-D2 or C-3PO (the famed *Star Wars* robots). Instead, the robot's fluid gait made it resemble an animal—a dog, say.

The ability to move nimbly on four legs isn't merely a matter of aesthetic appeal, explains Jeff Hyde, a researcher at Los Alamos National Laboratory. As a part of the Laboratory's Modern Manufacturing Methodologies group, Hyde works to deploy new types of robots—including several Spot robots—at Los Alamos, using the robots' unique abilities to support the Laboratory's national security mission.

Before the Spot robots came on the scene, researchers were working to deploy wheeled robots at Los Alamos. They suspected that robots fitted with radiation-detecting equipment could support the Laboratory's radiological control technicians (RCTs), who use specialized tools to detect and monitor radiation levels in places where radioactive materials are present. RCTs play a crucial role in ensuring that the Laboratory achieves its mission safely.

Although the wheeled robots could monitor hazardous areas, they suffered from limitations. “Wheeled robots are very temperamental,” Hyde says. “They would do turns that would damage flooring, or they’d damage cables by rolling over them, or they’d end up in corners and get stuck.”

The wheeled robots’ limitations were such that they never achieved widespread deployment at the Laboratory. It wasn’t until Hyde’s team acquired a Spot robot in 2021 that the goal of augmenting RCT work with robots became feasible.

Spot robots are designed to operate autonomously. With their quadrupedal design, Spot robots can turn on a dime, mount or descend stairs, and avoid obstacles. The Spot robots have also proved durable. In one test, working in a secured area of the Laboratory, Hyde’s team exposed a pair of Spot robots to a very high dose of radiation, determining that the robots could function even when faced with radiation levels far above what a human being would be exposed to at Los Alamos.

Next, Hyde and his colleagues developed a custom payload that could be carried by a Spot robot and used to monitor for radiation. This payload consisted of a Los Alamos computer, LiDAR (or light detecting and ranging, which allows the robot to “see”), and an alpha-beta detector paired with a scintillation counter to measure radiation.

Fitted out, the Spot robots proved well-suited to completing truck radiation surveys. RCTs are sometimes called upon to scan the beds of delivery trucks that have carried hazardous materials such as depleted uranium—a tedious and physically demanding process that involves moving a radiation detector over the truck bed at a rate of around 5 centimeters per second. A Spot robot outfitted with a Los Alamos–designed payload can complete this task autonomously, bolstering efficiency and safety.

Other potential applications for Spot robots include general area radiation surveys. These surveys are conducted as a matter of course in facilities containing nuclear material, and they involve mapping radiation levels and tracking changes in those levels over time—a task that could be completed quickly and accurately by a Spot robot with a gamma-ray detector. Spot robots could also be used to scan facility floors for radioactive contamination, characterize radioactive objects, and assist with emergency response efforts (by going into areas that first responders suspect could be hazardous to enter).

Of course, Spot robots have limitations: they can’t climb ladders, for example. Even so, Hyde says that RCTs have been quick to see how the Spot robots can supplement their work, all the better to achieve the Laboratory’s mission. “The goal of the Spot robots is to augment tasks that are dangerous, tedious, or require high precision,” Hyde says. “We want to free up our RCTs, which will allow them to better support our mission.” ★

FROM TRASH TO TREASURE

The waste product americium is also a valuable commodity.

BY KEVIN ROBINSON-AVILA

If you purchase a common household smoke detector, it will likely contain the radioactive element americium. That americium will likely have come, by way of the Department of Energy’s Isotope Program, from Los Alamos National Laboratory.

Los Alamos is the nation’s sole supplier of americium, which forms as another radioactive element, plutonium, ages and decays. As part of its plutonium pit production mission (see p. 66), Los Alamos removes impurities—including americium—from aged plutonium. Rather than dispose of the americium, Los Alamos processes it for commercial applications, including not only smoke detectors but also medical research and space applications. The Lab shipped its first commercial batch in 2020 and is working to increase production.

Until 1984, americium was produced domestically at the Rocky Flats Plant in Colorado. Following the closure of Rocky Flats, the United States became entirely dependent on americium from abroad, primarily from Russia. But now, americium production at Los Alamos reduces dependence on foreign suppliers.

“Overall, resuming production of americium and mitigating dependency on sensitive countries has been beneficial to all parties involved: the U.S. nuclear complex, taxpayers, and industry,” writes Owen Summerscales, editor of the Lab’s *Actinide Research Quarterly* magazine. “A true win-win.”

Americium production is also a win for the environment because instead of being packaged and shipped to the Waste Isolation Pilot Plant in southern New Mexico where it would be permanently stored underground, the element is now kept out of the waste stream.

“As plutonium used in the nuclear security complex ages, the source of americium only keeps growing,” says David Kimball, a deputy group leader in the Lab’s Actinide Material Processing and Power division. “This program means we don’t have to throw that away as a waste product—more and more customers have come to us with orders.” ★

■ Americium is particularly useful as a high-energy emitter of positively charged alpha particles, which are not significantly harmful unless received internally. In smoke detectors, americium emissions enable an electric current to flow between two electrodes. When smoke particles enter the detector, they block the current, sounding an alarm.

■ Robotics and Automation Summer School students Ritvik Dutta, William Escobar, and Angelika Canete work with a robotic arm.

MANUFACTURING ROBOTICISTS

The Robotics and Automation Summer School attracts promising robotics students to Los Alamos.

BY JAKE BARTMAN

At Los Alamos National Laboratory, robotics and automation play an important role in helping the Laboratory attain its manufacturing objectives and accomplish its national security mission. But how is the Laboratory "manufacturing" the experts it needs to support that work?

One program that's training a new generation of roboticists is the Robotics and Automation Summer School (RASS). Founded in 2023, RASS is a 10-week program that allows talented college students to gain hands-on experience with the type of projects that Laboratory staff researchers undertake.

"I describe it as Top Gun for automation because we get the best of the best students," says RASS organizer Daniel Preston, who leads Los Alamos' Automation, Robotics, and Controls group. "It's a three-month boot camp that throws these world-class students into an environment where they can create things, develop proofs of concept, and demonstrate to sponsors what they're able to do."

Beth Boardman, who directs RASS, says that through academic and extracurricular programs, students gain robotics experience at younger ages and are ready to hit the ground running by the time they come to Los Alamos. In the program's first summer, for example, students designed a robotic system that could move a hazardous material container—a complex undertaking. "Everyone was really impressed by how much the students were able to do in just 10 weeks," she says.

The students selected for RASS had varied academic backgrounds: Some were studying robotics, while others were studying electrical engineering, computer science, and even biomechanical engineering. "That diversity of backgrounds was definitely intentional," Boardman says. "The problems we have for students to solve are very diverse and complex, and we wanted the students to work together to solve those problems."

The goal of RASS was to task students with projects that would necessitate working across the Laboratory and the nuclear security enterprise in much the same way that staff roboticists do. One of these projects supported Los Alamos' ARIES (Advanced Recovery and Integrated Extraction System) program, which converts surplus plutonium to its oxide form. Another project involved using robotics to laser weld thin sheets of foil together—a proof-of-concept of a recently developed additive manufacturing technique. A third project saw students develop a robot that could bolt and unbolt shipping containers

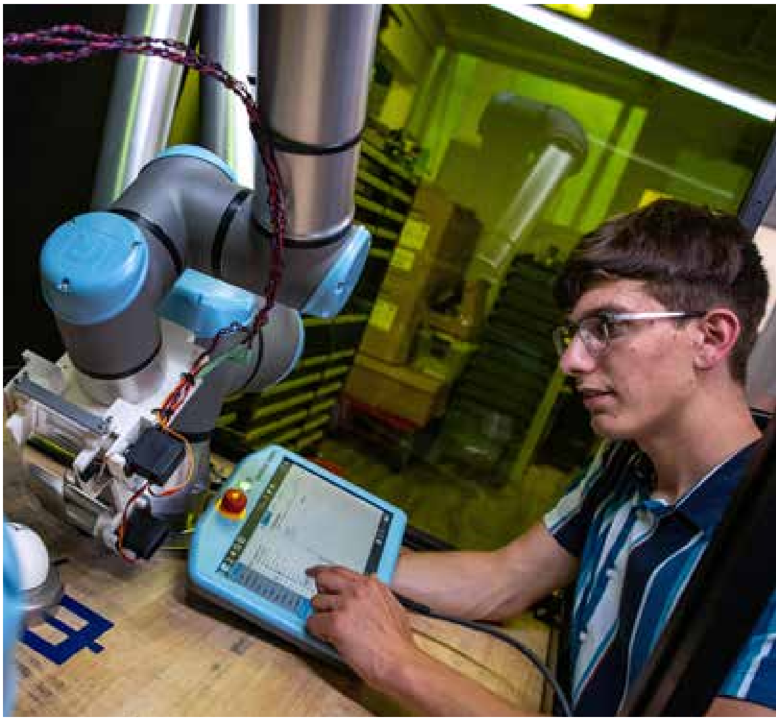
at the Y-12 National Security Complex in Tennessee. And a fourth involved coordinating the movements of a robotic arm and a conveyor belt.

Wisconsin native Joseph Krahn is a senior at Liberty University in Lynchburg, Virginia. As a 2024 RASS student, Krahn spent his summer working on the laser welding foil project. “At Los Alamos, I got to see how robotics work from a practical point of view—how robots can save people from having to do repetitive or dangerous tasks,” he says.

Robotics, Krahn says, is a field that demands technical know-how and creativity alike. By pooling his experience with teammates knowledgeable about electrical and software engineering, Krahn’s three-person team was able to complete its task successfully. “No robotics problem can be completed alone,” Krahn says. “You have to work with a team, learn from them, and combine strengths to solve a problem.”

Krahn adds that the project was rewarding in part because it wasn’t mere busywork. Instead, the techniques that the team developed may be further developed by Laboratory scientists to support Los Alamos’ mission.

“One thing that’s very cool about Los Alamos is the emphasis on the ‘why’ behind what we’re doing,” Krahn says. “I’m excited because we’re doing cutting-edge research to achieve meaningful change. That’s what the Laboratory is all about.” ★



RASS student Joseph Krahn.

DELIVERING SUCCESS

Los Alamos National Laboratory's complex distribution chain serves an essential role.

BY IAN LAIRD

Advancing scientific and technological knowledge requires a wide variety of elements, alloys, and compounds. The Los Alamos National Laboratory employees responsible for procuring and delivering these materials play an essential role in ensuring the Lab achieves its goals.

Each year, the Lab receives more than 2.5 million pieces of mail. Deliveries include items ranging from classified, hazardous, and radioactive materials to textbooks and historical films.

Joe Abeyta, the operations manager for the Logistics division Packaging and Transportation group, helps ensure the Lab's researchers stay supplied with necessary materials. This group is just one part of the Lab's complex distribution chain.

Abeyta says finding, purchasing, transporting, and distributing certain materials requires knowledge of processes and security requirements. Radioactive materials, such as uranium for fuel fabrication research, are often transferred within the Lab or obtained from other Department of Energy or National Nuclear Security Administration facilities.

For materials that are easier to procure and are widely produced, the Lab prioritizes finding local vendors. "This is part of our commitment to supporting our state economy and being a force for good," says Frances Chadwick, Los Alamos staff director.

Once suppliers are identified and materials are procured, most materials are either physically shipped to or electronically processed at the Lab's central warehouse.

"Everything that comes to the Lab gets distributed through this warehouse, and everything that goes out of the Lab comes through this warehouse to get shipped around the world," says Traballis "Trae" Rouse, the group leader for Materials Management.

Along with controlling warehouse operations, Rouse manages a fleet of transportation vehicles tasked with nonnuclear deliveries ranging from mail to construction materials and pieces of heavy equipment. He also oversees a team responsible for transporting classified material to a secure vault until the recipient can collect it.

Regardless of what Lab employees are delivering, safety remains the top priority. "We aren't ever pressured to trump safety and security with delivery speed," Abeyta says.

At the end of the Lab's supply chain are people like Aiping Chen—a scientist at the Center for Integrated Nanotechnologies (CINT), where researchers frequently work with rare or unique materials. Chen says Los Alamos' procurement expertise and ability to transfer materials between groups helps facilitate experiments. "There are some materials that are much easier to obtain internally through the Lab where externally you might not even be able to get them," he says.

The National High Magnetic Field Laboratory's Pulsed Field Facility—known as the MagLab (see p. 12)—is also home to exploratory materials research. Researcher Eric Bauer works with uranium compounds. "We use fairly high purity depleted uranium for basic research on quantum materials and unconventional superconductors," he says. He adds that Los Alamos is one of the few locations in the world authorized to procure, handle, and investigate these types of materials.

Bauer's research could be critical for quantum information and quantum computing, the next big step in computing capabilities. But his work depends on the availability and timely delivery of necessary supplies.

"We know things grind to a halt if our Logistics groups don't execute," Rouse says. "The foundation has to be laid to support the Lab's mission scope." ★

■ Receiving, transporting, and keeping track of the deliveries received by the Lab requires a collaborative effort by many groups of employees.

From left: Martin Oltmanns, Jason Benkoski, and Eric Martin, all of the Lab's Engineered Materials group, conduct polymer research.

POLYMER PARTNERSHIPS

Los Alamos scientists develop materials that are eventually manufactured by the Kansas City National Security Campus.

BY WHITNEY SPIVEY

Polymers are substances composed of very large molecules called macromolecules. If that's where your memory of high school chemistry fades, Kimberly DeFriend, a program manager at Los Alamos National Laboratory, offers a more detailed explanation.

"Polymers can be hard or soft materials," explains DeFriend, who until recently led the Lab's Engineered Materials (MST-7) group. "You can change their composition, density, or crystallinity to dial specific properties, such as mechanical response over a range of temperatures. Because of their versatility, they are applicable to different environments, and that makes them attractive for national security applications."

When DeFriend says national security applications, she's referring primarily to the use (past and present) of polymers in America's nuclear weapons, all of which are decades old. Many polymers and the parts made from them are original to the weapons and, due to aging or environmental concerns, must be replaced. If they are replaced, scientists have to decide if they should be swapped with the same polymer or a new one.

Polymer research and development (R&D) occurs primarily in MST-7 at Los Alamos, and full-scale polymer manufacturing or commercial procurement occurs at the Kansas City National Security Campus in Kansas City, Missouri. Although the organizations form two ends of the process—Los Alamos is the design agency that dreams up a polymer component or manufacturing process and Kansas City is the production agency that makes it a reality at a large scale—they are in close contact throughout. They even duplicate equipment to ensure what happens at Los Alamos can be replicated at Kansas City. "We try to work out the manufacturing and materials issues together," DeFriend says. "Bringing in Kansas City at the beginning of the R&D is important to ensure the best possible success of both developing and manufacturing the material."

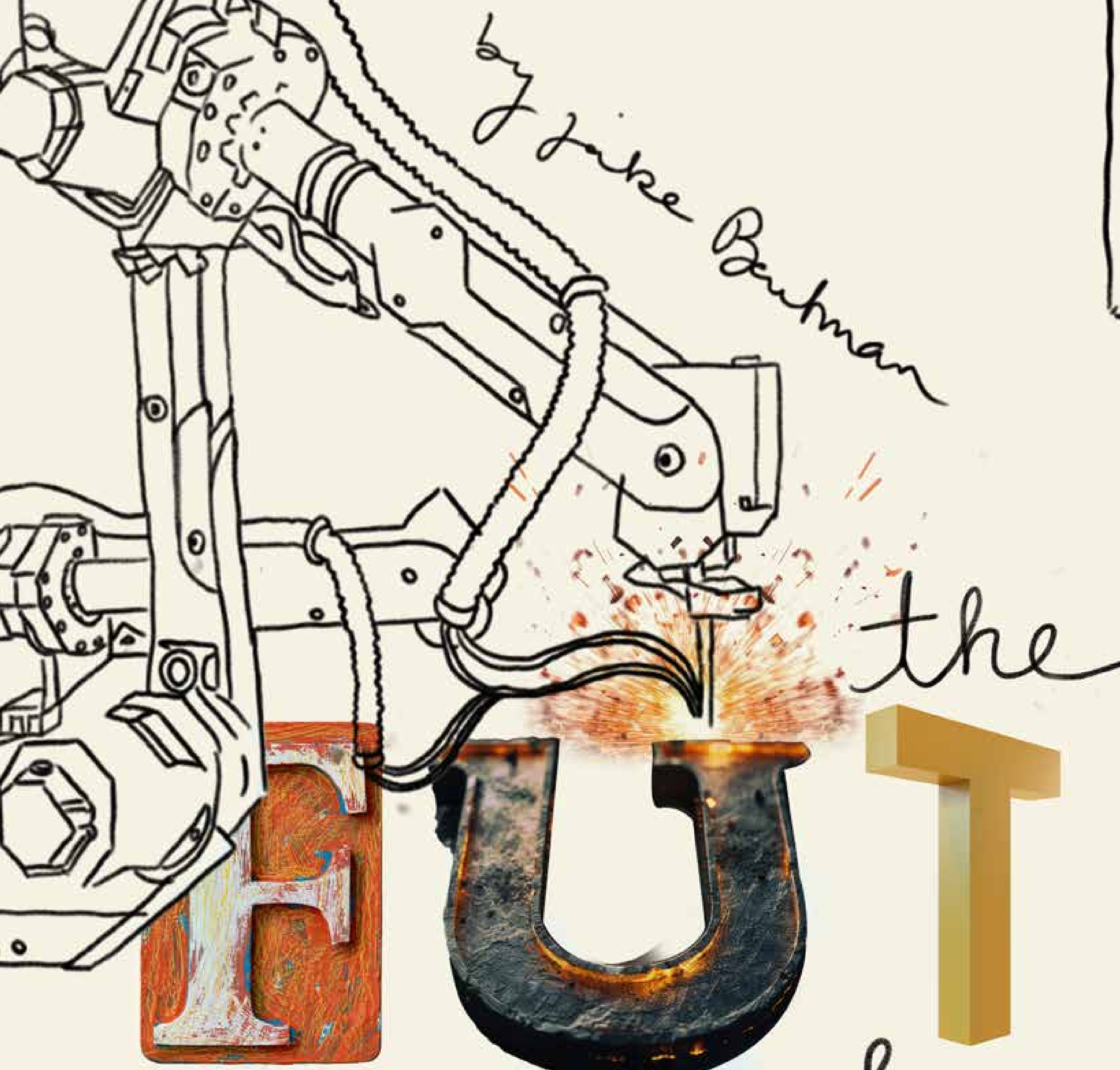
DeFriend gives a real-life example of a polymer component that has proved challenging. One of its materials is difficult to source, and other of its materials are hazardous to manufacture—they produce dust that requires workers to wear respirators. "Los Alamos and Kansas City have been working jointly to identify solutions to help mitigate these problems," DeFriend says.

So far, Los Alamos scientists have come up with a few innovative solutions. One is to replace some materials with more environmentally benign materials, coupled with a new synthetic for manufacturing them. Another is rethinking the material manufacturing process and using additive manufacturing instead of traditional subtractive machining, which creates not only dust but also quite a bit of waste.

"It's all promising, and Kansas City is excited about this new synthetic route and printing process," DeFriend says. "The issue now is making sure the printed part has the same characteristics and performance as the traditionally made component." That's where rigorous testing and inspection comes in—at both Los Alamos and Kansas City.

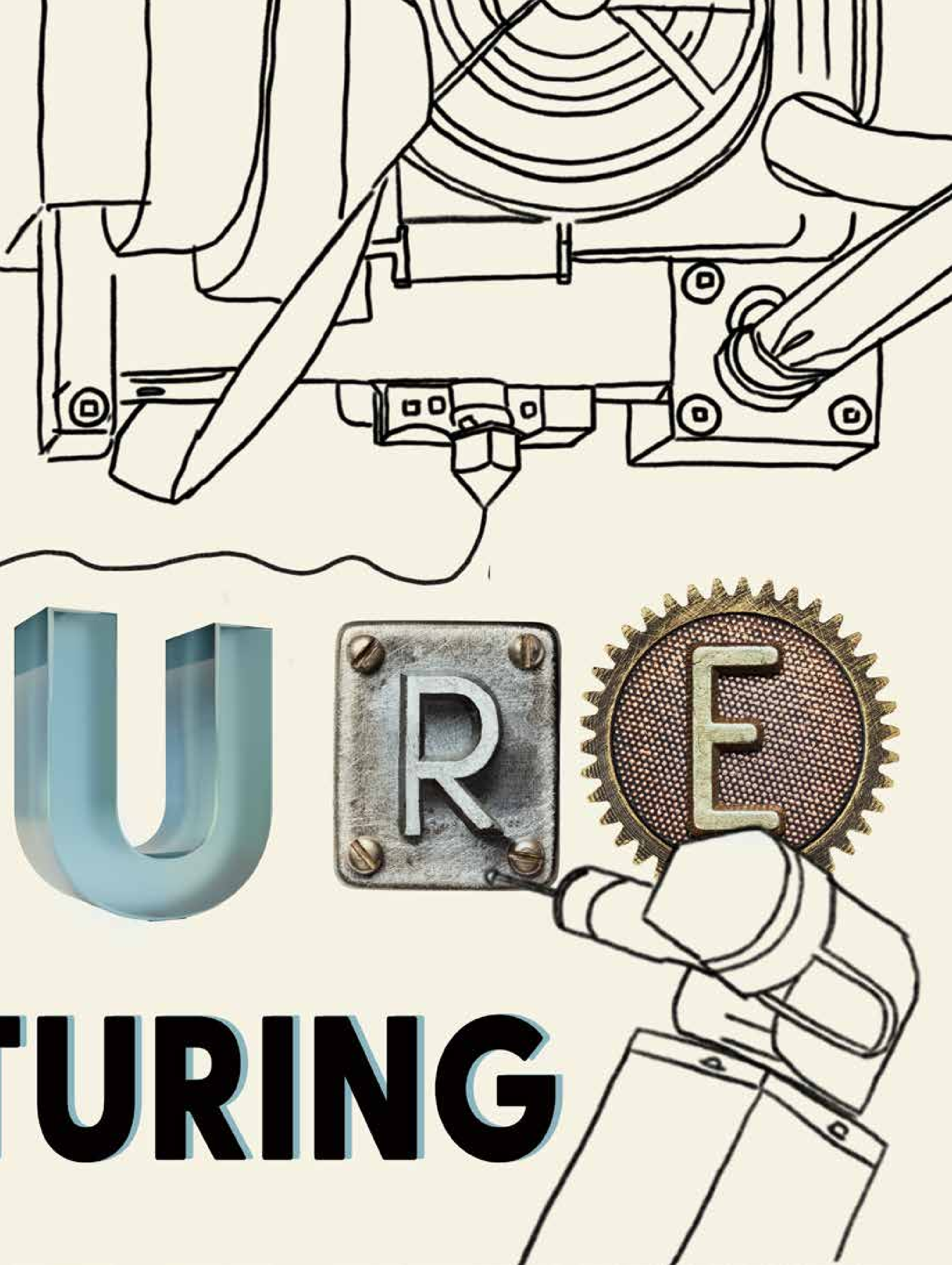
DeFriend says she's fortunate to have collaborated with colleagues at Kansas City for more than 20 years, and the current relationship between Kansas City and Los Alamos is the most robust she's ever seen it. "The need for new materials is driving the interaction, and people want to collaborate," she says. "Having this healthy partnership is really important to our national security." ★

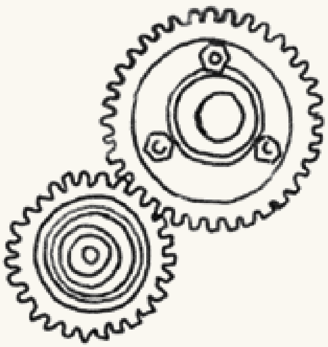
by Jake Bachman



the FUT of MANUFACT

Researchers at Los Alamos advance cutting-edge manufacturing techniques to support national security.


U R E
TURING



> To have a responsive enterprise, we must revolutionize manufacturing technology."
>
> —JOHN BERNARDIN

Look around, and you're almost certain to find yourself within arm's reach of a manufactured product. From carpeting to cardboard, computers to cars, the modern world consists largely of raw materials—metal ore, plant matter, petroleum, or any of countless others—that have been converted, by a series of industrial processes, into finished products.

Although the techniques used in manufacturing are innumerable, many key techniques were developed hundreds or even thousands of years ago. Take forging, for example. Forging—which involves shaping metal through a series of blows—has been in use since at least 4,000 BCE, when the technique was developed to make jewelry, tools, weapons, and other objects.

Forging looks far different today than it did in ancient Mesopotamia (hydraulic presses and computer-controlled tools have long since replaced stone hammers). But at its most basic, the technique remains the same: a piece of metal is repeatedly struck until the metal assumes a desired shape.

Over the past few decades, new techniques have redefined manufacturing as we know it. One major advance was the development of additive manufacturing (also called 3D printing) in the 1980s. Unlike traditional techniques that can involve cutting, machining, stamping, or otherwise removing pieces from a raw material until the material assumes a desired shape, additive manufacturing involves applying layers of material, one on top of another, to create a structure.

3D printing isn't the only technique that is changing the way society thinks about manufacturing. Advances in sensing technology have made it possible to monitor manufacturing processes in real time. Developments in computing have led to sophisticated modeling programs that can take into account the unique properties of diverse materials. And innovations in the field of robotics are allowing for the automation of all kinds of tasks that are repetitive or potentially dangerous.

Taken together, these methodologies are sometimes described as "advanced manufacturing"—a catchall term that encompasses both new approaches to manufacturing and the ways in which innovative methods can augment older ones.

At Los Alamos National Laboratory, researchers are developing and exploring novel advanced manufacturing methods. In doing so, researchers are supporting the nation's nuclear security enterprise at a time when the enterprise is manufacturing key weapon components on a scale not seen since before the end of the Cold War.

"To have a responsive enterprise, we must revolutionize manufacturing technology," says John Bernardin, a researcher in the Laboratory's Modern Manufacturing Methodologies group. "At Los Alamos, we have the ability to rapidly perform manufacturing research and enable the down-selection of technologies for the production of weapon-related components."

In January 2024, the Laboratory identified advanced manufacturing as one of five signature institutional commitments that must be pursued to help Los Alamos achieve its national security mission. The goal, according to the Laboratory Agenda—an annual comprehensive framework that aligns Los Alamos' long-term objectives with concrete, near-term milestones—is to ensure the Laboratory's ability to rapidly develop prototypes. In this way, the Laboratory will "build, qualify, and certify new components with new manufacturing technologies" that could be adopted for use throughout the nuclear security enterprise.

Across Los Alamos, researchers are developing new manufacturing methods and technologies that support the Laboratory Agenda's mandate. Researchers in materials, computer codes, 3D printing, and other areas are helping the Laboratory to achieve diverse manufacturing-related goals. Bernardin helps lead an additive manufacturing working group that aims to coordinate Los Alamos' research and development (R&D) efforts related to advanced manufacturing. The Laboratory, Bernardin says, is the right place to conduct research into cutting-edge manufacturing technologies that will support the nation's security.

"Our expertise in manufacturing science and R&D has always been connected to our knowledge of weapons physics, weapons engineering, and computational modeling. It all works together," Bernardin says. "We know our weapons better than anybody else."

3D printing ceramics

Additive manufacturing is one area in which Los Alamos conducts significant research. The Laboratory acquired its first 3D-printing capabilities in the 1990s. Over the years, as additive manufacturing technologies have advanced, Los Alamos' exploration of the technology has evolved apace.

"You hear people say, '3D printing is going to revolutionize the world,'" says Lindsey Bezek, a postdoctoral researcher in the Laboratory's Chemical Diagnostics and Engineering group. "While I can't say what the future will bring, what I can say with certainty is that 3D printing offers a unique—and thus sustainable—alternative manufacturing solution with many promising directions."

Today, the Laboratory conducts research into many kinds of 3D-printing technologies. Los Alamos' size and diversity are such that you'll find researchers exploring virtually every aspect of the additive manufacturing process, including the materials that are used as feedstock (the polymer, metal, or other material that is fed into the machine and deposited to make an object), the tools that deposit material, the software that guides those tools, the post-production processes required to "finish" additively manufactured parts and certify their quality, and more.

■ Postdoctoral researcher Lindsey Bezek evaluates the effect of heating on 3D-printed ceramic parts.

"A promising direction in additive manufacturing is the integration of the materials, the process, and the design," Bezek says. "At the Laboratory, we have so many different groups that can approach the subject from different angles."

Bezek's work reflects the way that researchers at Los Alamos bring varied perspectives to bear on additive manufacturing research and development. Although she earned her PhD in mechanical engineering, for the past two years, Bezek has been a part of the Laboratory's Chemistry division, where she researches the properties of materials used in 3D-printing technologies. Among other subject areas, as a part of her postdoctoral fellowship, Bezek is conducting research into 3D printing ceramics.

For most people, the term "ceramics" brings to mind porcelain or earthenware pottery. Technically, a ceramic is a nonorganic, nonmetallic material—such as clay or silica—that has been shaped and heated to a high temperature. Today, high-end ceramics are made not with clay but with elemental oxides that yield ceramics with specialized properties. Researchers at Los Alamos have worked with ceramics for decades, developing them for use in everything from satellites to nuclear reactors.

Although ceramic 3D printing has a breadth of applications—from making electronic and aerospace components to dental crowns and joint replacements—ceramic 3D printing is a much smaller part of the commercial industry

■ 3D-printed ceramic parts can suffer cracks and other damage when, as a part of the finishing process, they are heated (much like clay objects are fired in a kiln).

than metal or polymer additive manufacturing. (Polymers are long chains of molecules with repeated units, like plastics; see p. 25 for more.)

Bezek says that there is a need for additional research into ceramic 3D printing to increase quality assurance before industries can confidently invest in the technology. At the Laboratory, Bezek works to understand some of the fundamental processes that take place when ceramics are 3D printed and processed.

One of the most common techniques for 3D printing ceramics is called vat photopolymerization. This technique involves using a beam of ultraviolet light to harden layers of liquid resin—a mix of polymer and ceramic particles—one on top of another to produce a part.

Other kinds of 3D printing (with metal or polymers, say) can result in parts that are finished as soon as they've been printed. Ceramic 3D printing is different: After a ceramic part is printed, it must be heated before it's ready for use, much as clay pottery must be fired in a kiln. This heating process "burns out" the polymer particles that previously held the ceramic molecules together and fuses the ceramic particles into a hardened, sintered part.

Vat photopolymerization is a well-researched technique; in fact, it was one of the first 3D-printing techniques developed. However, the heating process that's necessary to finish a 3D-printed ceramic part is less well researched. Sometimes, the heating process can result in parts that are cracked or otherwise defective.

The causes of such failures remain poorly understood by additive manufacturing researchers. Bezek's research involves attempting to understand exactly what causes these undesirable results. By heating ceramic parts of a variety of shapes and sizes, and by tracking the parts' characteristics when exposed to different amounts of heat for different lengths of time, Bezek is able to better explain how temperature and time affect 3D-printed ceramic parts at very small scales.

"The benefit here is learning how to design for ceramic additive manufacturing," Bezek says. "We're working toward predictable part performance for future design and manufacture of complex, functional parts, and we're moving toward using novel materials in the future."

> “We're providing machinists with tools that can make their manufacturing better.”
>
> —ANDRE BOS

Multi-axis 3D printing

Although 3D printing allows for the rapid creation of complex parts, the technique has limits. For one thing, most 3D-printing technologies can only create parts out of a single feedstock.

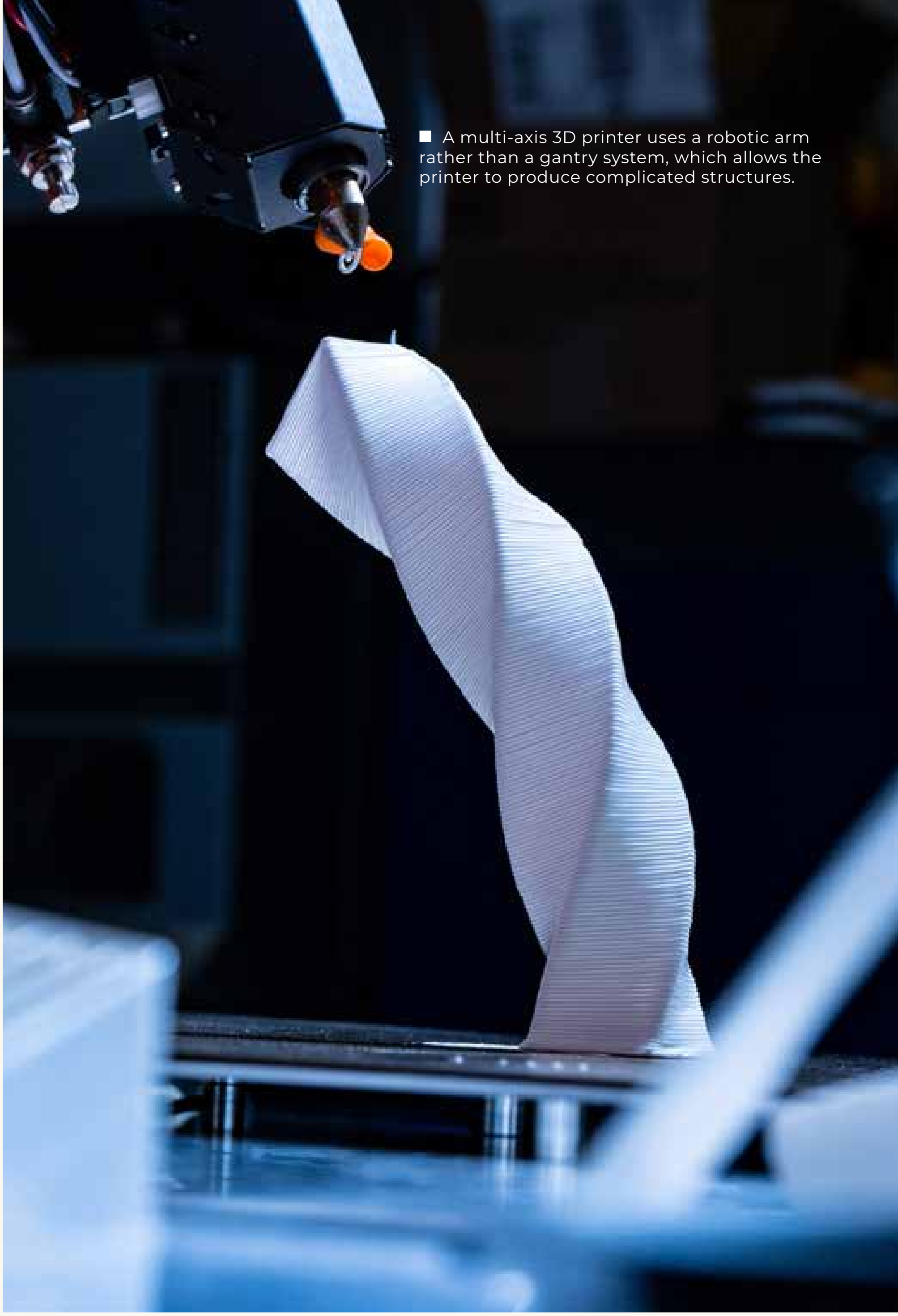
For another, 3D-printing tools struggle to make certain shapes. Because 3D-printed parts are manufactured layer by layer, gravity can be a limiting factor. In the same way that it is more challenging to build a brick wall on a steep slope (the bricks are likely to slide out of place) than on level ground, it can be difficult to ensure that layers of material applied additively will stay put on slanted or uneven surfaces. This drawback requires designers to incorporate cumbersome support structures into objects.

A new multi-axis 3D printer that's being evaluated by the Laboratory's Modern Manufacturing Methodologies group could help overcome both the material constraints and the challenges posed by gravity. The 3D printer, which was designed by One-Off Robotics, uses fused deposition modeling (FDM)—one of the most common 3D-printing techniques—to melt polymer filaments into a desired shape.

Traditional FDM 3D printers use a gantry (a bridge-like structure from which the 3D printer–head is suspended) to move their

“3D printing offers a unique—and thus sustainable—alternative manufacturing solution with many promising directions.”

—LINDSEY BEZEK



A multi-axis 3D printer uses a robotic arm rather than a gantry system, which allows the printer to produce complicated structures.

tool heads either horizontally or vertically. In recent years, however, researchers have found that using a robotic arm, which has a much greater range of motion, allows them to print different kinds of shapes.

“Robotic arms have been around for decades, and they haven’t really changed much,” says Andre Bos, a researcher who studies multi-axis 3D printing. “But the software has developed a lot, which has made it possible to apply material along nonplanar paths.”

The ability to apply material in nonplanar, or non-horizontal, ways makes it possible to 3D print structures that are thinner or more complex than can be created with traditional additive manufacturing techniques. Moreover, the ability to 3D print in this way means that some complex parts can be printed without cumbersome features designed to support the structure. This technique also allows material printing onto existing structures, making it possible to repair damaged or worn components.

Bos and other researchers have printed a variety of test objects, the better to understand the limits of this new technology and how it might be further developed in support of the Laboratory’s mission.

Combining robotics with 3D printing opens other doors as well. The multi-axis system that Bos is helping evaluate also has the capacity to change its printer heads automatically. That capability allows the robot to print objects made of more than one material. The robot can apply a few layers of one material, change printer heads, apply a layer of another material, change heads again, and so on.

In principle, multiple robotically controlled 3D printers could also be coordinated to work together to print ever more complex structures. “What robotics really means is that if we spend the time to develop the control mechanisms and to integrate the software and hardware, we can print basically whatever we want,” Bos says.

■ Student Jason Pieck works with a multi-axis 3D printer, which is capable of producing parts in a variety of complex shapes.

Process monitoring

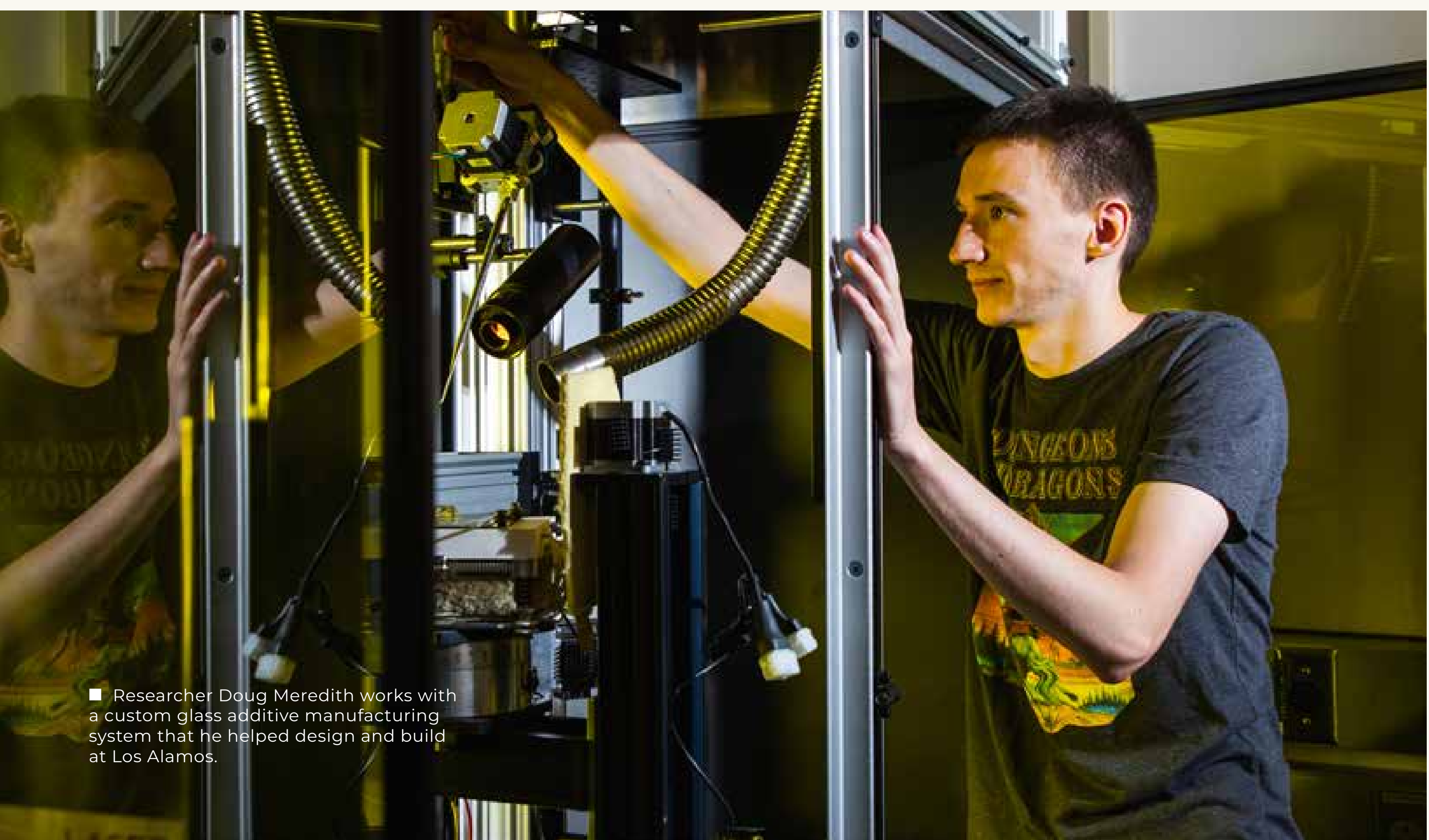
In industry, manufacturers often take some waste for granted: It is understood that a certain percentage of finished parts will fail to meet specifications and be thrown away. At Los Alamos, however, machinists often work with extremely valuable metals that can't be discarded as readily as, say, an aluminum aircraft component.

To better ensure that such metals don't go to waste, Laboratory researchers are working to develop techniques that will allow machinists to ensure that the parts they're creating are on track to meet specifications.

One way to help ensure accuracy is by incorporating a laser scanner into the manufacturing process. A machinist working with a lathe might make three or four "passes" over a piece of metal, working with each pass to bring the metal nearer to a desired shape. By pausing after one of these passes and using a laser scanner to take several "pictures" of the surface of the part, a machinist can see, in high resolution, how the part's creation is progressing.

This technique has several advantages. For one thing, the procedure takes only a few seconds to complete. For another, it is comprehensive, allowing an operator to inspect the entirety of a part with relative ease. And because the scan is optical—the scanner doesn't have to physically touch a part to inspect it—the measurements can't be inadvertently altered.

Laser scanning does come with challenges. Many high-value parts manufactured at Los Alamos have curved geometries. Because laser scanning is an optical technique that relies on the reflection of light off a surface, laser scanners often struggle to accurately scan curved surfaces. However, researchers at the Laboratory found ways to overcome these difficulties, and Bos says that the technology is ready for deployment. He and other researchers are working to further develop the system, envisioning a



■ Researcher Doug Meredith works with a custom glass additive manufacturing system that he helped design and build at Los Alamos.

■ Glass additive manufacturing is still in the early stages of development, but the technique might one day be used to produce hard-to-make glassware.

day when robotics might make laser-scanning parts fully automated.

"By implementing this additional monitoring and inspection system, we're making the process smart," Bos says. "We're providing machinists with tools that can make their manufacturing better."

3D printing glass

Today, it is possible to 3D print many kinds of materials, including concrete, food, and high explosives (see p. 64). And yet, one of the materials that's the most challenging to 3D print is an integral part of day-to-day life: glass.

Glass is challenging to print for several reasons that, taken together, necessitate the combined use of robotics and sophisticated monitoring techniques. Glass must be heated to a very high temperature to become soft enough to shape. However, overheating the glass can affect its optical quality: Once deposited, glass can appear cloudy or distorted because of bubbles or the vaporization of substances—defects that can be especially problematic if the glass is for applications like optical lenses.

At Los Alamos, researchers have followed the lead of researchers at the University of Notre Dame in developing a system to 3D print glass. First, a laser melts a glass rod, which is about the width of a strand of spaghetti, onto a build plate (a rectangle of heated glass). Then, using a robotic system to move the build plate as the glass rod is melted, a 3D glass structure can be printed.

Precisely controlling the temperature of the glass is key. This constraint requires on-machine monitoring to observe the glass as it is melted. Bos and other researchers found that by focusing cameras (including thermal cameras), spectrometers, and pyrometers on the point where the laser melts the glass, it is possible to monitor the melting and adjust the laser's temperature as needed.

Unfortunately, different glass types have varied chemical compositions, meaning each type requires different printing and temperature parameters. Determining these parameters is, at present, a tedious process of trial and error, although researchers are working to find ways to speed up this kind of analysis.

Another challenge has to do with the propensity of glass to crack under temperature-induced stress. In much the same way that a glass casserole dish can shatter if moved from an oven into a refrigerator, when a layer of hot glass is applied atop cooler, previously deposited layers of glass, the cooler glass is liable to crack. That means that to manufacture a glass structure any taller than an inch or so, it is necessary to keep the entire structure hot. Researchers at the Laboratory who have produced small test prints in a variety of shapes are seeking ways to address this need.

Beyond advancing the science of additive manufacturing, there are

■ The glass 3D-printing system being evaluated at the Laboratory extrudes a filament of glass that is melted with a laser onto a mobile build plate.

practical reasons to 3D print glass. Many laboratory experiments rely on complicated glassware that might ordinarily be manufactured by skilled glassblowers. However, glassblowers are in ever shorter supply, meaning that some important pieces of equipment are becoming more and more difficult to acquire. And even the most skilled glassblowers can't produce glass in certain shapes.

"You can only do certain things with glass blowing, and you can only get so much accuracy," Bos says. "If you want greater accuracy and complexity, or if you want a square shape rather than a round shape, glassblowers can't do that very repeatably."

Bos says that the capacity to 3D print glass will help ensure that the Laboratory has the resources it needs to continue to achieve its mission.

"One of the main reasons to use 3D printing is to make repeatable, complex structures," Bos says. "We need to be able to find a way to make these structures for the future."

Real-world applications

One of the ways that researchers put advanced manufacturing techniques to use is in developing new types of shielding for Laboratory employees who work with radioactive materials.

Researcher Nick Baumann is part of a team that's creating new types of radiation shielding for workers in the Laboratory's Plutonium Facility (PF-4) by developing gloves, panels, and windows for gloveboxes (specialized enclosures that workers use to contain hazardous materials). These new shielding technologies are intended to provide greater protection while eliminating the use of lead, which has traditionally been used throughout PF-4.

"Lead is hazardous, and its use produces mixed waste," Baumann explains. "If you need to dispose of a leaded glovebox window or gloves, you might have something that is both radioactive and has lead in it. So, you have a compounded problem."

The shielding materials team is developing shielding technologies that use tungsten metal rather than lead. This new type of shielding has other advantages, too. By manufacturing the shielding using advanced techniques, it is possible to create shielding that is lighter, stronger, and more effective.

The shielding materials team is evaluating three distinct processes within PF-4 and exploring avenues for replacing or augmenting the shielding involved in each. Already, the team has completed its evaluation of a pyrochemical process (which involves exposing materials to high temperatures), determining that with improved, additively manufactured shielding, it is possible to reduce workers' yearly radiation exposure by 34 percent, helping ensure that these workers' radiation exposure remains at safe levels.

In addition to benefiting workers' health, reducing radiation exposure means that workers can perform more tasks before reaching exposure limits set by the Department of Energy and the Laboratory. That could increase the productivity of this

> "One of the main reasons to use 3D printing is to make repeatable, complex structures."
>
> —ANDRE BOS

■ Engineer Andre Bos works with a glass 3D printer.

pyrochemical process by 65 percent, Baumann says.

Much of the new shielding—including pieces that can be used inside a glovebox to control radiation exposure and wrist cuffs that can be worn to provide additional radiation protection—can be 3D printed. Researchers use a filament made of polylactic acid, or PLA (a polymer made from renewable sources), and tungsten to create custom shielding for use inside gloveboxes. By 3D printing tungsten PLA, it is easier to fabricate high-density parts than by traditional methods: Tungsten is extremely dense and abrasive, making the metal notoriously difficult to machine.

The shielding materials team is exploring related uses of 3D printing, too. For example, the team has demonstrated that it is possible to laser scan a worker's arm, and to use that scan to 3D print a mold and design a custom glovebox glove for the worker. Gloves produced from molds in this way could also be designed to have different levels of shielding, depending on which part of the arm will receive the greatest radiation dose.

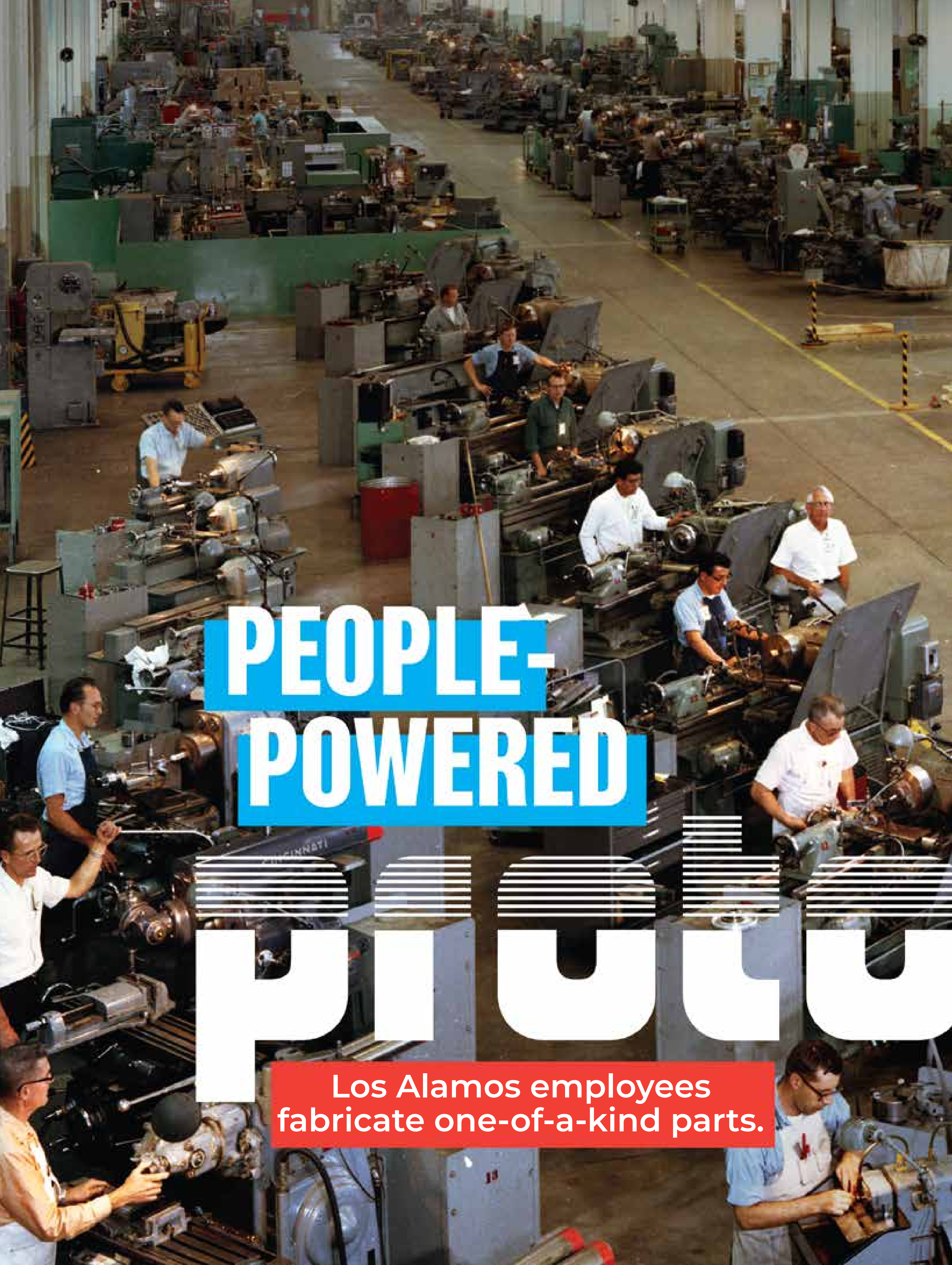
Baumann says that while some types of shielding, such as the gloves and glass, could be mass produced by commercial vendors after they've been developed, the ability to 3D print shielding blocks at the Laboratory means that new pieces of shielding can be produced on demand to help the Laboratory achieve its production mission.

"The configuration of the equipment inside the glovebox could change, but you want shielding that can be conformal and fit around things," Baumann says. "Additive manufacturing is perfect for that."

A manufacturing powerhouse

Although the techniques that Baumann and other researchers are developing at Los Alamos are novel, Bernardin says that their development comes from a tradition of manufacturing-related work that stretches back to the Laboratory's earliest days. The goal, Bernardin says, isn't to dispense with traditional manufacturing techniques. Instead, developing and implementing novel manufacturing techniques at Los Alamos will help the Laboratory—which he describes as "a manufacturing powerhouse"—to better achieve its mission.

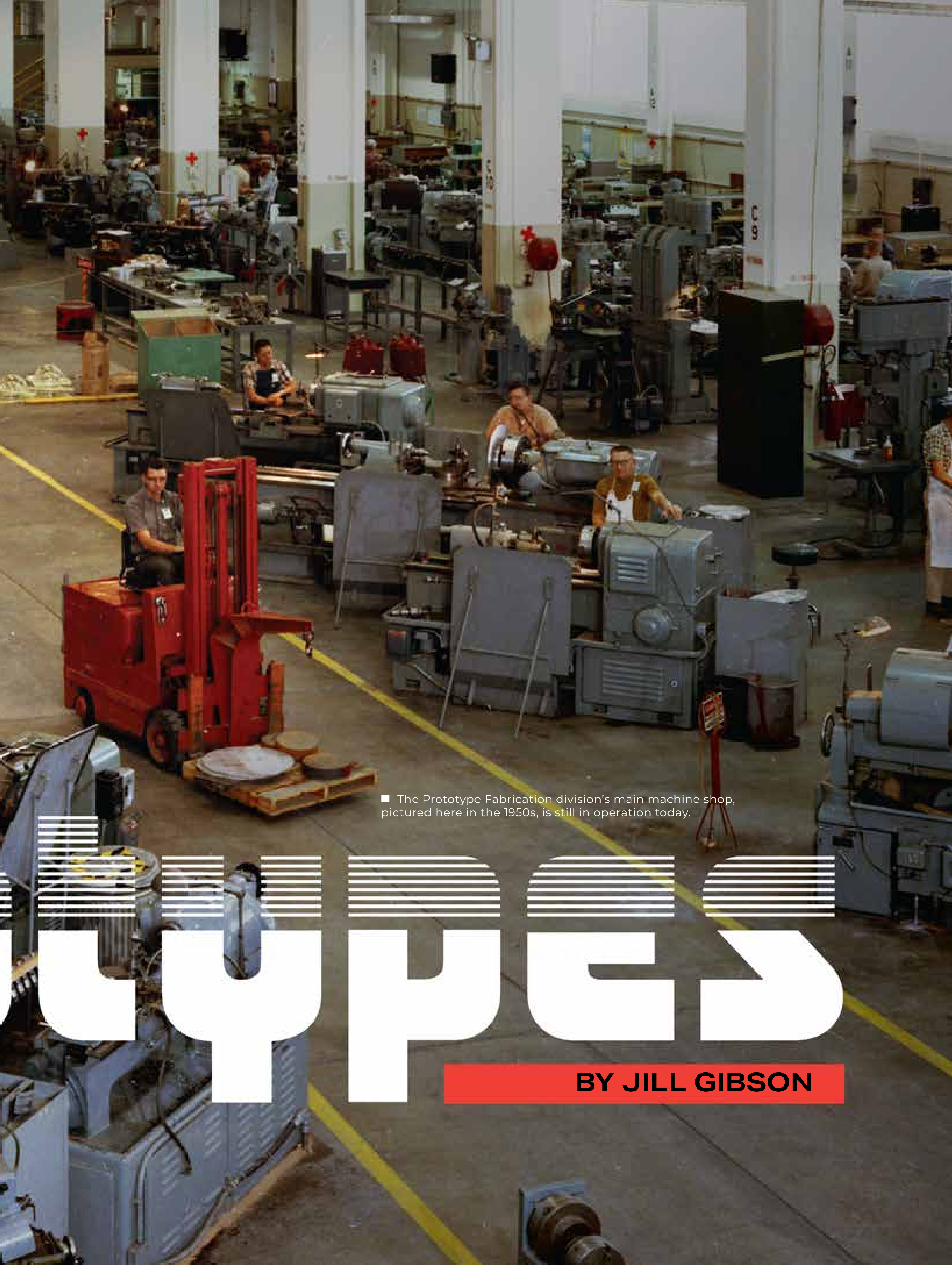
"We're working to get these new technologies to a place where we can use them reliably," Bernardin says. "But we'll still have the old technologies, too—and that's what's exciting." ★



PEOPLE-POWERED

produ

Los Alamos employees fabricate one-of-a-kind parts.



■ The Prototype Fabrication division's main machine shop, pictured here in the 1950s, is still in operation today.

types

BY JILL GIBSON

Since 1953, Los Alamos National Laboratory's Prototype Fabrication (PF) division has operated out of the same building: a 153,000-square-foot structure where, for more than 71 years now, the hum of machinery has filled the halls. The machines here have always been state of the art, but of course, what's considered state of the art has changed through the decades. Today, PF's machinists operate millions of dollars' worth of computer numerical controlled (CNC) machinery, coordinate measuring machines (CMMs), and the most advanced computer-aided design (CAD) and manufacturing (CAM) software available. Using this high-tech equipment, PF produces and inspects more than 15,000 critical parts annually for national security research and development. But, according to the engineer leading many of the PF's machining functions, the machines are not the key to success.

"It's all about the people," says Ray Guffee, PF division leader.

Employees working in the division's eight machine shops manufacture pieces and parts for scientific and engineering prototype devices and systems. The division's approximately 120 employees work with CAD, CAM, and CMM inspection software tools to program and operate CNC machinery. They are versed in reading designs and spend their days helping create and inspect parts that support the development and maintenance of the nation's nuclear stockpile.

"What we do is extremely important," says Mark Smith, who works as a machinist in the division's main shop, which exclusively handles classified parts. "There aren't many places in the country where you are exposed to classified manufacturing. Managing the daily logistics of keeping classified components safe and secure can be challenging."

Smith's job involves creating one-of-a-kind parts that are used for experiments. He also develops new ways to build and handle those parts—including a vacuum system for holding parts during the machining process. "There's always something new to learn, and the field of machining is constantly evolving," he says. "You have to stay ahead of the curve and embrace new technologies and techniques."

Guffee says the division's state-of-the-art equipment and sophisticated processes allow scientists to design parts with specific research goals in mind. As a research and development facility, PF often makes only one or two iterations of each part. Staff work closely with the engineers and physicists who lead experiments to ensure the final products meet their goals. "We fill a service role; anyone at the Lab can be one of our customers," Guffee points out.

"We are constantly trying new things," says Jose Olivas, the supervisor of the machining shop for depleted uranium. "The physicists are always driving us to the next level of perfection. Their goal is to remove as many variables as possible so they can get good data."

While the physicists aim to remove variables, Guffee's goal is to remove any obstacles to his employees' success. As he walks through the main shop dressed just like his staff members in a plaid shirt, jeans, and steel-toed boots, Guffee greets and visits with the employees, asking about their work and also about their families and weekend plans. He says building a positive work culture is the key to better performance. "Details and communication really matter."

Motivation and materials

PF machinists work with many materials, including aluminum, steel, tungsten, tantalum, high-density foam, acrylics, and plastics, as well as pyrophoric materials that can ignite. Three of PF's eight shops are specialized, meaning they are dedicated to working with specific, potentially hazardous, elements, including depleted uranium and beryllium. Although PF does not handle plutonium, one shop exclusively machines parts used by the Plutonium Fabrication team, which supports the Laboratory's plutonium pit mission (see p. 66).

The equipment used ranges from older manual tools that can rough-cut pieces to high-tech computerized lathes, mills, and grinders. "Often one machine can perform a variety of tasks," Guffee says. "The machinists must determine how to use the machines to produce the parts in the most efficient and precise manner possible."

One of the shops in the division recently built parts for a first-of-its-kind series of plutonium-imaging experiments at the Lab's Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility. These experiments, conducted in May 2024, represent the first plutonium tests carried out at DARHT, which consists of two linear accelerators that produce high-powered x-ray images of materials exposed to a variety of conditions.

"There were more than 100 drawings of parts and assemblies for the experiment series," says physicist Matthew Snowball, who led the tests. "Prototype Fabrication came through in a really big way for us—machining the parts for the containers that hold the plutonium. Our engineers kept a large spreadsheet to track the status of the work from drawings, through checks, to procurements and part production."

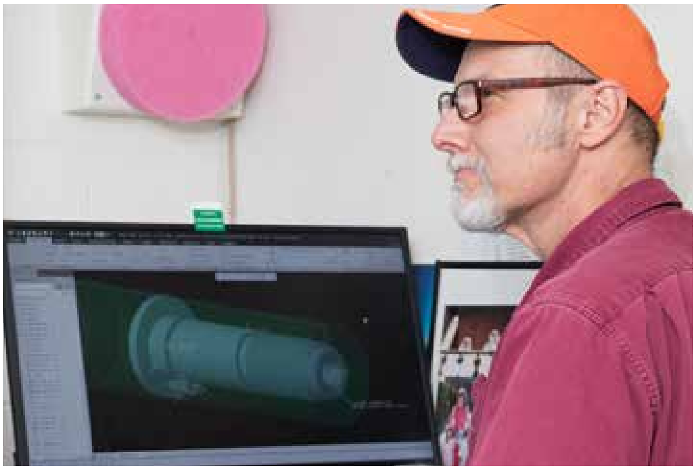
Ross Roybal, who supervises the shop that worked on this project, says he found the work quite challenging. "There were many parts that had never been built before or required specialized tooling," he says. "Our machinists had to work closely with the engineers and scientists as they revised their drawings on a tight timeline. It took a lot of collaboration, which paid off because the experiments were a success."

> **There aren't many places in the country where you are exposed to classified manufacturing."**
>
> **—MARK SMITH**

From design to realization

Joseph Corriveau is the only fabricator in the PF division. His job involves bending, cutting, punching, and welding

Mark Smith, Ross Roybal, Louie Leyba, Ryan Stothard, Jonathan Chavez, Tim Butcher, Travis Johnson, and Matt Hinde gather in the Prototype Fabrication division's main machine shop, but many of them are deployed to work in other machine shops at the Lab.



Jacob Tafoya builds a software program to load on the CNC machines.

An organized workbench in Prototype Fabrication's Mark Quality Manufacturing Center (p. 44) ensures nothing is ever out of place.

Machining apprentice Taylor Sills practices making parts. During the apprentice program, students rotate among different machine shops across the Lab to diversify their experience.

> It took a lot of collaboration, which paid off because the experiments were a success."
>
> —ROSS ROYBAL

metal to make finished parts. Corriveau describes his work as "problem solving with a prize at the end every time when I make the final part." As a fabricator, he uses laser cutters, rollers, and press brakes to transform flat sheets of metal into parts and components. He holds up a small metal bracket and explains, "It took six or seven development parts to make this final piece."

While Corriveau usually works with drawings or models created on the computer, Alex Galindo, another machinist, says sometimes scientists bring him sketches on napkins or sticky notes. "It's important to be able to look at a napkin sketch and visualize a three-dimensional object," says Galindo, who makes specialized precision metal parts for weapons production tests.

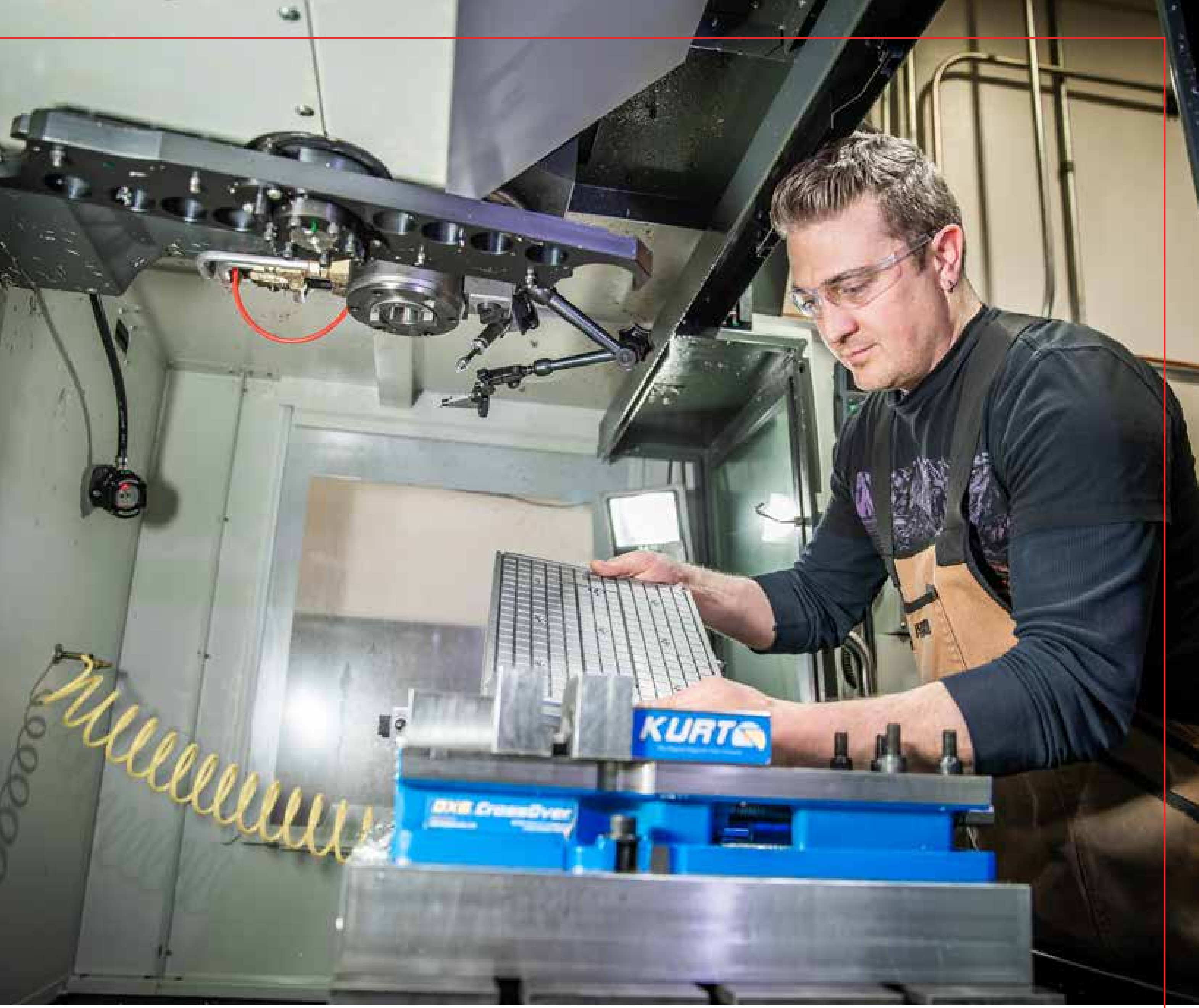
Guffee notes that Galindo, a graduate of the Lab's machining apprenticeship program (see p. 42), has mastered a diverse set of skills through targeted hands-on training. "The best machinists have exposure to a lot of different settings and have worked with a large variety of machines and parts to be made," he says.

The move toward modernization

Guffee says the PF division's current focus is on modernization. "This building was constructed as a machine shop in 1953," says Guffee. "Now, we're still a machine shop, but we have moved into modern times."

Even tool storage has become state-of-the-art. Gary Monce oversees 175,000 items and tools using vertical computer-controlled storage and retrieval systems. Automated extractors retrieve parts stored in the 35-foot-high device, making it simple to monitor and replace consumable pieces and maintain inventory for every need.

"I can't make a part, but I sure can keep track of stuff," Monce says.



Machinist Jesse Hesch prepares to operate a CNC mill.

Another area where the division takes advantage of modern processes is additive manufacturing. Four additive manufacturing machines are used to make plastic fixtures to hold parts for machining and inspection. "Whenever we can embrace new technology, we do," Guffee says.

One of the most advanced areas in the division focuses on inspection. Every part must be inspected to ensure it meets precise specifications. This work is done using sophisticated CMMs and scanning devices that measure parts to the micron. "A strand of silk in a spiderweb is six microns in width, and we measure to one micron," Robert Mietz, an inspection engineer says. "These machines are incredibly accurate."

Because of the classified nature of many parts, the Lab's inspection engineers must calibrate and maintain their own machinery. "We had to go to Germany where the CMMs are built to get trained to do calibrations on the inspection machinery," explains engineer Frederick Garcia. "It is extremely challenging work."

If a part fails the inspection step, it must be adjusted or remade. Irving Vasquez is a dimensional metrologist who is responsible for measuring, calibrating, and inspecting parts. He also trains the apprentices to correct errors. "Nobody likes to be told to go back and redo things," Vasquez says, "but we're all friends, and it's how they sharpen their skills."

Guffee points out that with measurements to the micron, the PF machinists can't cut corners or take anything for granted. "Our work is an essential component of the Lab's research and development work underlying national security," he says. "All the people in our division take that mission seriously and are committed to doing their best." ★

Apprentices Matt Cordova (left) and Ben Peterson Ross (right) make parts to complete the proficiency requirements of the apprenticeship program.

The 2022–2024 machinist apprenticeship program participants. Back row, from left: Benjamin Clark, Matthew Cordova, Bernard Hayden, Jacob Gallette, Benjamin Peterson Ross, and Theodore Ross. Front row, from left: Taylor Sills, Emma Womack, Joseph Meraz, and John Montoya.

MANUFACTURING MACHINISTS

An apprenticeship program trains skilled workers for the Laboratory.

BY JILL GIBSON

The Prototype Fabrication (PF) division's machining apprenticeship program provides a pipeline of skilled machinists with the unique knowledge and experience that Los Alamos National Laboratory's mission requires. The two-year program takes students through a series of competency-based training modules and then rotations through different Laboratory shop settings. The program is based on the performance objectives and qualification criteria developed by the National Institute for Metalworking Skills.

"Entering the program is competitive," says PF Division Leader Ray Guffee. Only 15 to 20 apprentices are accepted every 2 years. Before applying, the applicants must complete an associate degree or certificate in machining from an accredited community college machining program.

"I know I will have complete confidence in my skills when I finish the program," says Taylor Sills, an apprenticeship student. Sills graduated from Central New Mexico Community College before coming to Los Alamos.

Emma Womack joined the apprenticeship program in 2022 after earning an associate degree in welding and a machining certificate at Amarillo College in Texas. “I’ve learned so much here and I’m still learning,” she says. “Everyone has been extremely supportive and positive.”

Travis Johnson is another Amarillo College graduate who joined the apprenticeship program. “I can’t say enough good things about our instructors at the Lab,” Johnson says. “It’s exciting that we get to rotate through the different shop settings and gain multiple perspectives.”

The program instructors say a student’s success depends on the desire to learn. “Skills can be taught, but motivation is ingrained,” says machinist John Lamar, who leads the program. “It helps if prospective students can visualize parts in three dimensions and can retain information. Knowledge of trigonometry and other math skills are also important, but ultimately self-motivation is key.”

Students who complete the program become “journeyperson” (formerly “journeyman”) machinists, which is an industry-recognized title. Although not everyone who successfully completes the program is offered a permanent position at Los Alamos, Lamar says the Lab’s need for qualified machinists means the likelihood of being hired is good.

“I’m excited about my future in machining,” Johnson says. “I love working with prototype machining. The work is interesting, and customers bring in something different every day.” ★

■ Machinist and apprenticeship program graduate Henry Roberts uses a file to prepare the edges of a part for welding. This process ensures a solid weld that is free of voids and imperfections.

Machinist Marshall Maez (right) trains John Montoya, a machining apprentice, to use a wire electrical discharge machine.

Machinist Kevin Kilgore operates a CNC lathe.

PRODUCING PERFECT PARTS

Los Alamos' Mark Quality Manufacturing Center makes nuclear weapons components.

BY JILL GIBSON

About five years ago, the National Nuclear Security Administration, which oversees all aspects of nuclear weapons design, production, and maintenance, expressed interest in standing up a small facility in which certain nonnuclear parts for nuclear weapons could be made quickly and in small numbers. The new facility would complement the Kansas City National Security Campus, where the majority of such weapons components are manufactured.

"We put our foot in the door and said, 'Hey, we can be agile and stand up this brand-new capability and provide these parts for you," says Scott Schaffer, a manufacturing engineer at Los Alamos National Laboratory.

From there, the Mark Quality Manufacturing Center (MQMC) was born. Part of the Lab's Prototype Fabrication division, MQMC makes parts and assembled components for weapons alterations, which are upgrades to a weapon's systems, subsystems, or components. Since 2021, MQMC has provided 608 components for a B61-12 gravity bomb alteration and 230 assemblies for a W88 warhead alteration. MQMC is scheduled to complete 110 assemblies for a W76 warhead alteration by the end of 2025.

"We are equipped to perform machining, assembly, and inspection of any product that will go directly on a weapon system," says Ike Timko, another manufacturing engineer. "All our production parts are tiptop quality. They're exactly the same rolling off the line, and we have qualified and documented processes that ensure they are consistent. That's what we do here at the shop—make perfect parts."

Within MQMC are six computer numerically controlled (CNC) machines, a wire electrical discharge machining device, and assembly workspaces. "We're cranking out parts constantly—it's pretty exciting," Timko says. "The thing about manufacturing that's most exciting to me is being able to turn a chunk of metal into a complex, custom part."

Timko gestures to a large (about 20 feet long and 8 feet high) five-axis CNC machine. "On this machine, we're making teeny-tiny little screws out of titanium right now," he explains, "but we have also used it to make parts that are two or three feet long, all with super-high precision." He points out that all the machines can carry out multiple processes and adapt for a variety of projects, so MQMC is ready for whatever manufacturing task comes next.

"Our goal is to make the shop as modular as possible, as diverse as possible," says MQMC shop supervisor Bob Qualick. "These are flexible multi-axis devices, meaning they can machine in any direction to create super complex geometries in one setup."

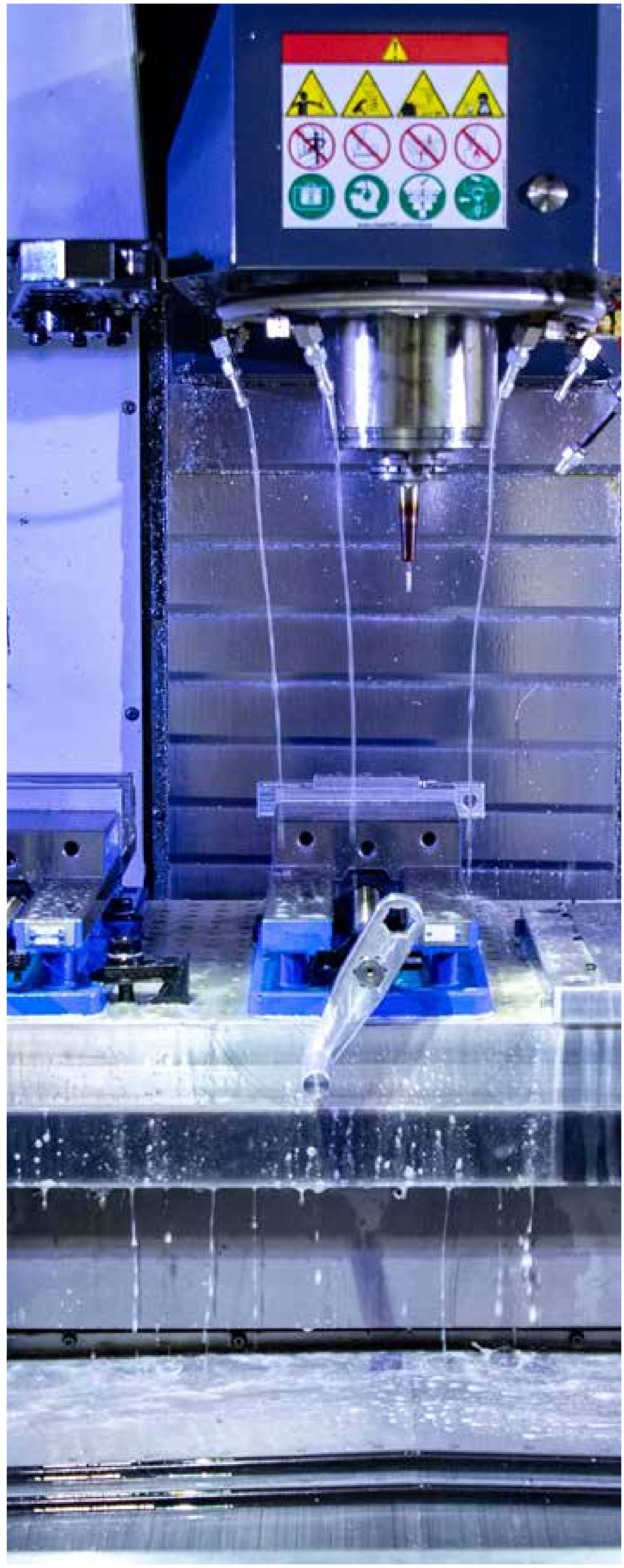
After parts are manufactured, they head to the MQMC's high-precision inspection space, where temperature, humidity, and particulates are carefully monitored and controlled. Three coordinate measuring machines (CMMs, nicknamed "the triplets"), an optical comparator, a perthometer, and a profilometer are used to conduct 3D measuring and scans of every manufactured part.

"The machines are phenomenal," says inspection shop supervisor Steve Pattinson. "The CMMs are capable of measuring parts with an accuracy of just a few microns. For comparison, a human hair is about 70 microns." To maintain security, Pattison and his staff calibrate and maintain the high-precision measurement machines themselves, without outside assistance. He notes that "if the temperature in the room goes above or below our acceptable standards, we have to recalibrate them."

Once inspected and certified, the parts and assemblies receive a diamond-shaped stamp that signifies their quality, precision, safety, and readiness for installation into a weapon. "The fact that we are approved to diamond-stamp parts within the MQMC as 'stockpile ready' is a testament to the quality of the work," Schaffer says.

The MQMC also maintains rigorous quality standards when storing manufacturing process data. The staff uses specialized software to compile detailed records that accompany every part. "It's paperless, barcoded, and meticulously organized," says Timko (who admits that his personal garage is also meticulously organized).

Timko says every aspect of MQMC is aimed at creating a highly efficient facility that can adapt to multiple demands and projects. "It's kind of a startup, agile approach to manufacturing," he says. "The whole spirit of this place is to just get things done quickly in support of our mission." ★



■ This multi-axis CNC machine can be programmed to complete complex parts in one session. Coolant sprayed inside the CNC during the machining process maintains the temperature of the part.

VOICES OF MACH

"I have spent nearly three decades in the field, and I have given everything to machining. I love the rewards and the challenges. I need to be constantly challenged. There's so much to learn. I don't think you can ever know everything. I love being able to focus on something, to have the ability to solve problems on my own, to have the ability to grow."

—MARK SMITH

"I like machining because I really enjoy working with my hands. Everyone has really helped me learn."

—TAYLOR SILLS

"The job requires attention to detail. Trying new machines is challenging, and there are always different ways to do things. I like knowing that I can rely on my team any time I need help."

—JONATHAN CHAVEZ

"What is there not to like about machining? I like getting to make things—and serving the country."

—TRAVIS JOHNSON

"It's always something new and exciting. We have to be flexible and learn to adapt. I like that we can provide design input and consult about what is possible, which improves the final product and the delivery time."

—ROSS ROYBAL

"Working in an R&D environment makes things interesting and challenging, plus it's rewarding to know that what we are doing is contributing to the success of our nation."

—MATTHEW HINDE

PROTOTYPE FABRICATION STAFF SHARE THOUGHTS ABOUT THEIR CAREERS.

NISTS

"I've worked in this shop many years and have learned from the older guys. Now I'm the older guy. I like the work and enjoy the challenges. A recent project involved using acrylic blocks to manufacture parts for optical and laser detonators. Working with acrylic is difficult because you must avoid chipping and achieve clarity."

—LOUIE LEYBA

"I enjoy working face to face with customers to help solve technical problems. As a machinist, I see things from a different angle than an engineer does. I look at form, fit, function to help make the finished product work."

—RYAN STOTHARD

"I like helping engineers develop pieces, and I enjoy working with my hands."

—JOSEPH CORRIVEAU

"I like going from sketches to finished products—seeing the whole process and solving problems with a team. If you like a challenge, this is the career for you."

—TIM BUTCHER

"I like machining because it's hands on—I'm not sitting at a desk. Also, I like that there's math involved."

—EMMA WOMACK

"Twenty-four years as a machinist, and I'm still learning. I think this is a really good career for visual thinkers. I think in pictures. A lot of my career has been spent helping design parts for scientists who come to me trying to figure things out. The challenges come daily. It keeps me engaged."

—MARSHALL MAEZ

QUALI GUARA

Los Alamos National Laboratory's Sigma Complex supports national security through manufacturing science.

BY WHITNEY SPIVEY

TY ANTEED

■ Inside Sigma's electrochemistry area, nitrogen dioxide fumes from a tantalum sheet that's been etched with an acid solution. The sheet will be used in an experiment at the Lab's Dual-Axis Radiographic Hydrodynamic Test facility.

Inside Sigma's foundry are a gantry crane (yellow), an induction furnace (red), and an assortment of graphite and uranium parts (foreground).

The average No. 2 pencil contains approximately 0.2 grams of graphite—a naturally occurring crystalline form of the element carbon.

The average graphite log at Los Alamos National Laboratory's Sigma Complex is 16 inches in diameter and weighs more than 3,000 pounds. "They show up on semitrucks," explains manufacturing manager Mike Schuch. "We move them around with forklifts and cranes."

And unlike the graphite in pencils, which is typically mixed with clay, the graphite at Sigma is pure, which means it's prone to chipping and cracking. But according to Schuch, who leads the 10-person team that uses tools, such as lathes and mills, to carefully remove graphite from a graphite log until what's left is a very specific shape and size, these properties are part of what makes working at Sigma so gratifying. "We take a lot of pride in being able to machine graphite," he explains. "Our specialty is materials others find difficult to work with."

Schuch notes that in addition to graphite, Sigma's machinists are trained to work with dozens of other elements—everything between hydrogen and uranium on the periodic table. Elements often take different forms and can even be hazardous or radioactive.

Machinists work closely with materials scientists and engineers in support of Sigma's manufacturing science mission. Manufacturing science involves studying how raw materials are turned into finished products. Material properties and manufacturing processes must be considered in tandem. "We want to know not only that we can do things but also why we can do them," Schuch explains. "We can tell you if something succeeded or failed and the process that led to that outcome."

Most items manufactured at Sigma are prototypes or test hardware with national security applications. For example, a customer (typically someone at the Laboratory or at a production plant within the nuclear security enterprise) might contact Sigma with an idea for a new type of nuclear weapon component or a new way an existing component could be manufactured. "We are the manufacturing science hub for the nuclear security enterprise," Schuch explains. "We can receive a napkin sketch and take it from design to final part to put in a test."

Sigma researchers and machinists will iterate on a part, process, or technology, tweaking and testing it until it's just right. "We take theory and apply engineering to make parts," says Matthew Zappulla, a scientist in Sigma's Fabrication Manufacturing Science group. "Since the Manhattan Project, Sigma's mission has been to make parts efficiently, predict a part's functionality, and guarantee a part's quality."

On a tour of the Sigma building, Schuch gestures to parts, some of them a little wonky or broken. "Most things you see around the building are demonstrations or things that went wrong," he explains. "Because if they were done correctly, they've been blown up as part of a test."

Under one roof

Although Sigma's products are complicated—structurally and materially complex—manufacturing occurs rapidly. According to Sigma Division Leader David Pugmire, "Sigma delivers production-ready manufacturing technologies for the enduring and future nuclear stockpile in a timescale measured in years, not decades."

Zappulla explains that the speed at which Sigma operates is largely due to having a collection of integrated capabilities—including machining, forming, welding, characterization, electrochemistry, and even a foundry—housed in a single 200,000-square-foot facility. "We can do things quickly because everything is under one roof," he says. "All 157 people in this building are working toward the same mission."

Laser powder bed additive manufacturing systems, a plasma spray chamber, scanning electron microscopes, hydraulic forming presses, slot-die coaters, vacuum heat treatment furnaces, and multiple uranium-casting

■ Scientist Erik Luther works in an inert atmosphere glovebox to process reactive materials.

A deformation processing technician removes a hot billet of uranium from the pre-heat furnace.

> "Our specialty is materials others find difficult to work with."
>
> —MIKE SCHUCH

furnaces are just some of the equipment found throughout the facility. Schuch points to a flow forming machine, which is akin to a potter's wheel for metal that "can turn a plate into a vase in two minutes." There's also a Manhattan Project–era rolling mill that is used to create foils out of different types of metal plates (see inside front cover).

Of course, none of the machinery matters without qualified people behind it. "The Sigma capability is a combination of its facility and its people," Pugmire says. "Deep subject matter expertise in essential technologies is being transferred to future leaders, modernization programs are reestablishing expertise, and investments in Sigma are attracting talented early career staff."

What does it take to be a machinist at Sigma? "You look for someone who wants to learn, someone with the right focus and mindset," Schuch says. Machinists also must interface well with scientists and engineers to collaboratively tackle challenging and often pressing problems.

But even with the high-impact and sometimes dangerous work, Schuch says, "it is very, very difficult to not have fun." He points to a hand-drawn spinner (like something you might find in a board game) that hangs on the wall. If a machinist is having trouble getting a part just right, the spinner offers humorous suggestions on what to do next. "When all else fails, we turn to the Wheel of Variables," he laughs and gives it a spin. The arrow passes over "roller angle" and "increase speed" and stops squarely on "ask the next person who walks by."

Production agency partnerships

Once a part or a manufacturing process is perfected at Sigma, it is handed off to the customer or to a larger-scale production agency. This handoff requires careful collaboration to ensure both the technology and the knowledge behind it are transferred appropriately.

One example of such a collaboration starts with the aforementioned graphite logs. The logs are machined

■ Sigma's induction furnace is used to direct cast parts for research and development, weapons, and other high-priority projects. The furnace design and modern controls provide greater control over the casting process, which results in higher quality manufactured products and added clarity to scientific and engineering results. Here, engineer Casey Shoemaker adjusts the breaker assembly on the furnace.

into single-use molds—vessels into which molten metal is poured. As the metal cools, it hardens into precise shapes. Graphite, although difficult to machine, is the ideal material for such molds due to its ability to withstand high temperatures and its thermal conductivity.

Sigma currently manufactures the graphite molds used for plutonium pit production (see p. 66), which occurs nearby in the Lab's Plutonium Facility—the only place in the United States equipped to work with significant quantities of plutonium, a complex radioactive element that is used in nuclear weapons.

Nuclear weapons also require another radioactive element, uranium. For more than 70 years, the Y-12 National Security Complex in Oak Ridge, Tennessee, has manufactured all uranium components for America's nuclear weapons. For decades, the uranium in these components was wrought, or extruded. Finished uranium components were (and still are) shipped to the Pantex Plant in Amarillo, Texas, for assembly into nuclear weapons.

> "We take theory and apply engineering to make parts."
>
> —MATTHEW ZAPPULLA

Because Y-12 is an 811-acre, full-on production facility, its research into new manufacturing techniques is limited, even if those new techniques might be beneficial—faster, safer, less expensive—down the road. But this type of rapid prototyping and experimental work is exactly where Sigma excels.

In the early 2000s, a team of Sigma metallurgists developed a concept for direct casting some uranium components made at Y-12. In direct casting, uranium is heated to high temperatures and poured into graphite molds. When the uranium cools, the molds are broken and removed, and the cast uranium is further machined.

After many years and much testing, the National Nuclear Security Administration (which oversees both Los Alamos and Y-12), decided to supplement wrought processing at Y-12 with the direct casting method developed by Sigma. Teams from Sigma began working with teams from Y-12 to implement direct casting at Y-12 at a larger scale than was demonstrated at Sigma.

"Y-12 makes their own graphite molds," Schuch says, "but their molds are informed by our work here at Sigma." He explains that direct casting allows for more flexibility in weapons designs. For example, if a physicist wants to

The Wheel of Variables provides "solutions" for when metal spinning doesn't go quite as planned.

Engineer Kayla Molnar and scientist Matthew Zappulla take measurements and examine steel cups made on Sigma's metal spinning machine.

make a change, now only the graphite mold (not the steel tooling) must be updated. "Direct casting makes us more agile," he says. "We can try new things and be responsive to military needs." He notes that Sigma and Y-12 have the same equipment—right down to the vacuum induction melting furnace used to heat the uranium—to ensure that both facilities are on the same page and that each facility can support the other's work.

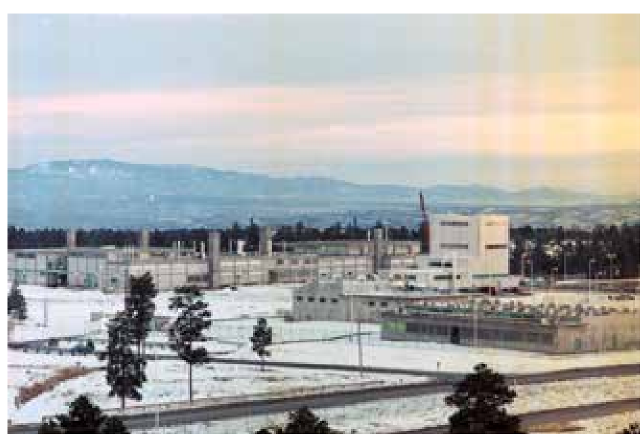
Although dozens of people were involved in this knowledge and technology transfer, the collaboration really flourished under the direction of two men: metallurgist Rob Aiken at Sigma and Jason Steward, a metallurgical engineer at Y-12.

"Rob has eagerly shared this knowledge with Jason," says Valerie Newman, a production liaison who is employed by Los Alamos and works at Y-12. "Jason has just as readily absorbed a great deal of uranium science and processing knowledge from Rob."

Newman notes that Aiken worked at Sigma for nearly 25 years before his retirement in September. His decades of knowledge were acquired on the job. "This stuff is not taught in college," Newman says. "So, this relationship—lots of conversations, lots of working alongside one another—was really the primary way of transferring information."

Steward agrees. "Although Rob was over 1,400 miles away, his technical expertise and commitment to supporting metallurgical processes at Y-12 has been felt across the site for decades," he says. "I appreciate the time and effort Rob has provided in mentoring; this relationship has been foundational in facilitating a fluid technology transfer of direct casting technology from Sigma to Y-12."

Newman says the smooth transition will benefit the nation. "I personally believe that implementing this technology at Y-12 would have had many more challenges if not for the collaborations between Rob and Jason," she says. "Sigma's focus on manufacturing science ensures that transformative fabrication methods will continue to be investigated in partnership with Y-12 and other production agencies. This benefits our current weapons work and the nuclear security enterprise of the future." ★



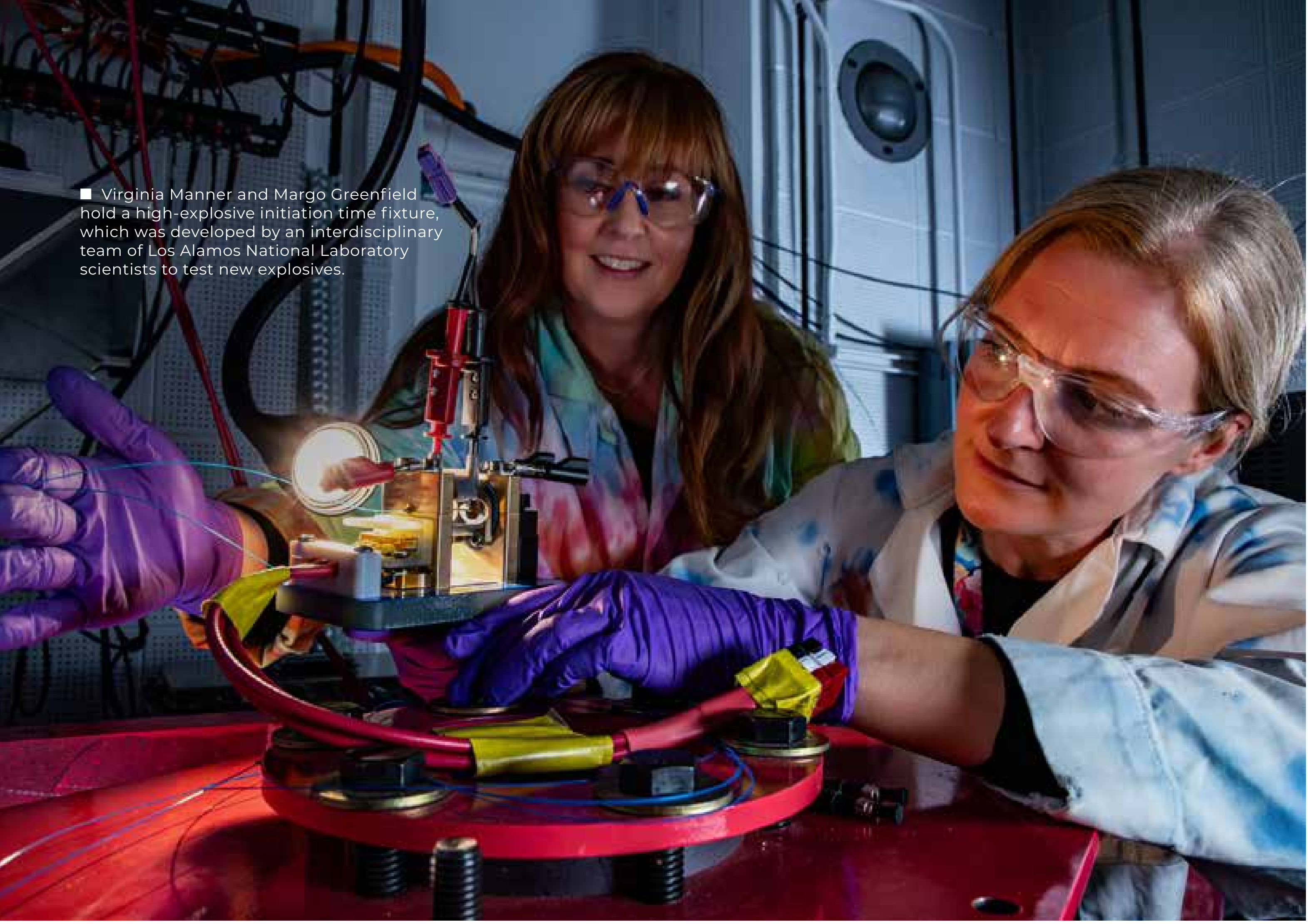
The Sigma Complex in the 1960s.

SPARKING SUCCESS

High explosives research and development booms at Los Alamos.

BY JILL GIBSON

■ A new high-efficiency explosive is tested at Los Alamos National Laboratory.



■ Virginia Manner and Margo Greenfield hold a high-explosive initiation time fixture, which was developed by an interdisciplinary team of Los Alamos National Laboratory scientists to test new explosives.

SOME DAYS WHEN LOS ALAMOS National Laboratory chemist Virginia Manner goes to work, she—literally—has a blast. That's because Manner works with high explosives, materials that, when triggered, produce a rapid and powerful release of energy.

High explosives differ from regular explosives, such as fireworks or gunpowder, primarily in the speed and intensity of their chemical reactions. A high-explosive reaction occurs almost instantaneously after it's triggered, creating a powerful blast and high-pressure shock waves. But before new high-explosives formulas are considered for national security uses, including for use in nuclear weapons, Manner and her colleagues put them to the test.

"Our initial tests involve hitting pea-sized amounts of explosive powder with a hammer and lighting them on fire," Manner says. The goal is to see how the explosives react to heat, impact, friction, and electrical discharge (such as static).

"Much of our research is based on finding ways to make explosives safer—safer to handle, safer to transport, and safer in the event of an accident," Manner says. "Our goal is to make sure the high explosives cannot detonate accidentally but will perform as needed if detonated intentionally." (See p. 63 for more on Manner's thoughts regarding safety and risk.)

DECADES OF DETONATION

For decades, Los Alamos scientists have detonated explosives and studied the results. This research began nearly 80 years ago as Manhattan Project scientists developed a way to use high explosives to set off the Gadget, the world's first nuclear device, at the Trinity site in July 1945.

"During World War II, Los Alamos scientists really worked hard to understand explosive materials and how they perform," says scientist Alex Cleveland of the Lab's High Explosives Science and Technology group.

Inside the Gadget (and in fact inside all nuclear weapons), high explosives serve two roles. First, they are found inside detonators, tiny electrical devices (see p. 8). When explosives in detonators go off, they trigger the detonation of a larger quantity of high explosives located around a weapon's plutonium core, called the pit (see p. 66). When the explosives surrounding the pit detonate, the pit implodes, which creates nuclear yield, or power.

In other words, Cleveland says, "the detonator creates a smaller bang to then get the larger bang."

In 1952, the Lab created the first plastic-bonded explosives, in which explosive powder is mixed with a plastic binder. This process makes explosive material easier to handle and shape and less sensitive to accidental detonation. Plastic-bonded explosives are used in all modern nuclear weapons and in conventional munitions, rocket propellants, and other civilian and military applications.

Today high-explosives research, development, and manufacturing continues to boom at Los Alamos. Scientists are constantly creating new explosives because different characteristics and properties are necessary to meet various needs.

"We are working to develop formulations that are safer, more powerful, easier to make, or less expensive to produce," says explosives scientist Bryce Tappan. "Plus, the physicists researching new weapons designs are asking us to develop new and different explosives that have unique characteristics, such as enhanced detonation pressure or higher velocity. We interact closely with these scientists to develop energetic materials that meet their needs."

Cleveland explains that the group is "always reevaluating the materials we have in the stockpile and working on ways to make them safer and more stable and better performing."

This work also contributes to advancing counterterrorism efforts and detecting and defeating explosive devices. Additionally, high explosives play an essential role in many experiments conducted at the Lab. When scientists want to analyze a material's properties, discover how components react to shockwaves and pressure, or generate an extreme amount of energy for physics experiments, they often start by blowing things up.

SYNTHESIS AND FORMULATION

Chemist Bi Nguyen creates new explosive molecules (groups of two or more atoms chemically bonded together) by combining different atoms or smaller molecules to form a larger, more complex molecule. This process is called synthesis and is similar to combining ingredients when cooking to create a new dish. "We are always trying to synthesize new molecules so we can stay competitive and keep our technical edge," Nguyen says.

"WE ARE WORKING TO DEVELOP FORMULATIONS THAT ARE SAFER, MORE POWERFUL, EASIER TO MAKE, OR LESS EXPENSIVE TO PRODUCE."
—BRYCE TAPPAN

Creating a new explosive starts with research. "When I make a new molecule, I review the literature and think about what properties I want it to have," Nguyen says. "New synthesis is hard and takes a long time." Nguyen says she can tweak different characteristics such as melting point, power, detonation velocity, and other factors depending on the molecules she chooses to combine.

Tappan notes that "the ease of manufacturing and the scalability of production are key considerations when developing something new. Every molecule carries a compromise," he says. "To make a safer formulation, one that is less susceptible to accidental initiation, we might have to give up some of its power or make it heavier, which could impact a weapon's performance."

Coming up with new explosives is challenging. "It takes a lot of creative work," says Manner, who leads the Energetic Materials Synthesis team. "Plus, we want to create a broad array of explosives with different properties for different applications." Other concerns involve production costs, environmental impacts, and speed of manufacturing. "Synthesizing

■ Aqueous ammonia is added to a copper precursor in the final step of synthesis.

■ Bi Nguyen and Bryce Tappan prepare a small sample of a powerful new explosive.

new molecules requires trying many different things before you succeed."

When scientists make a new formulation, they must develop a process to mix the explosive with selected binder components. They often use the wet slurry method, which suspends particles of explosive material in water while the binder is added. After filtering and drying, this process produces prills, tiny explosive pellets that look like Nerds candy. The prills can then be pressed and machined into specific shapes. The type of explosive dictates whether the process will be conducted in person or remotely to ensure safety.

"SYNTHESIZING NEW MOLECULES REQUIRES TRYING MANY DIFFERENT THINGS BEFORE YOU SUCCEED."

—VIRGINIA MANNER

At Los Alamos, explosive pressing and machining takes place in a building that contains several bays with two-foot-thick concrete walls. "Aside from the obvious fact that the material we are machining is explosive, the biggest difference between machining explosives and other materials is that machining explosives is a lot slower," says Angelo Echave, deputy group leader for High Explosive Fabrication and Disposition. "We have multiple safety procedures and never take shortcuts."

Echave walks through the bays pointing out the computer-controlled machining equipment and the remote stations where machinists monitor their work. "The formulations vary in sensitivity—how easily they can detonate—which determines how we machine pieces and implement safety controls. There are different colors for different explosive materials, which can help in identifying the type."

Pressed explosives are x-rayed before machining and finished explosives are inspected using coordinate measuring machines (CMMs). "Explosives can detonate if you insult the material in some way," Echave explains, "but everything we do here is considered an insult to the material. We cut it, we press it under thousands of pounds of pressure, and we expose it to heat and handling. That's why every safety test and process is essential as we produce these parts."

PERFORMANCE AND SAFETY

Initial safety tests are followed by more advanced safety and performance experiments that involve detonating larger portions of explosives and subjecting the material to more extreme conditions, such as higher heat and stronger impacts. For example, high-speed gas gun experiments and intentional detonations of kilogram quantities of explosives are regularly performed at indoor and outdoor firing sites run by the Lab's Dynamic Experiments division.

"We do everything from safety testing—looking at how the explosive will behave under accident scenarios—to performance testing, in other words, will it do what it's supposed to do," says Philip Rae, High Explosives Physics and Diagnostics team leader. "We'll measure the velocity of the detonation, how much force is imparted by the whole explosive process, the pressure output, how powerful the explosive blast is. We do a bit of everything and customize each experiment to each specific research need."

Michelle Hogan runs some of the tests on new explosives. "These tests measure the ignitability and explosiveness of large consolidated charges to ensure worker safety and rank the relative safety of novel explosive formulation," she says. Hogan primarily performs what's called the skid test, a safety test that simulates a handling accident in which an explosive charge is dropped onto and dragged across a gritty surface, causing it to reach a temperature high enough to ignite. "Once ignited, we then observe how violently the explosive reacts," she says.

In another type of experiment, called a cookoff, scientists apply controlled heating to a high-explosive sample until it ignites, often resulting in an explosion. These experiments provide necessary information about the safety of different explosive types.

Advanced diagnostics equipment measures velocities, pressures, and temperatures to study all the characteristics of a high-explosive formula. "It comes down to really understanding how materials behave under all the different conditions to be able to model and predict them," says High Explosives Science and Technology Group Leader Margo Greenfield. "The science and technology aspects are key. How does the formula age? How does it perform? How safe is it? Answering those questions requires a multidisciplinary effort."

SCALE AND SUPPLY

As if developing and testing explosives isn't challenging enough, scientists face an additional obstacle: the supply chain. "After the end of

■ Alex Cleveland adds trichlorotrinitrobenzene to a pressure vessel as part of a large-scale explosive synthesis reaction for triaminotrinitrobenzene, an explosive in nuclear weapons.

■ Bryce Tappan performs the final synthesis step of a high-nitrogen metal complex, where two atoms of nitrogen are added to displace unwanted water molecules bound to the metal.

the Cold War, we sometimes depended on materials that could only be sourced from sensitive countries, such as China or Russia," Tappan says. "Now, we are redesigning our formulations to use chemicals we can obtain without going outside the United States."

> "EXPLOSIVES CAN DETONATE IF YOU INSULT THE MATERIAL IN SOME WAY."
> —ANGELO ECHAVE

Greenfield stresses the importance of understanding and adapting to these issues. "We must be responsive to supply chain problems and investigate ways to develop different formulations," she says. "The goal is to use no components that are at risk for supply chain issues."

To help meet this goal, the National Nuclear Security Administration is investing in a new high-explosives synthesis and formulation facility at the Pantex Plant in Amarillo, Texas. Los Alamos scientists are working with Pantex to develop the facility and help ensure that Pantex can produce larger quantities of the explosives developed at Los Alamos. "Our goal is to make sure that Pantex's new facility is agile so we can scale up new formulations as needed in the future," Cleveland says.

Cleveland notes that "scaling up" an explosive means producing kilograms (instead of grams) of the formulation. Currently, Los Alamos works with both Pantex and the Holston Army Ammunition Plant in Kingsport, Tennessee, to scale up formulations. Los Alamos scientists travel to Pantex and Holston to work with the operators, scientists, and engineers producing the explosives. "When they initially run our material, it's a pilot plant production campaign, and we go out and observe and help guide the work," Nguyen says. The eventual goal is to move from pilot-scale production to large-scale production of the new explosive.

FUTURE DIRECTIONS

As the Laboratory's high-explosives scientists look toward the future, they see many opportunities. "Over the next few years, we will be making things that have new benefits, and we will continue developing our understanding of molecular properties and new formulations," Greenfield says. "Our goal is to be ready when a physicist asks, 'Do you have this material that will do this thing?'"

At the same time, the group must continue working on research and development so explosives production can become more agile, cost effective, and environmentally friendly. "We try to move where the country needs us while pushing science ahead and predicting future directions," Manner explains.

Tappan agrees. "Our explosives work is crucial to fulfilling the Lab's national security mission," he says. "We will remain competitive with the country's adversaries." ★

SCIENCE PLUS SAFETY

An explosives scientist reflects on risk and reward.

BY VIRGINIA MANNER

I have a fond memory of being seven months pregnant and, together with my Los Alamos National Laboratory coworker, filling a half-inch inner-diameter copper cylinder with my favorite explosive, erythritol tetranitrate. Over many months, we had synthesized the explosive and characterized its safety properties. With a team of people, we pressed it into pellets, machined and heat-treated the copper cylinder, and attached diagnostics for the experiment.

The pellets were 3 grams each, and the tolerances were tight: There would be microns of space between the explosive and the cylinder walls as we placed the pellets inside the tube. If a total of 30 grams of confined, high-performing explosive were to initiate next to us, we were well aware of the consequences: loss of life for ourselves and my unborn child.

So, why is this a fond memory? With the careful risk analysis that we performed beforehand, using multiple subject matter experts, scientists, and controls, the task had become something far safer than driving my car to work that day. And I was grateful that even during pregnancy, I didn't have to be afraid to participate in a project that I really cared about. Now, 10 years later, this is one of our favorite family stories, and the process is one of hundreds I've gone through to keep myself—and others—safe.

One of the special things about working with explosives is the way we can break down a potentially hazardous situation into its fundamental parts, so we can decide whether or how it could become safe. The most important first step is to ask "what if" questions with the right group of scientists, engineers, and managers. These knowledgeable experts each have thousands of hours working with explosives in relevant situations and can help answer tough questions. What if I drop this explosive and step on it? What if there's a static discharge while I am holding it? What if the explosive scrapes against the side of the copper cylinder?

Once we ask the questions, we assess the likelihood and consequences of the worst possible outcomes and determine if we can prevent or mitigate those. This process, known as hazard analysis, boils down to two questions: What's the chance of something going wrong? And if something does go wrong, how serious will the outcome be?

If the chance of an accident is higher than one in 10,000, then the severity of the accident must be very minor (such as a small cut on a finger or lost time in an experiment). If the severity of the accident is anything close to loss of limbs or life, then the possibility of it happening must be one in a million, or even less. Otherwise, we implement controls that reduce the frequency or severity of an event to an acceptable level.

This is how we stay safe on the job, but this approach to handling hazards works in a variety of settings. As an open water swimmer, I'm often listening to concerned relatives and friends, and the night before a big swim I often lie awake

After a careful risk analysis in their Los Alamos kitchen, these children have decided to eat raw cookie dough.
Photo: Christopher Waidmann

worrying about currents, wind, waves, jellyfish, sharks, and hypothermia. Breaking down each potential hazard into pieces that I can either let go or control is very calming during the 2 a.m. hour and also the entirety of the swim ahead. For example, I decide not to worry about sharks, as my lifetime risk of a fatal shark attack is one in four million according to the Florida Museum of Natural History. However, after thousands of hours of swimming, I know I am almost 100 percent certain to encounter wind and currents, which means I must plan around these conditions during long ocean swims.

I also use risk analysis when deciding how much time I want to spend driving a car (there's a 1 in 366 chance of an accident for every 1,000 miles driven) or determining whether I should eat raw cookie dough with my 7-year-old in front of my skeptical husband (1 in every 20,000 eggs are contaminated with salmonella, according to Centers for Disease Control and Prevention). My brother and my officemate, both pilots, employ risk analysis every time they fly.

One of the things that makes our explosives community and Laboratory unique is that we aren't afraid of the unknown. Instead, we face it with logical, thorough analyses that keep us safe. Some of my coworkers' hobbies include baking, woodworking, hunting, hand-to-hand combat, and a variety of unusual outdoor activities. I sometimes think our methodical analysis of hazards is what allows us to do interesting things both at work and in our personal lives. We can separate things that simply sound scary from legitimate dangers we must avoid or mitigate.

So, the next time someone tells you something is dangerous (or safe!), my advice is to go research the actual numbers that describe the frequencies of the hazards and the consequences of them happening. Understanding and analyzing risk is an important part of the scientific process, and it's something we do at Los Alamos National Laboratory every day. ★

Virginia Manner is an explosives chemist in the Laboratory's High Explosives Science and Technology group.

Duncan Isbister observes the nozzle of the 3D printer, which is directed by a toolpath that provides coordinate and speed data.

3D-PRINTED EXPLOSIVES

Layer by layer, scientists manufacture materials that go boom.

BY IAN LAIRD

Scientists can additively manufacture ceramics (p. 29), glass (p. 33), and polymers (p. 25), among other materials. So why not explosives? In 2016, the High Explosives Science and Technology group at Los Alamos National Laboratory started to explore this possibility. Fast forward to today, and the group members are designing and producing explosives that are often safer and more effective than those made through traditional methods.

Research and development (R&D) engineer Adam Takeshita explains that the process is called direct ink writing. “That’s when you push a paste through a nozzle, and the paste is deposited layer by layer into a formation that hardens,” he says.

Producing explosives this way opens up a range of possibilities that are tricky, if not impossible, to replicate with traditional production methods. Scientists can create complex internal lattices and structures that influence the explosive characteristics of each build. The way an explosive is printed affects how it detonates.

“The design and safety implications of this research and technology may transform the function and production of high explosive parts throughout the nuclear security enterprise,” says scientist Alex Mueller.

As with any additive manufacturing device, the way in which an object is printed has to be programmed into the printer. “The machine doesn’t know what to do, so you have to tell it what to do,” Takeshita says.

To achieve the enhanced print fidelity of complex parts, however, the team requires more control over the process than what standard 3D printers offer. The 3D printer used for printing explosives uses the typical x, y, and z axes for movement and also has two rotational axes, which allow for more fluid movement to create more complex designs. A large part of Takeshita’s job is creating toolpaths that direct the movement of the printer in a coding language called G-code.

“The machine interprets the code, and it will tell all of the axes to move in a coordinated way,” Takeshita explains, “including what speeds to print at and how fast to move.”

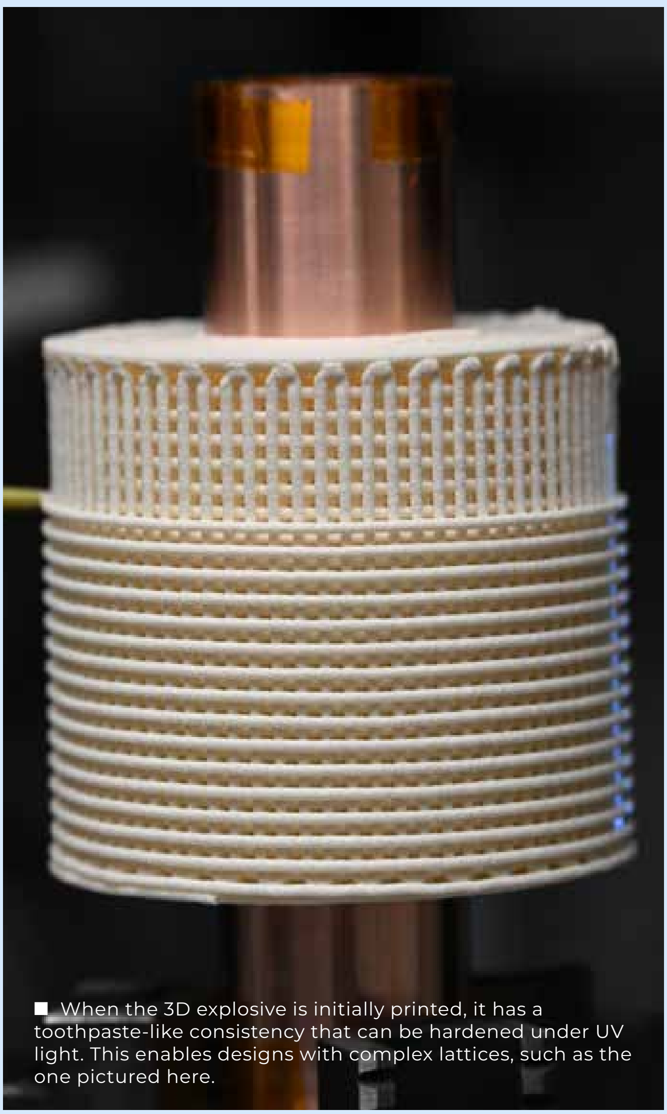
Developing the explosive material for the printer has also been a challenging process. Chemists in the group eventually created an explosive material with a toothpaste-like consistency that can be extruded through the printer nozzle. The material is also ultra violet (UV) curable—shining a UV light on it causes it to harden and thus hold its shape.

Takeshita and his colleagues work closely with the people or organizations requesting an explosive design. “It can take a lot of time and conversation to develop a design to meet their needs,” he says.

Some builds can take up to a year, depending on how many design iterations the team has to go through. But most simple designs can be produced in a matter of days. Once an explosive design is printed, the team tests the design to ensure it behaves as anticipated. For any unexpected responses or failures, the team heads back to the drawing board to iterate on the design.

Although the team has been largely successful in developing both 3D-printed explosives and the appropriate toolpaths, Takeshita admits there's still plenty of room for improvement. "There are any number of things that can go wrong," he says. "Any day-to-day variation in formulation or process can lead to structural and performance changes."

Takeshita takes the challenges in stride, noting that the benefits of 3D-printed explosives outweigh the obstacles. "Lots of people do 3D printing in general, but explosives R&D is something pretty much only the national labs do," he says. "And it might be part of the bias of working at Los Alamos, but I really do believe Los Alamos does it best." ★



■ When the 3D explosive is initially printed, it has a toothpaste-like consistency that can be hardened under UV light. This enables designs with complex lattices, such as the one pictured here.

■ Carson Archuleta, of the High Explosives Science and Technology group.

"WE HAVE COMMENCED WAR-RESERVE PIT PRODUCTION"

Associate Laboratory Director for Weapons Production John Benner discusses the effort to manufacture the plutonium cores of nuclear weapons.

BY WHITNEY SPIVEY

Before diving into this article, make sure to read "Pit production explained" in the winter 2021 issue of National Security Science *(or at least the CliffsNotes on p. 68!). That article describes the history of plutonium pit production, why new pits are being made, and why much of that manufacturing work is taking place at Los Alamos.*

John Benner, an engineer, has made a career in the nuclear security enterprise. Working for more than 30 years at Los Alamos National Laboratory, he's led efforts to maintain or modernize every Los Alamos–designed weapon in the current nuclear stockpile (the B61, W76, W78, and W88).

Since 2022, Benner has served as the associate Laboratory director for Weapons Production. In this role, he oversees the Lab's effort to manufacture plutonium pits—the cores of nuclear weapons. When compressed by explosives inside a warhead or bomb, a pit generates incredible amounts of energy. Los Alamos is establishing the capacity to eventually manufacture at least 30 pits pet year, starting with pits for the forthcoming W87-1 warhead. The first war-reserve (stockpile-bound) pit was built this summer. Also called the first production unit (FPU), this pit underwent extensive inspection to ensure it met all design and military requirements. On October 1, the pit was diamond stamped—essentially given the stamp of approval to be placed into a weapon.

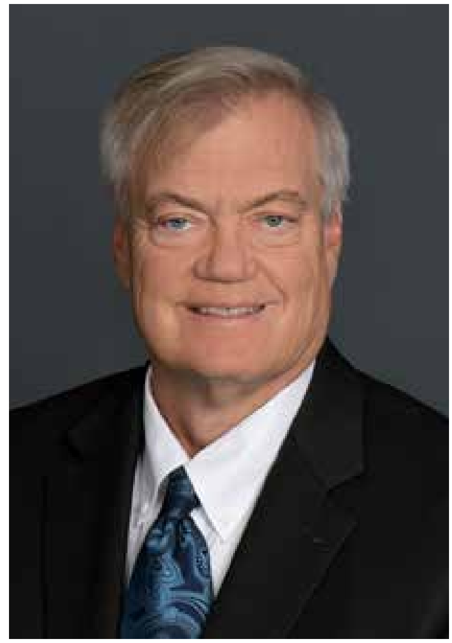
"Los Alamos is the only place in the nation that has the people and facilities to accomplish this mission," Benner explains. "And now we have commenced war-reserve pit production."

Benner sat down with *NSS* to discuss the path to pit FPU.

You became the associate Laboratory director for Weapons Production in January 2022. How has the pit mission evolved since then?

We've addressed a lot of significant, technical challenges. We engaged the full science and engineering base of the Laboratory to solve metallurgical challenges, material science challenges, and engineering challenges. Innovative solutions were identified for problems that were encountered in production. Solutions were needed to address production challenges; we changed aspects of the pit design to make it more producible. We now have a producible design and an initial production process. We will be refining that as we scale up production toward 30 pits per year.

We've also improved operational discipline in the Plutonium Facility as equipment has been removed or installed, as we've refined our processes, and as we've trained our workforce. In 2021, we had 19 operational weeks in the pit production areas, and we've improved that to about 33 weeks. To make at least 30 pits per year, we must improve the operational availability to 40 weeks. Operational availability is when an area is online and available for producing pits. It can't be down for any reason. And keep in mind that in addition to actual production work, we are running security, a cafeteria, nuclear materials control and accountability, and a lot of other support work. There is a large ecosystem of people that has really come together.



■ "John's strategic vision and leadership has been instrumental in maintaining stability and meeting deliverables as we work to produce at least 30 pits per year and execute other important national security missions," says Bob Webster, deputy Laboratory director for Weapons. "John's deep understanding of weapons engineering and his steady management have been essential to the success of Weapons Production."

Lawrence Livermore National Laboratory, a design agency, developed the design for the W87-1 warhead and pit. Los Alamos, also a design agency, has put on its production agency hat as the organization doing the pit manufacturing work. How does design inform production?

My experience as part of the Los Alamos design agency involved developing components here at Los Alamos and then producing them at production sites such as the Kansas City National Security Campus and the Y-12 National Security Complex. When you are designing, you may think that a certain production process will be sufficient. But as you get into production, you learn by doing as you move from early production into full rate production. Now that you're having to do it every day, even multiple times a day, suddenly it dawns on you: Wouldn't it be better if we had different tooling? How might we tweak the process? Could we do it like this? Or could we cut down on the variance and do something twice as fast?

Typically, you can develop a more efficient process because people bring improvements that they thought of as they're building parts. Production staff and product engineers find efficiencies and learn from early issues to help refine production, reduce scrap rates, and improve yield rates as production continues. Necessity is the mother of invention, as they say.

What are some of the manufacturing processes necessary to make a pit?

I can say a few of them. We purify plutonium, which involves electrorefining. We cast plutonium shapes. We weld. We rough-machine and then final-machine some components. We assemble the components into pits.

Over the past couple years, we've developed an improved engineering understanding of how and why pit production works—not just that it works. I'm happy about that. That understanding will allow us to continue to solve problems and eventually build different pit types—there are only a small number of operations that are unique to specific pit types.

Los Alamos is currently manufacturing pits to go inside the still-in-development W87-1 warheads, which will sit atop the still-in-development Sentinel missiles. What happens to these pits from now until these missiles are finally on alert, some time in the 2030s?

The plan of record was always to build ahead and create a stockpile of W87-1 pits in advance of the W87-1 system FPU. That is because the production rate at Los Alamos is less than the production rate of W87 systems at the Pantex Plant, where weapons are assembled. In the interim, the pits will be temporarily staged in a safe and secure location.

■ During a visit to Los Alamos, General Anthony Cotton, commander of U.S. Strategic Command, shakes hands with Pit Technologies division leader Matt Johnson (left) as John Benner looks on. "General Cotton spoke with many of the production technicians and engineers and communicated the importance of their work and his appreciation for what they were doing," Benner says. "I think his visit had a big impact on morale."

After a war-reserve pit is manufactured, it is diamond stamped. What does that signify?

The diamond stamp indicates that a nuclear weapon component meets the design, production, and quality requirements for insertion into the nuclear stockpile.

On different types of components, the diamond stamp shows up differently. Many components are physically stamped with a diamond shape. Some components—like wires—are not physically stamped, but they have a diamond-stamped label or tag.

What is the significance of FPU—to you personally and to the nation?

My background is in weapons engineering, and I've worked in support of all the Los Alamos–designed weapons in the enduring stockpile at one time or another. In my previous roles, I helped put into production most weapons components with a few exceptions, including pits, which were always reused in my experience. So, here at the end of my career, it's interesting that I am putting pits into production.

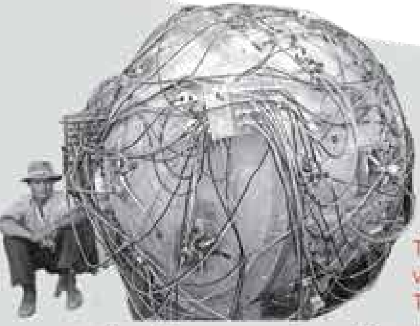
But that's not why FPU is significant. It's significant because the United States now has the ability to produce war-reserve pits and has the ability to fully refresh warheads and build new warheads to support the nuclear stockpile. ★

John Benner will retire from the Laboratory in January 2025.

■ Pit production happens at the Lab's Plutonium Facility.

PIT PRODUCTION 101

Haven't read "Pit production explained"*? Here are the CliffsNotes.

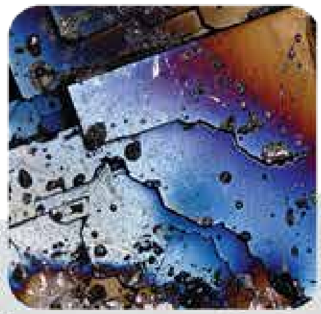


The Gadget, which was detonated at the Trinity site

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.

Rocky Flats

From 1952 to 1989, the majority of plutonium pits for U.S. nuclear weapons were manufactured at the Rocky Flats Plant near Denver, Colorado. **Most of the pits in the current stockpile were made at Rocky Flats.**



Plutonium crystal

Plutonium is unstable and radioactively decays over time. Plutonium can also absorb neutrons. Eventually, the loss or gain of 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.

An induction furnace for plutonium casting

NNSA headquarters

To ensure that aging pits pose no risk to the nuclear stockpile, the **National Nuclear Security Administration tasked Los Alamos with developing a pit production process** and delivering a minimum of 30 new pits per year.

A HELPING HAND

A robotic arm automates one step of pit production.

BY KEVIN ROBINSON-AVILA

A newly installed robot inside a glovebox at Los Alamos National Laboratory's Plutonium Facility is programmed to remove surface impurities from plutonium parts used in nuclear weapon cores, or pits. The robot, affectionately named APPA (Automated Plutonium Part Abrasion), came online this summer after a rigorous safety evaluation and approval process. Its use marks the first instance of robotic automation in the pit production process.

"This is a first of its kind for us," says Pit Technologies Assembly Operations group leader Iris Molina. "We're excited because it gives us the ability to let the robot do the work without constant hands-on production by operators. Employees won't have their hands in gloveboxes for hours on end anymore. You just set the program and let the robot run." She notes, however, that employees will always be at the controls, monitoring the robot and intervening if necessary.

Molina explains that APPA is really a robotic arm that holds a part in place. "It's programmed to manipulate and move the part as needed," she says. "There's a tool on the end of the robotic arm that does the surface cleaning."

APPA helps keep employee radiation exposure as low as reasonably achievable. Employees have an annual dose limit of 2,000 millirem, which is stricter than federal policy, and few ever get close to it. Nonetheless, reducing that exposure is a constant goal.

Even with the support of robotic equipment, employees are necessary to maintain and program APPA. The group members share this responsibility. "Nothing this cool gets done by just one person," says Pit Technologies Assembly Operations deputy group leader Brian O'Neil. "We all worked together with real team camaraderie right from the start." ★

APPA works inside a glovebox.

A diamond stamp indicates that a component has met or exceeded all quality and design requirements established by its design agency, which in the case of the W87-1 pit is Lawrence Livermore National Laboratory.

Los Alamos will salvage usable plutonium from old pits to make new pits. Plutonium from multiple old pits is necessary to make one new pit.

The Los Alamos Plutonium Facility

Plutonium, which is radioactive, is handled inside gloveboxes—sealed compartments that are 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.

Working inside a glovebox

The Savannah River Site in South Carolina is also tasked with producing pits. Using the Los Alamos process, Savannah River plans to deliver at least 50 pits per year, starting in the 2030s.

The Savannah River Plutonium Processing Facility

*See the winter 2021 issue of *National Security Science.*

PRODUCTION PASTIMES

Meet six employees who enjoy making things in their free time.

BY WHITNEY SPIVEY

Weaving, painting, welding, carving, you name it. Outside of work, Los Alamos National Laboratory employees moonlight as makers of everything from watches to wine. Meet six employees who take their hobbies just as seriously as their day jobs.

STEPHANIE FRANKLE

WOODWORKER, QUILTER

RESEARCH AND DEVELOPMENT SCIENTIST, INTEGRATED DESIGN AND ASSESSMENT

When Hurricane Hugo hit the East Coast in 1989, Stephanie Frankle and her husband, Chris, were in graduate school at North Carolina State University. “We were able to help some homeowners out by removing large trees,” she remembers. “One of Chris’ undergraduate professors had a sawmill, so we had wood planks cut.”

The planks enabled the Frankles to fully embrace woodworking as a hobby, and the unused planks came with them when they moved to Los Alamos. Together, the couple builds furniture, which Chris sands and Stephanie finishes. Some of their creations, such as an adjustable-height sewing cabinet, are custom-built for Stephanie’s other hobby: quilting. “My perfectionist nature comes out in woodworking, whereas I am able to take a more relaxed approach to quilting,” she says. “In very different ways, both allow me to put the world away and come back refreshed.”

Standing in front of two cabinets she and her husband built, Frankle holds a stained-glass quilt she made. “The next quilting project is a king-sized quilt that I will be tackling as I head into retirement later this year,” she says.

JANET HERRERA

VINTNER

PROGRAM MANAGER, PROGRAM ASSURANCE OFFICE

Herrera’s vineyard is called Frügente—a Spanglish word that means fruits of the people.

Janet Herrera lives in her childhood home in El Rancho, New Mexico, where she and her husband have planted 300 vines that supply about 2,000 pounds of grapes most years. Those grapes are picked, cleaned, crushed, and eventually turned into wine that’s bottled right in Herrera’s kitchen. Although Herrera doesn’t sell her wine commercially, it is enjoyed by friends, family, and those lucky enough to receive it as a gift.

Herrera grows several French-American hybrid varietals that tolerate New Mexico’s cold winters and loamy soil. “A lot of people hear that we make wine and think it’s so romantic,” Herrera says. “Really, we’re farmers, and it’s a lot of hard work.”

Even so, Herrera wonders if perhaps someday she’ll expand operations. “Maybe we’ll even build a small tasting room to share our passion with more people,” she says. “But for now, we’re happy where we’re at—it’s been great fun.”

DAVID KATONAK

HOROLOGIST

RESEARCH AND DESIGN ENGINEER, W76 SYSTEMS ENGINEERING

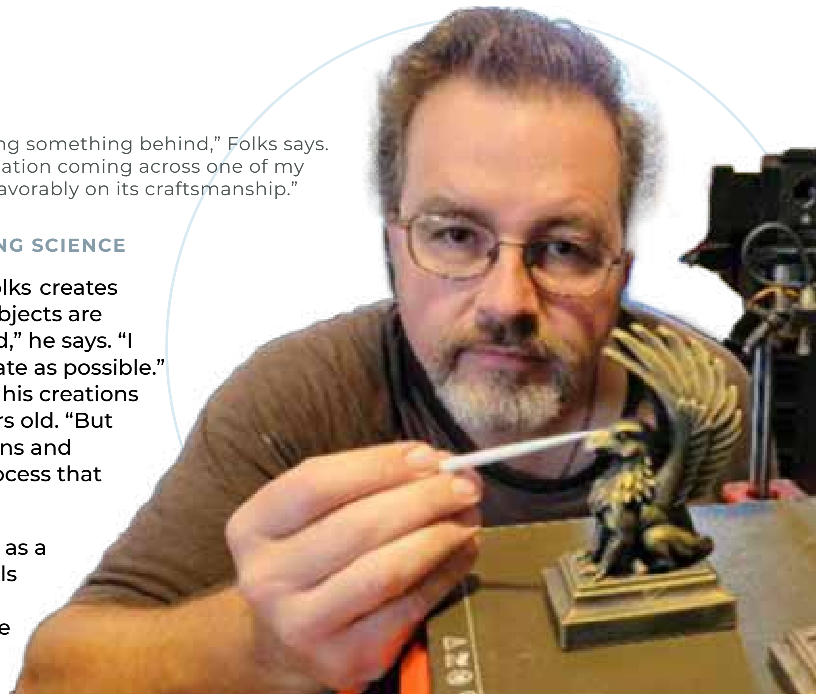
Even as a kid, David Katonak had an interest in the way things worked and how interactions and movements between small parts could produce larger movements. “I grew up in the country, and my family was quite a ways away from the nearest town,” Katonak explains. “So, we had to learn to fix things, and we always had dirt bikes or tractors to work on.”

In 2019, when Katonak inherited a grandfather clock in need of refurbishment, a new hobby was born. Katonak has since taken a clock repair class and built up a collection of vintage clocks, pocket watches, and watches. At his in-home workshop, he has developed the tooling and taught himself the skills necessary to repair and service the timepieces, and he’s even assembled a watch from parts that he carefully researched and sourced. “I think the end goal is to get to a point where I can repair and service my parents’ grandfather clock,” Katonak says. “I feel some attachment to that clock, and being able to do that would show a high level of skill.”

BO FOLKS

SCULPTOR

SPECIAL MATERIALS MACHINIST, FINISHING MANUFACTURING SCIENCE



■ "I like the idea of leaving something behind," Folks says. "I imagine the next civilization coming across one of my bobbles and remarking favorably on its craftsmanship."

In the living room of his 900-square-foot home, Bo Folks creates and reproduces jewelry and figurines. "My favorite subjects are animals, dragons, and symbols from around the world," he says. "I love researching my subject matter so I can make it as accurate as possible." Folks used to sculpt using clay or stone. He would reproduce his creations using lost wax casting, a process that is more than 6,000 years old. "But now," he says, "I primarily sculpt on a computer using electrons and pixels." He brings his creations to life using 3D printing, "a process that is younger than I am," he notes.

Folks says his experience as a sculptor has informed his work as a machinist at the Laboratory. "I've built up a foundation of skills that are highly uncommon in an advanced manufacturing setting," he says. "Therefore, I often have a unique perspective to bring to a problem." Folks is quick to note, however, that "sometimes the simplest solutions are best." ●

■ In his sunroom full of carefully curated and restored equipment, Nizolek's creations are both functional (parts for his motorcycle) and aesthetic (a sleek corkscrew for his PhD advisor). "My hobby is a constant reminder of how much work and skill is involved in making even a 'simple' component," he says. "It's extremely challenging and rewarding."

TOM NIZOLEK

MACHINIST

RESEARCH AND DEVELOPMENT ENGINEER, FINISHING MANUFACTURING SCIENCE

Tom Nizolek restores used metalworking and machining equipment. "The machines in my collection," he explains, "were made between the 1890s and the 1980s, with many originating from the surge in industrial activity associated with World War II."

Recently, while rebuilding a metal cutting shear, Nizolek discovered a plaque covered in grease that revealed the machine had been purchased by the Atomic Energy Commission (the predecessor to today's Department of Energy, of which Los Alamos is a part) and used at the Nevada Test Site (known today as the Nevada National Security Sites, where Los Alamos conducts many experiments). "To give this piece of equipment a new lease on life—along with many other tools that literally built America's industrial might—is very satisfying," Nizolek says. "After I have restored a machine, I know exactly how all parts of it work, and I almost always learn something new about mechanical design." ●

JESSE SALAZAR

LEATHERWORKER

RESEARCH TECHNOLOGIST, NUCLEAR MATERIALS SCIENCE

When Jesse Salazar's son wanted to try leatherwork, Salazar got him a starter kit. Soon thereafter, the boy lost interest, and the kit went into the closet. Later, Salazar was shopping for a leather belt but couldn't find one he liked. "Then I remembered that starter kit," he says. "I took it out of storage and made my own belt—that was the beginning of my love for the craft."

In addition to belts, Salazar makes everything from purses to pistol holders. "Designs for these items percolate in my head," he explains. Using a pencil, he draws a design on leather, then dampens the hide and uses a swivel knife and stamping tools to carve and imprint the pattern. Lastly, he oils the leather before adding any special finishes. "With a cup of coffee and my favorite music on the radio, I just let the process flow," he says. "Day-to-day challenges disappear and a sense of tranquility sets in." ●

■ "Skill comes with time, and making that time requires desire to work the leather," Salazar says.

ACCOLADES

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.

W88 Systems Engineering deputy group leader **Justine Davidson** received the 2024 Office of the Secretary of Defense Medal for Exceptional Public Service. The award is the highest honor presented by the Secretary of Defense to non-career federal employees who have made significant contributions to the nation's security. Davidson was selected for her performance while serving as senior scientific advisor to the Office of the Deputy Assistant Secretary of Defense for Nuclear Matters from April 2021 to April 2024 through an Intergovernmental Personnel Act assignment.

The DOE Hydrogen Program recognized **Piotr Zelenay** with a lifetime achievement award for his contributions to the fields of electrocatalysis and electrochemistry. Zelenay was commended for his decades-long efforts in advancing the field of platinum-group-metal-free electrocatalysis.

In April, a team of 33 employees from across the Lab received the 2023 National Nuclear Security Administration's Randy D. Putt Outstanding Security Team of the Year award. The honor comes for their work "developing a classified wireless network solution to support plutonium production programs, which requires significant communication, collaboration, and problem solving," according to a memo from Lewis Monroe III, the associate administrator and chief of Defense Nuclear Security at NNSA.

Research scientist **Raymond Newell** was named Battelle's Los Alamos Inventor of the Year. Newell's recognition stems in part from his development of the Quantum Random Number Generator, a device that generates random numbers from quantum fluctuations in the intensity of an optical source.

John Tapia of the Accelerator Strategy Office was appointed to the Department of Energy's Project Leadership Institute advisory board. He is an alumnus of the DOE training program designed to cultivate future leaders for DOE's high-risk scientific mega-projects.

Laurel Winter was elected vice chair for the American Physical Society Topical Group on Instrument and Measurement Science, which provides a forum for discussion and offers professional recognition to those who advance this science.

Kirk Flippo of the Physics division was named a referee of the month by *Communications Physics*, a *Nature* portfolio journal that focuses on research advances in the physical sciences. Flippo was recognized for going "above and beyond what is expected of a reviewer in terms of the value of their reports, the detail of their analysis, or the degree to which they have helped the authors improve their manuscripts prior to publication."

At the 59th Annual Department of Energy Classification Officers Technical Program Review meeting, **Diana Hollis** received the 2024 Classification Award of Excellence. DOE's Office of Classification presents the award annually to the classification officer who has made the most significant contributions to the program.

The Laboratory's director of the Center for Nonlinear Studies and recognized authority in astrophysics, **Chris Fryer**, was awarded the Marcel Grossmann Award in Italy. Fryer was awarded by the International Center for Relativistic Astrophysics for his "pioneering and groundbreaking theoretical and numerical simulation contributions that have advanced our understanding of supernovae, gamma-ray bursts, and binary stellar evolution connecting them."

Scott Aeilts is the new associate Laboratory director for Business Services. Aeilts oversees all business service areas, including the Chief Information Security Officer, I&T Infrastructure Services, Acquisition Services Management, the Controller, the Finance division, and the Office of Planning and Analysis.

Former under secretary of defense **Steve Cambone** is leading the Lab's new Strategic Assessment and System Analysis Office, which assists Los Alamos leadership in critically evaluating the Laboratory's national security initiatives and their alignment with broader national objectives. The office is tasked with identifying, analyzing, and presenting options that leverage the Laboratory's scientific and technical capabilities to shape and successfully implement programs that meet these objectives.

Jennifer Hollingsworth of the Center for Integrated Nanotechnologies in the Materials Physics and Applications division at Los Alamos National Laboratory was selected as a fellow of the American Chemical Society. Hollingsworth's recognition stems from her nanomaterials work with quantum dots, her mentorship and leadership within the chemistry community, and her service to the society.

Tanmoy Bhattacharya and **Stefano Gandolfi**, both of the Lab's Theoretical division, were elected fellows of the American Physical Society. APS fellows are society members nominated by colleagues, with election based on original research and publications that offer significant, innovative application of physics to science and technology.

Two Laboratory scientists each won a DOE Early Career Research Program award, which provides five years of funding for a mission-centric R&D project. **Keegan Kelly** is developing a measurement capability to better understand how fusion reactors work. **Daniel O'Malley** is using quantum computing and machine learning to represent a wider range of scales in complex fracture networks. ★

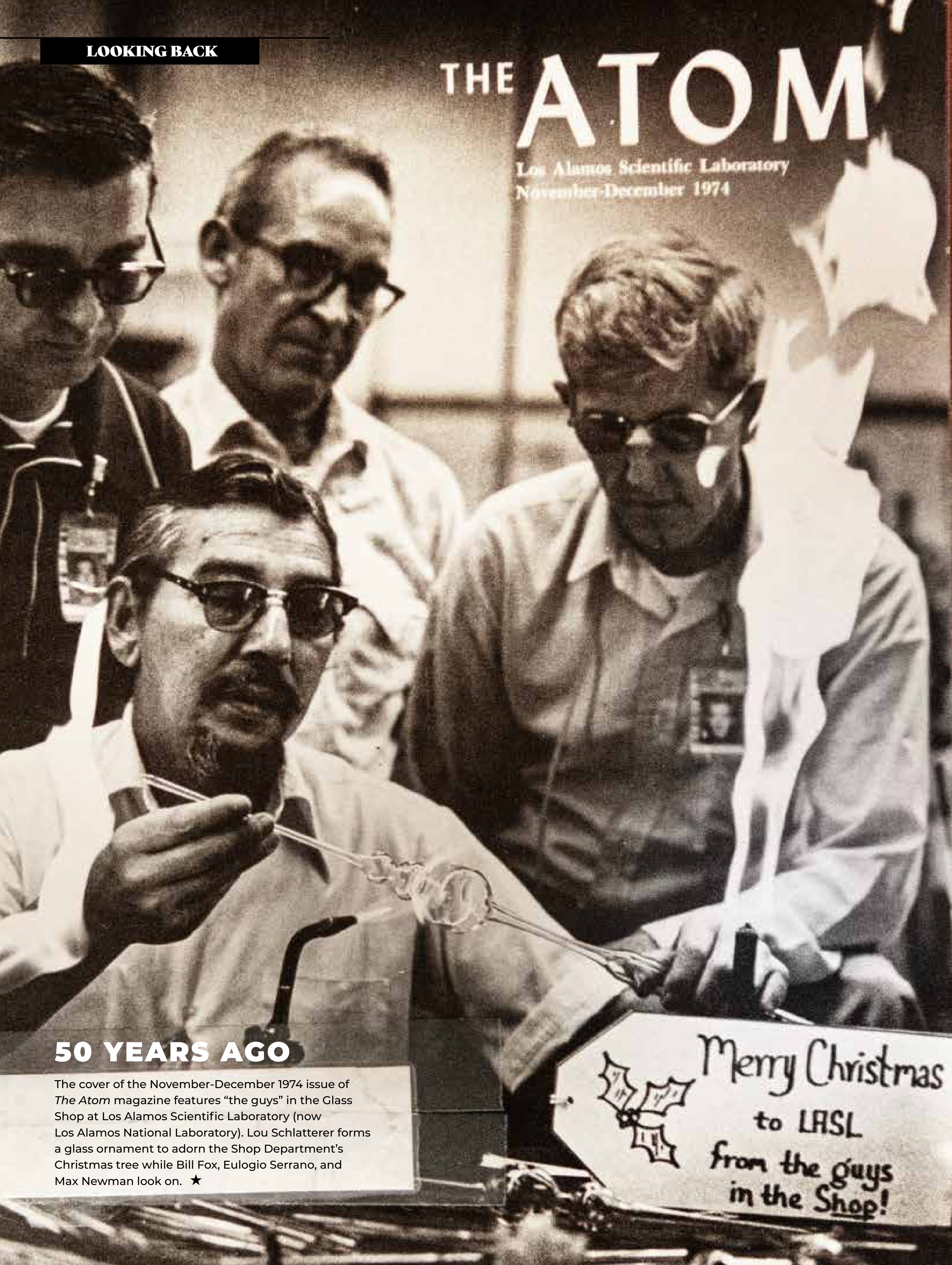
IN MEMORIAM

After 22 years at Lawrence Livermore National Laboratory, Charles McMillan became the associate director for Weapons Physics and then the principal associate director for Weapons at Los Alamos National Laboratory. He became the Laboratory director in 2011 and focused on ensuring the safety, security, and effectiveness of the U.S. nuclear deterrent, while also promoting the broader scientific work of the Laboratory.

"He had a remarkable ability to be both firm in direction and kind in manner all at the same time," says Charlie Nakhleh, associate Laboratory director for Weapons Physics. "He always seemed to appear whenever difficult leadership challenges reared their head. When we needed him, he was always there."

After retiring from Los Alamos in 2017, McMillan remained active in national security work; he was particularly interested in the oversight and potential geopolitical implications of artificial intelligence.

McMillan died in a car crash in Los Alamos on September 6. ★



50 YEARS AGO

The cover of the November-December 1974 issue of *The Atom* magazine features “the guys” in the Glass Shop at Los Alamos Scientific Laboratory (now Los Alamos National Laboratory). Lou Schlatterer forms a glass ornament to adorn the Shop Department’s Christmas tree while Bill Fox, Eulogio Serrano, and Max Newman look on. ★

Los Alamos
NATIONAL LABORATORY

NATIONAL ★ SECURITY SCIENCE

Mail Stop A107 ■ Los Alamos, NM 87545
lanl.gov/magazine

NNSA
National Nuclear Security Administration

Presorted Standard
U.S. Postage Paid
Albuquerque, NM
Permit No. 532

Scan code to subscribe to our newsletter and read the magazine online.

THEN & NOW

Located in downtown Los Alamos, Fuller Lodge was constructed in 1928 as part of the Los Alamos Ranch School. During the Manhattan Project, Fuller Lodge was used for meals, plays, dances, and other occasions. Today, Fuller Lodge is still used for community events, and it is also the setting for *Nutcracker on the Hill*, a ballet that follows the same storyline and score as the original *Nutcracker* but with a Los Alamos twist. The localized rendition features J. Robert Oppenheimer, General Leslie Groves, and many Manhattan Project scientists and their families. ★