

LOS ALAMOS NATIONAL LABORATORY ◇ SPRING 2019

NATIONAL ★ SECURITY SCIENCE



THE INNOVATION ISSUE

Additive manufacturing:
the power of powder

Faces of innovation:
scientists and engineers
pioneer new technology

Beyond Trinity: 75 years of
weapons advances

+PLUS:

Meet the new Lab director

Los Alamos wins eight
“Oscars of Invention”

The science of policy

PHOTOBOMB

▼
The accelerators at the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility produce intense, high-energy electron beams that generate radiographs (x-rays) of nuclear-type explosions. These images help validate computer simulations of nuclear weapon performance.

Photo: Michael Pierce





2



4

IN THIS ISSUE

- 2 Letters: Innovation** National security depends on pioneering scientists and engineers who respond to challenges with new, often-surprising, ideas.
- 4 Abstracts: Notes and news from around the Lab** Director Thom Mason takes the helm at Los Alamos, the Laboratory wins eight “Oscars of Invention”, and more.

FEATURES

- 10 Faces of innovation:** Meet seven scientists and engineers whose groundbreaking ideas, experiments, and data have big implications for national security.
- 24 Beyond Trinity: 75 years of weapons advances** In addition to creating the world’s first nuclear device, Los Alamos has made nuclear weapons more effective, safe, and specific to military needs.
- 34 Additive manufacturing: The power of powder** At the Laboratory’s Sigma Complex, metal components are created with powder, layer by layer, to withstand extreme environments.

- 44 Analysis: The science of policy** Three members of the National Nuclear Security Administration (NNSA) share their thoughts on innovation and how having a science background is important for shaping policy.
- 46 Being Essential: The need for speed** Jeffrey Luehring is all about parts—weapons parts for his job in materials management and boat parts for the jet boat he drag races.
- 48 Accolades:** The distinguished achievements of Los Alamos employees.



10



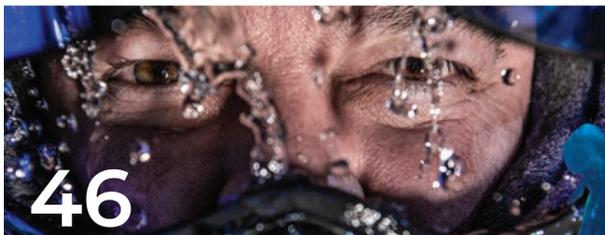
24



34



44



46

49



- 49 Looking Back:** A scuba diver explores the wreck of the USS *Arkansas*, which was sunk during the 1946 Baker test of Operation Crossroads.

ABOUT THE COVER:

Technical Area 3—the administrative hub of Los Alamos National Laboratory—is where innovation happens in support of the Lab’s national security mission.

INNOVATION

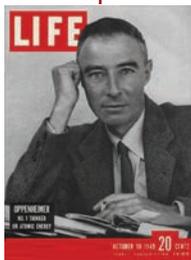
NATIONAL SECURITY depends on pioneering scientists and engineers who respond to challenges with new, often-surprising, ideas.



BY BOB WEBSTER

DEPUTY DIRECTOR, WEAPONS

“THERE IS NO PLACE FOR DOGMA IN SCIENCE,” Robert Oppenheimer, the first Laboratory director, told *Life* magazine in 1949. “The scientist is free, and must be free, to ask any question, to doubt any assertion, to seek for any evidence, to correct any errors.”



Seventy years later, Oppenheimer’s words still ring true, and Los Alamos remains a hotbed of creative thinking and innovation. From Frederick Reines’ Nobel Prize in physics to the Laboratory’s collective 153 R&D 100 Awards, Los Alamos is world renowned for pushing the boundaries of science and engineering.

This issue of *National Security Science* magazine highlights just a handful of the innovative people and technologies that have put—and keep—Los Alamos on the map.

On p. 21, physicist Katie Mussack defines innovation as “slow, steady progress that builds to one thing that people notice.” She and her colleagues, profiled in “The Faces of Innovation,” share

challenges and successes of pioneering new technologies—such as Scorpius, a linear induction accelerator that will take x-rays (radiographs) of the late stages of implosion experiments at the Nevada National Security Site (NNSS).

Innovation, of course, also builds on previous discoveries.

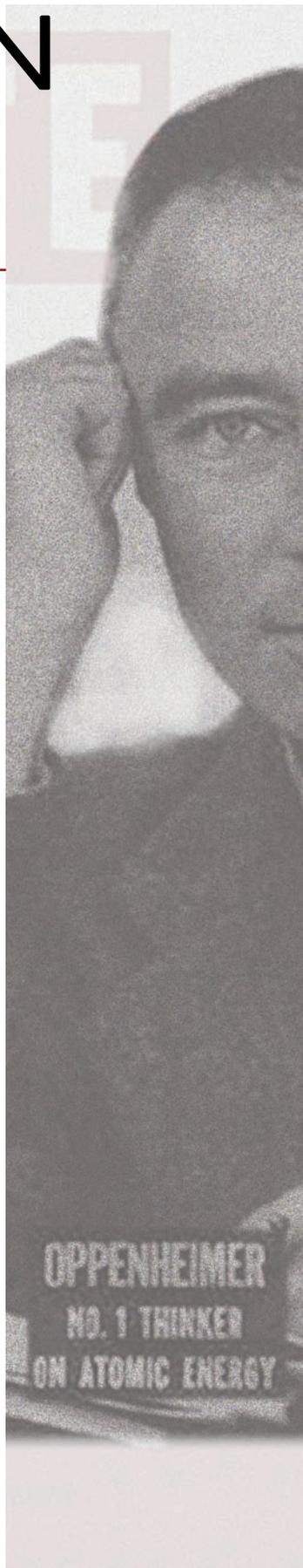
“Beyond Trinity: 75 Years of Weapons Advances” (p. 24)

reminds us that Los Alamos designed the first nuclear test (Trinity) and then traces the progressive breakthroughs that made nuclear weapons not only more effective but also safer and better maintained.

Today, Los Alamos stewards the stockpiled variants of the B61, W76, W78, and W88 nuclear weapons and is updating the W76, W88, and B61 to ensure that these weapons remain safe, secure, and reliable.

As part of this modernization, Los Alamos is considering new materials and manufacturing techniques. On p. 34, “Additive Manufacturing: The Power of Powder” examines how complex metal components are created with powder, layer by layer—a kind of 3D printing.

Ten years ago, 3D printing of weapons parts would have been science fiction. Ten years from now, who knows what technology we’ll be using? (The three NNSA officials interviewed on p. 44 have some ideas about that.) One thing is certain, however: Los Alamos will remain central to the safety and security of the United States. ★



MASTHEAD

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NSS STAFF SPOTLIGHT



Editor Whitney Spivey stands in front of the Sedan Crater at the NNSS. The 320-foot-deep crater was formed when a nuclear test device was detonated underground on July 6, 1962, and displaced 12 million tons of earth. Today, underground testing is prohibited, but scientists are finding new ways to better understand how nuclear weapons perform. Turn to p. 12 to learn more about Scorpius, an innovative project at NNSS that will help researchers “see,” using radiographs, what happens to plutonium in the late stages of a nuclear implosion.

BY THE NUMBERS: 2018 COMMUNITY GIVING

Maintaining a good relationship with Northern New Mexico is essential to the success of the Laboratory's national security mission.

In his first all-employee meeting, Laboratory Director Thom Mason explained how the Lab's national security mission is served by excellent operations and community relations.

"We've got to be excellent in nuclear security; that's why we're here," he said. "That means we have to design, produce, and certify current and future nuclear weapons and reduce global nuclear threats. That's our primary reason for existence—not the only thing we do, but we'd better be best in class at that. We also have to deliver the scientific discoveries and technical breakthroughs that support those missions."

"It's not enough to be great at those things," he continued. "In fact you can't be great at those things unless you're not also excellent in mission operations: able to sustain operations that are reliable and responsive to mission needs. If a facility is shut down, by definition, it's not going to be delivering on those nuclear security missions."

"And finally, we have to be excellent in our relationships with the community because if we lose their confidence and trust, we will actually lose the ability to operate, and we'll lose the support we need to get our job done. So we've got to sustain and enhance Los Alamos' partnerships with the community all across Northern New Mexico." ★

EMPLOYEE GIVING CAMPAIGN
\$2.9 MILLION
 RAISED FOR NONPROFITS



1,017

BACKPACKS FILLED WITH SCHOOL SUPPLIES DONATED DURING THE BACK TO SCHOOL DRIVE



EMPLOYEES VOLUNTEERED FOR A TOTAL OF

\$440,000

RAISED DURING THE LOS ALAMOS EMPLOYEES' SCHOLARSHIP FUND (LAESF) ANNUAL CAMPAIGN

3,543 HOURS
 OF STEM EDUCATION TIME IN THE COMMUNITY

240 FROZEN TURKEYS
 donated on Bring Your Turkey to Work day



988

GIFTS DISTRIBUTED DURING THE HOLIDAY GIFT DRIVE



142
 NEW MEXICO STUDENTS AWARDED LAESF SCHOLARSHIPS TOTALING \$712,950

■ **Pictured below:** Scott Crooker from the Laboratory's National High Magnetic Field Laboratory demonstrates magnetic principles to students from Santa Fe Indian School during a STEM mentoring event.



THE INTERSECTION

Where science and culture converge in Northern New Mexico—and beyond.



Secret Cities: The Architecture and Planning of the Manhattan Project is on display at the National Building Museum in Washington, D.C., through July 28.

CULTURE

SCIENCE



Two of many science-themed license plates spotted at the Laboratory. Learn more about one-point safety on page 28.



To raise money for Alzheimer's Scotland, Laboratory physicist Malcolm Burns rowed across Scotland's longest lake, Loch Lomond—in a bathtub.

Many Lab employees wear Hawaiian shirts on Fridays as a nod to the days of nuclear testing in the Pacific.



QUOTED



The success we've achieved on the W76-1 is a testament to our ability across the Nuclear Security Enterprise to deliver on commitments to the Department of Defense, Congress, and the American people."

—NNSA Administrator Lisa Gordon-Hagerty on the completion of the W76-1 Life Extension Program (LEP), which was completed under budget and ahead of schedule in January 2018. The W76-1 is a refurbished W76 warhead, which is a Los Alamos–designed, submarine-launched ballistic missile system first introduced into the stockpile for the U.S. Navy in 1978. This LEP has strengthened the safety and security of the United States by extending the warhead's service life. ★

Photo: U.S. Navy

MOVING UP

The Lab's Trinity supercomputer is now ranked sixth in the world.

The Department of Energy has five supercomputers ranked in the top 10 of best-performing supercomputers in the world. The Laboratory's Trinity machine comes in at No. 6 on that list, up one spot from last year.

"Trinity, a Cray XC40 system operated by Los Alamos National Laboratory and Sandia National Laboratories, improved its performance to 20.2 petaflops, enough to move it up one position to the No. 6 spot," according to TOP500, which compiles the list.

Trinity arrived at Los Alamos in 2015, covers approximately 5,200 square feet of floor space, and was the first platform large and fast enough to accommodate finely resolved 3D calculations for full-scale, end-to-end weapons calculations. Complex 3D simulations of nuclear detonations are required for supporting the NNSA's Stockpile Stewardship program, which ensures that the nation's nuclear stockpile is safe, reliable, and secure.

As part of this program, a request for proposal (RFP) for Crossroads, an even-more-powerful supercomputer than Trinity, was released in February. Crossroads is expected to be installed at Los Alamos by the fall of 2021. Turn to p.18 to learn more about the Laboratory's High Performance Computing Division and its plans for the future. ★

■ **Pictured below:** The world's most powerful supercomputers according to TOP500.



MILITARY

THANK YOU

Two Air Force bases host visitors from Los Alamos.

Los Alamos National Laboratory thanks Malmstrom Air Force Base and Minot Air Force Base for hosting Laboratory personnel in November 2018. The visits were "an incredible learning experience for the weapons designers and engineers," says Jon Ventura of the Lab's Office of Nuclear and Military Affairs. "Seeing the bases in person will make a significant difference in how they approach life extensions and other efforts as we seek, together, to sustain the safety, security, and effectiveness of the nation's nuclear deterrent." ★

■ **Pictured above:** Lab employees visit Malmstrom Air Force Base in Montana.

VETERANS



LOS ALAMOS RECOGNIZED FOR VETERAN EMPLOYMENT

The Laboratory receives a Gold Award from the Department of Labor.

The U.S. Department of Labor awarded Los Alamos National Laboratory the 2018 HIRE Vets Medallion Program Demonstration Gold Award in recognition of the Lab's commitment to recruiting, hiring, and retaining veterans. The Lab was one of only 239 Gold Award recipients this year.

The HIRE Vets Medallion Program is the only federal-level award for veterans' employment. Recipients were evaluated on several criteria, ranging from hiring and retaining veterans to providing veteran-specific resources, leadership programming, dedicated human resources, and compensation and tuition assistance programs.

"Veterans and transitioned military personnel have always made very important contributions to our Laboratory," says Laboratory Diversity Officer C.J. Bacino. "We are incredibly grateful for their service and honored to receive this recognition. The specialized skills these amazing individuals bring to our workforce in support of our mission are indispensable. We will consistently remain dedicated to their recruitment and retention." ★

■ **Pictured above:** The veteran recruiting team at Los Alamos provides one-on-one support for individuals seeking employment or looking to transfer positions within the Lab.



LOS ALAMOS SCIENTISTS TEACH AT WEST POINT

Retiring Colonel Edward Naessens nurtured the relationship between the two institutions.



In November 2012, U.S. Army Colonel Edward Naessens sent a letter to then-Laboratory Director Charlie McMillan. "The United States Military Academy at West Point requests that the Los Alamos National Laboratory detail a technically qualified staff member to teach in the Department of Physics and Nuclear Engineering (PaNE)," Naessens wrote. "The position would require teaching approximately half-time, with the remainder of the time spent in scholarship, supervision of cadet and faculty research projects, faculty development, and participation in cadet development activities."

Naessens, the PaNE department head, was hoping to strengthen the relationship between the Army and Los Alamos that began more than 75 years ago during the Manhattan Project, which was directed by Army Lieutenant General Leslie Groves.

"Colonel Naessens sets the standard for the modern thinking soldier," says physicist Leo Bitteker, the first Los Alamos scientist to teach at West Point. Although the Army does not currently have a direct role in the nuclear triad, Army officers serve in key decision-making bodies that relate to nuclear weapons; Naessens had the foresight to realize the importance of building connections between the cadets—aka future officers—and scientists.

Since Bitteker, Laboratory employees Chad Olinger and Shirish Chitanvis have also taught at West Point. And although the tradition will continue, future appointments will never be quite the same. In May, Naessens will retire after 28 years of serving his country.

"Colonel Naessens clearly loved his job as leader of the PaNE Department, where he directed the effort to use physics education to build the character of the next generation of officers," Bitteker remembers. "His passion for PaNE was surpassed only by his passion for soldiering, and we are a safer nation because of his drive and leadership." ★

■ **Pictured above:** Colonel Naessens gives Lab Director Charlie McMillan a physics lesson at West Point in April 2015. Colonel Naessens studied physics at West Point and graduated in 1981. He then attended Rensselaer Polytechnic Institute, where he earned a master's in physics and a doctorate in nuclear engineering and science.

NEW PROGRAM FOSTERS MISSION-MINDED FUTURE LEADERS

Participants consider how science informs policy.

In an effort to cultivate the next generation of innovative thought leaders at Los Alamos, the Laboratory's Weapons Physics and Global Security programs launched the MEDAL (Mid-/Early-career Deter-detect-prevent Advanced Leadership) program in 2018.

The inaugural class of 12 Lab employees attended a series of lectures related to nuclear weapons, nonproliferation, counterproliferation, counterterrorism, and intelligence. The talks prepared them for a three-day trip to Washington, D.C., where they attended tours, meetings, and networking events with members of the National Security Council, the Office of Science and Technology Policy, the NNSA, the U.S. Department of Energy's Office of Intelligence, NNSA Defense Programs, the Department of Defense, and other organizations.

During these interactions, participants were encouraged to consider the intersection of technology and policy as related to the Lab's national security mission: maintaining a safe, secure, and effective nuclear deterrent and preventing, countering, and responding to the global threats of nuclear proliferation and terrorism.

"Physicists and engineers can easily recognize limitations imposed by nature," explains physicist Travis Burris, who participated in the program. "It's more difficult for us to recognize the purpose of limitations imposed by people (policy). This program puts policy into perspective and illuminates the benefits that result from policy. There's comfort in knowing that a lot of smart people are keeping us safe in many different ways."

Karen Miller, one of the MEDAL organizers, agrees. "The MEDAL program has given me a much better understanding of Los Alamos as an institution and our place in the larger ecosystem," she says. "In my role as a scientist, I spend most of my time thinking about problems that are narrowly focused. MEDAL gave me the opportunity to expand my aperture and gain new insights about how my work fits into the bigger picture." ★



LOS ALAMOS WINS EIGHT "OSCARs OF INVENTION"

Laboratory innovations that support national security win R&D 100 Awards.

Eight Lab technologies won R&D 100 Awards at *R&D Magazine's* annual ceremony in Orlando, Florida, on November 16, 2018. "These innovations continue the Laboratory's tradition of scientific excellence in support of our national security mission, industrial competitiveness, and the broader scientific community," says John Sarrao, deputy Laboratory director for science, technology, and engineering. "In addition, the awards demonstrate the strength of partnerships with industry, academia, and other national laboratories to solve challenging scientific issues."

The Los Alamos winners are as follows:

Charliecloud: This lightweight container software for supercomputers lets users package their own user-defined software stack in isolation from the host operating system.

Grand Unified File Index (GUFI): This fast software can search metadata at the scale used by supercomputer and enterprise centers.

Lighthouse Directional Radiation Detectors: These detectors determine the location, amount, and movement of a radioactive source in the presence of multiple sources.

Long-range Wireless Sensor Network: This turnkey, low-power sensor network enables data collection and transmission in rugged and remote outdoor environments.

Rad-hard Single-board Computer for Space: This lightweight radiation-hardened computer can be used on satellites and for other space applications.

Silicon Strip Cosmic Muon Detectors for Homeland Security: These detectors with slim profiles can be deployed to detect shielded nuclear materials.

Universal Bacterial Sensor: This sensor mimics biological recognition of bacterial pathogens to enable the detection of bacterial infections even before the onset of symptoms.

Video-Based Dynamic Measurement & Analysis (ViDeoMAGic): This technology extracts high-spatial-resolution structural vibration and dynamics information from videos of vibrating structures to analyze the health of civil, mechanical, and aerospace structures.

The R&D 100 Awards, selected by a group of *R&D Magazine's* judges, honor the top 100 proven technological advances of the year. Since 1978, Los Alamos has won 153 R&D 100 Awards. The Laboratory's discoveries, developments, advancements, and inventions make the world a better and safer place, bolster national security, and enhance national competitiveness. ★



**Los Alamos
National Laboratory**
Won 8 R&D 100 Awards
(out of 9 entries)



THOM MASON TAKES THE HELM AT LOS ALAMOS

The Laboratory's 12th director discusses national security, the annual assessment letter, and why he chose physics over English in college.



Perhaps it's no surprise that Thom Mason, who was director at Oak Ridge National Laboratory for 10 years, is now the director at Los Alamos. "I grew up in a science family," he explains. "My dad worked at a Canadian national lab, so it was sort of the family business, and it never really occurred to me to do anything else."

He pauses, reconsidering. "I did think about doing an English degree," he says. "And I decided that if I did physics, I could still read books. But if I took English, I probably couldn't have physics as a hobby."

Fast-forward nearly four decades, and reading is still one of Mason's hobbies, alongside hacking consumer electronics, cycling, skiing, and exploring his new hometown of Santa Fe, New Mexico.

But time for such activities is in short supply these days, as nearly all of Mason's energy

is focused on his new job at Los Alamos. "There is something healthy about really looking at things and trying to understand what's working and what's not working," he says of his new role with Triad National Security, which began managing the Lab on November 1, 2018. "This is an opportunity to take a fresh look at things, make some changes that need to be made, and emerge as a stronger organization as a result."

Here, Mason explains just how he intends to do that.

How is Los Alamos different from Oak Ridge?

Both labs were founded in 1943, so they have common roots in the Manhattan Project—the crash effort to bring the best of science and technology to bear on the crisis of the day. The difference—and one of the reasons I find Los Alamos interesting—is that Oak Ridge is

first and foremost a science and energy lab, although it does a lot of important national security work. Los Alamos is clearly, front and center, a national security lab, although it has a lot of outstanding science and energy technology work. That focus on national security and the nuclear deterrent brings challenges. This is a high-consequence place. It's high consequence in terms of the impact of the work that's done, and it's also high consequence in terms of what could possibly go wrong. It's important that the work be done well, and that's certainly a challenge I relish and everyone on the leadership team looks forward to.

What is your vision for the weapons program?

As we look forward, we have to deal with the reality of change in the stockpile. Weapons have been in service longer than their original design intent.

In response to that, the Lab has responsibility for things like life extension programs, modifications, and alterations.

In that world where we are starting to see more change, how do we certify weapons? What are the tools we need to be able to do that? We have progressively higher performing computers with codes that are optimized to run on them, so we can simulate things with a fidelity that we couldn't do previously—or at least we will be able to in coming years as we get to exascale computing and beyond. We have new experimental techniques that are giving us better-quality data to validate those simulations.

So the question will be: Does the rate of improvement of our scientific and engineering understanding of the stockpile stay ahead of the rate of change that's occurring in the stockpile? That's the thing I'm most focused on in terms of the longer-term

direction of the Lab. We have to make sure our scientific and engineering capabilities stay ahead of the challenges in the stockpile.

In September, you will sign the annual assessment letter that concludes the health of our nuclear deterrent. How will you make sure you're confident signing that letter?

That letter has four components: the state of existing stockpile, whether there is a need to resume testing, the adequacy of the tools, and the readiness to resume full-scale nuclear testing.

There's a large enterprise that's focused on the state of the stockpile. My responsibility is to make sure that the enterprise is properly staffed and funded and asking the right sorts of questions. There are also

“We have to make sure our scientific and engineering capabilities stay ahead of the changes in the stockpile.”

independent Red Team processes to crosscheck the enterprise and then of course the very important function between Livermore and Los Alamos to peer review one another. All of that can help increase my confidence that we have a good and correct technical judgment, whether it's on the state of the stockpile or the ability to continue the current posture of not doing full-scale nuclear testing.

In terms of the adequacy of the tools, I look at the types of questions we have about the stockpile. Do we—and will we—have the ability to answer questions that we see arising in the future? You can't wait until a question arises to start working on it.

In terms of the readiness to resume testing, a lot of the

things that go on now at NNSS are exercising that system to some extent—there's more going on now than there has been in many years, so that helps give me confidence. (See p. 12 for more on subcritical experiments at NNSS.)

I'm not a weaponeer by training, but I'm quite confident with the technical content. I am learning the specifics of Los Alamos' stockpile responsibilities. We've got a great team. Even though the letter gets signed by the Lab director, it's really the culmination of a very large effort that draws on people across the Laboratory.

How do you see the Lab's relationship with the military?

In the end, it's the military that deploys the systems that we create and develop. They set the requirements that the NNSA has to deliver, using the labs and the plants. Los Alamos has a long history and tradition of working with the military to understand those requirements.

It's also noteworthy that we have a lot of former military on staff at the Lab—approximately 10 percent of our workforce. People who have served in the military see working at the Lab as a way to apply their military experiences and continue their national service.

What do you think is the biggest national security challenge of the future?

One of the challenges of the future is there's not a single well-defined national security challenge. China is being aggressive—and successful—in developing its scientific and technical capabilities. Technologically and economically, China probably is a more powerful player than Russia, although from a nuclear point of view, Russia obviously has a larger stockpile. Add to that the various wannabe nuclear powers and non-state actors, and there is no longer a single biggest

challenge that we can identify and organize around.

In the end, it's about understanding the world around us. What technological surprises are lurking in the future that will require some new kind of response that—being at the forefront of cutting-edge science and technology—we might be able to anticipate and position for?

If we have people who understand the physics and the chemistry and the biology and environmental science, that understanding allows us to take action. That's part of the reason we have a place like Los Alamos. ★



SCIENTISTS AND ENGINEERS
PIONEERING NEW TECHNOLOGY

FACES OF
INNOVATION



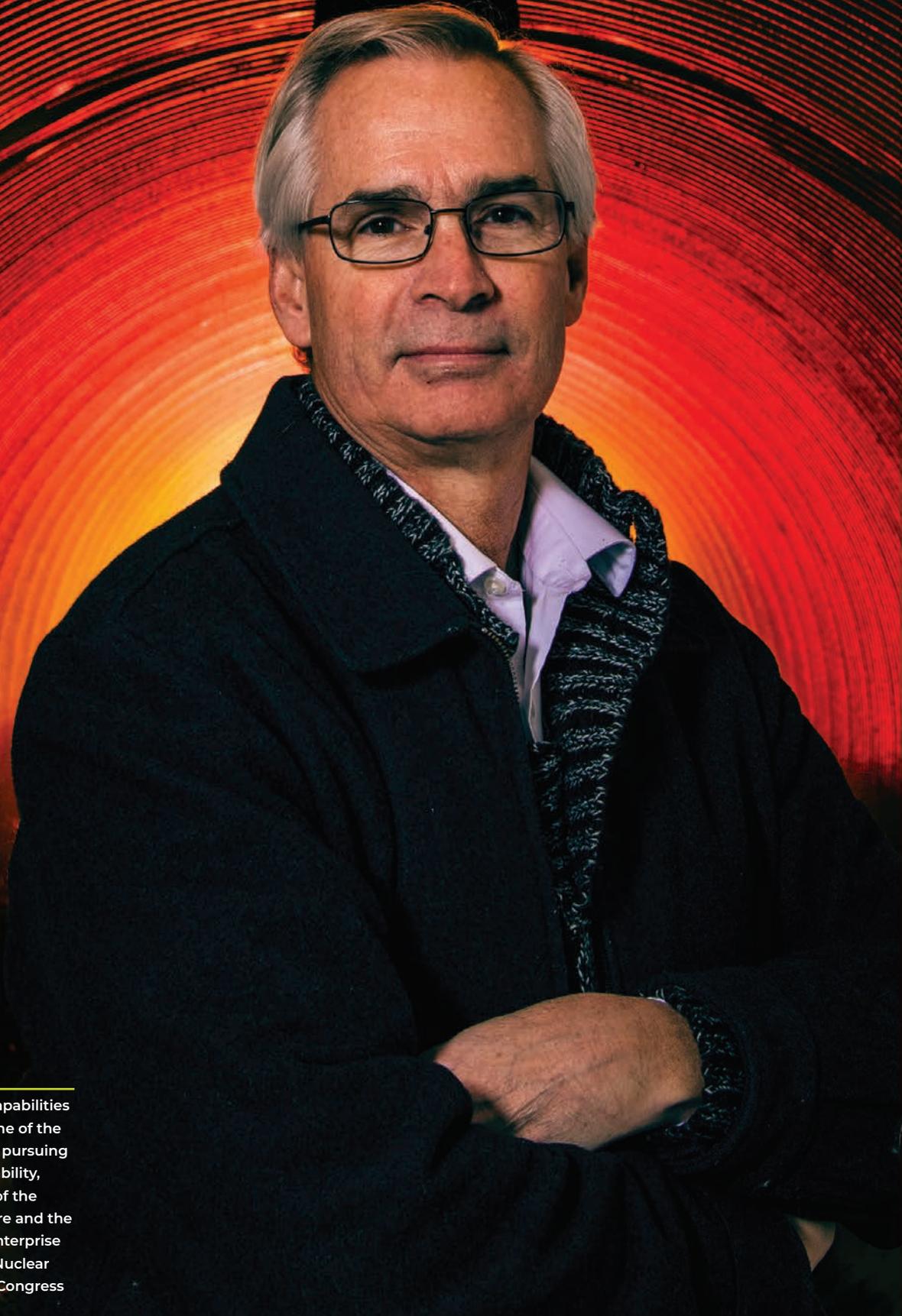
**BETTER SCIENCE =
BETTER SECURITY**

Scientists and engineers who think outside the box can address **national security challenges** in novel ways.

PHOTOGRAPHS BY MICHAEL PIERCE

INNOVATION





► Dave Funk leads Enhanced Capabilities for Subcritical Experiments, one of the initiatives the United States is pursuing “to ensure the necessary capability, capacity and responsiveness of the nuclear weapons infrastructure and the needed skills of the nuclear enterprise workforce,” according to the Nuclear Posture Review presented to Congress in 2018.

SENIOR PROJECT DIRECTOR DAVE FUNK

PLUTONIUM



Radiographic imaging for late-stage subcritical implosions

BY WHITNEY SPIVEY

Dave Funk has a complicated job. He leads a multi-lab effort to design and build a linear induction accelerator that can take x-rays (radiographs) of the late stages of implosion experiments at NNSS. Not only that, his team has to assemble the accelerator in a tunnel 960 feet underground.

Funk, of the Laboratory's Accelerator Development Program Office, is the senior director of the Advanced Sources and Detectors (ASD) Project, part of the Enhanced Capabilities for Subcritical Experiments (ECSE), a federally directed portfolio to enable studies of what happens to plutonium during the late stages of its implosion (compression) inside a nuclear weapon. Those studies will take the form of contained implosion experiments that include fissionable, or fissile, nuclear materials. Those materials, however, are not allowed to "go critical," so the experiments produce no nuclear yield. These noncritical experiments, called subcritical experiments, or subcrits, will be carried out in NNSS's U1a Complex, a subterranean laboratory.

Starting in the 1960s, U1a was used for underground nuclear tests, but those tests stopped with the 1992 moratorium on U.S. nuclear weapons testing and the advent of science-based stockpile stewardship—experiments and computer simulations that give scientists the confidence they need to ensure the safety, security, and effectiveness of

the nuclear weapons in the U.S. stockpile.

The accelerator for which Funk is responsible—Scorpius—will be located in a new U1a tunnel and will be a key ECSE diagnostic tool. The radiographs it takes will allow researchers to analyze exactly what's happening from the beginning to the end of each experimental implosion. Creating those radiographs requires a lot of high-energy x-rays, which is why the 20-megaelectronvolt (MeV) Scorpius is named after the brightest x-ray source, other than the sun, that is visible from Earth.

The ability to take radiographs of subcritical experiments is the biggest difference between Scorpius and the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at Los Alamos, which has been used since 2000 for hydrodynamic implosion experiments. These "hydros" get so hot that the imploded materials melt and flow like water. DARHT takes up to five high-speed radiographic images of a mock-nuclear device (it contains no fissile materials), capturing the images as the device implodes at speeds greater than 10,000 miles an hour. Data from the radiographs are compared with high-performance computing simulations that predict how well a real nuclear weapon will perform.

"While DARHT provides multiple high-quality radiographic images of the late-time implosion of weapons containing surrogate (nonfissile) materials, Scorpius

will provide, for the first time in the United States, the same radiographic imaging capabilities as DARHT, but on experiments that contain fissile materials such as plutonium,” explains Technical Director Mark Crawford, who oversees the development and implementation of the radiographic system.

Because Scorpius will radiograph subcritical implosion experiments containing plutonium, scientists hope to learn a lot about how this fissile material acts in the later stages of an implosion. Plutonium is

a key element in current U.S. nuclear weapons, some of which are more than 40 years old.

Does old plutonium behave like new plutonium?

“Scorpius will be used to help us learn more about aging plutonium,” explains Funk, noting that newfound knowledge will be coupled with data from past experiments and underground testing. “As we learn more, we’ll be able to make our weapons safer and more secure.”

Mining—aka drilling—the 420-foot-long tunnel for Scorpius is currently underway.

After the soil and rock are hauled up an 8-foot-square elevator shaft, the accelerator’s parts will be sent down the same shaft for assembly underground. Three-dimensional computer models are being used to work out the logistics of building a 300-plus-foot-long accelerator composed of an injector, 72 cells, a transport region, and an x-ray converter target.

Entombment drifts (tunnels) will also be mined. After each experiment, the six-foot spherical containment vessels in which the experiments occur will be “entombed”—placed at

the end of one of these tunnels and sealed off to isolate and contain the nuclear material.

“The biggest challenge for us in building Scorpius has been to develop the necessary accelerator architecture and technologies that will enable multi-image radiography in the very limited space of the underground tunnels where the experiments must occur,” Crawford explains. “We have strived to build on the technology base from DARHT wherever possible, but we will be using a novel solid-state (electronics) pulsed-power

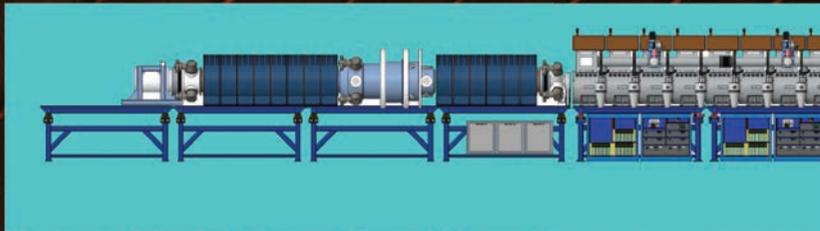
INFOGRAPHIC

SCORPIUS: A TEAM EFFORT ACROSS THE COMPLEX

The ASD Scorpius Team has broad experience on similar systems in the complex.



<p>Los Alamos NATIONAL LABORATORY EST. 1943</p> <p>PHERMEX</p>	<p>Los Alamos NATIONAL LABORATORY EST. 1943</p> <p>LAMPF LANSCE</p>	<p>Lawrence Livermore National Laboratory</p> <p>FXR</p>
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system developed by Lawrence Livermore National Laboratory.”

This innovative pulsed-power system allows for higher-quality images and the ability to take radiographs at very specific intervals. In this system, Scorpius generates high-energy electron pulses that are timed by the scientists and may be as close together as 200 nanoseconds (billionths of a second). Energy is added to the electrons as they travel the length of the accelerator. Near the end, magnets focus electrons onto a target that converts the electron pulses to x-rays. As the

x-rays go through the test device (the imploding subcritical experiment), they are converted to normal light in a scintillator. That light is recorded by a camera. (Of course, a camera that can capture four images as close together as 200 nanoseconds doesn't exist yet, but MIT Lincoln Labs is partnering with the Laboratory to change that.)

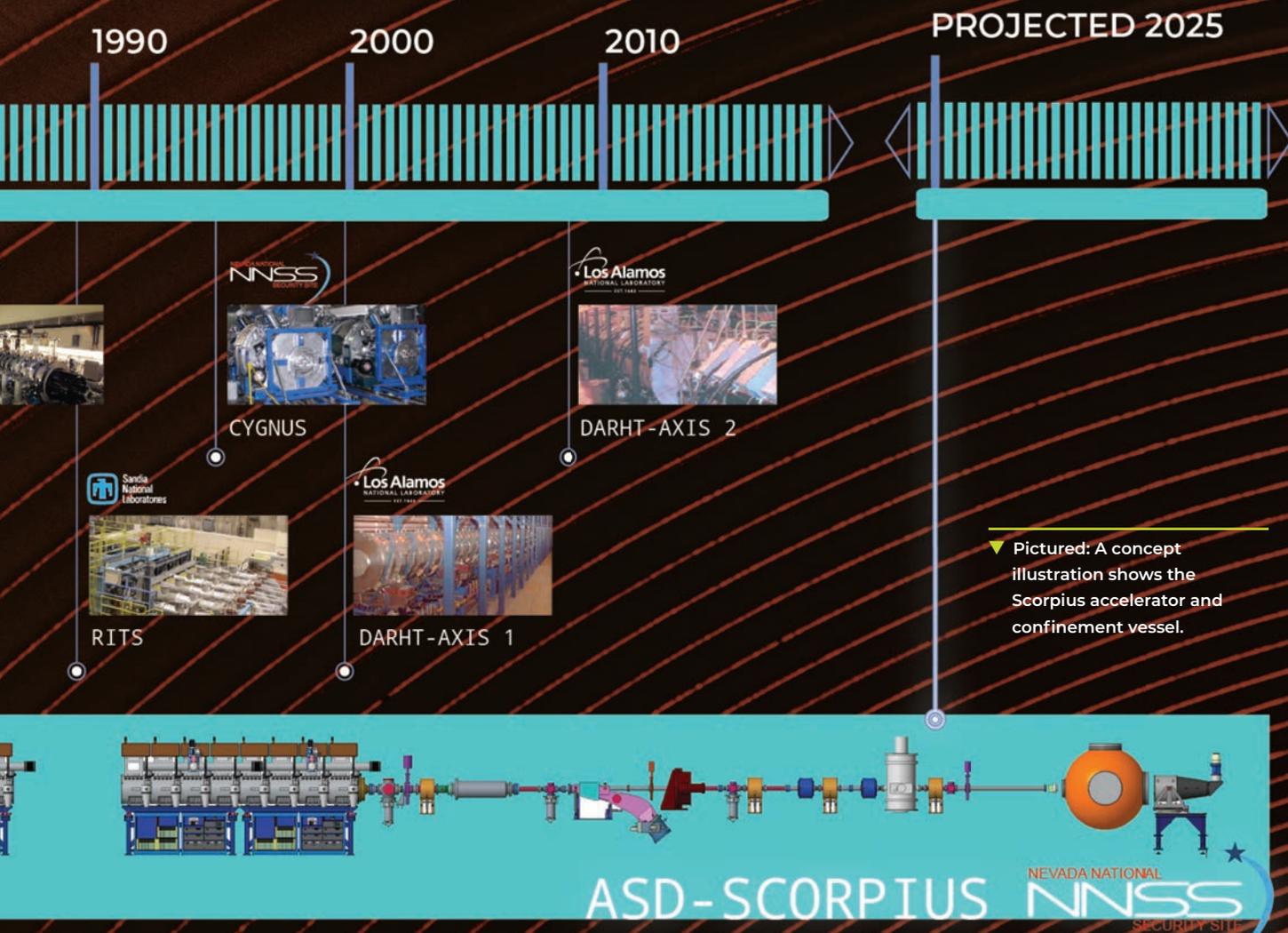
Scorpius is expected to be operating by 2025. Its first set of experiments will focus on the W80-4, a nuclear warhead currently going through a life extension program (LEP) that

will keep it in use in U.S. air-launched cruise missiles far into the future. Los Alamos designed the original W80 in 1976, and Lawrence Livermore National Laboratory is overseeing the LEP.

The multi-lab history of the W80 makes that warhead a fitting subject for tests at U1a. Scorpius, after all, is a multi-lab project. “This is a closely coordinated effort between Los Alamos, Livermore, Sandia, and NNSS,” Crawford says. “The coordination is necessary not only because of the broad range of technical skills required to bring the system to completion,

but also because no single site can provide the necessary number of people for the project while still meeting other institutional priorities.”

In addition, “with a planned lifetime of 30 years, Scorpius, with the capabilities it will bring to NNSS, will help us train the next generation of experimentalists and weapons designers across the entire DOE complex, ensuring the strength of our deterrent for decades to come,” Funk says. ★



▼ Pictured: A concept illustration shows the Scorpius accelerator and confinement vessel.

- ▶ Major funding for the PuLMo project is provided by the Defense Threat Reduction Agency. PuLMo is part of the larger ATHENA (Advanced Tissue-engineered Human Ectypal Network Analyzer) program to design an integrated, miniaturized surrogate human organ system that includes the heart, liver, and lung.



BIOLOGIST JENNIFER HARRIS

BIOSECURITY



Artificial lungs protect against threats on the battlefield and beyond

BY JUSTIN WARNER

Scientists rely on animal testing to show a new drug is safe for the public, but biological differences between humans and animals complicate the testing process. One such difference is simply the air animals and humans breathe. Mice, for example, scamper and sniff at ground level, so their lungs are adapted to life down low, often in filth. Humans walk upright, so their respiratory systems typically breathe higher, cleaner air. These differences mean that mice are imperfect analogs as test subjects for drugs meant for humans. In fact, drugs that have passed animal testing have even proven dangerous to humans.

The need to build a bridge between animal and human studies and effectively test new drugs with minimal risk motivates Jennifer Harris of Biosecurity and Public Health. Harris is one of the leaders of the bioengineering capability at Los Alamos National Laboratory. She specializes in creating laboratory-based artificial organs designed to be better preclinical test platforms than animals.

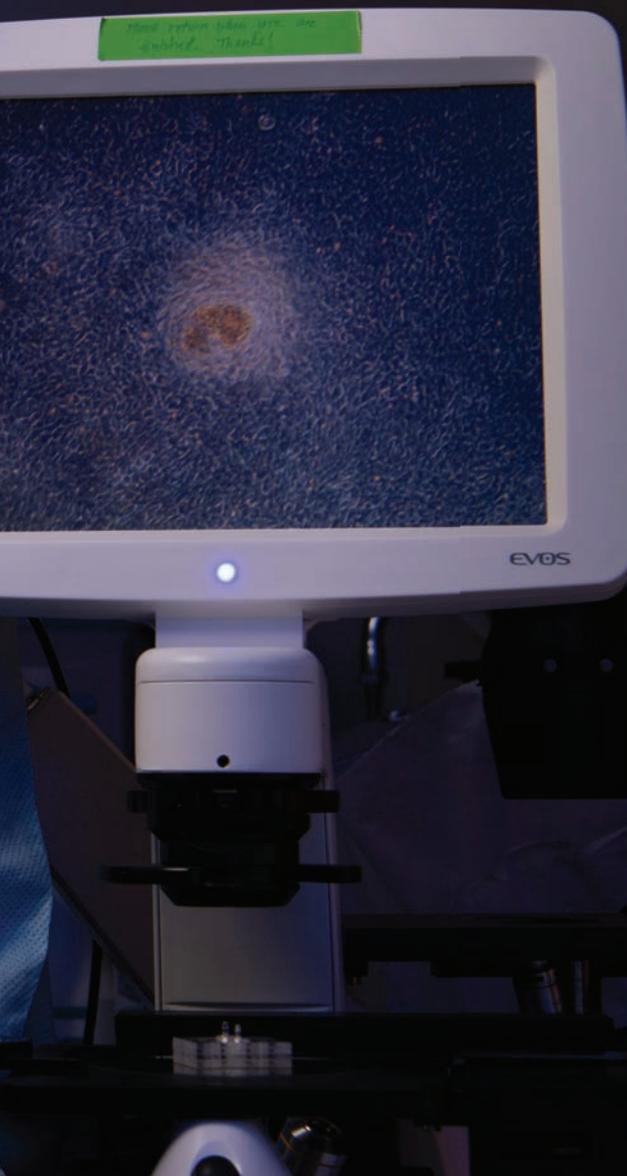
Harris' love is the lung, and her team won an R&D 100 Award in 2016 for its work on PuLMo, a miniature human lung model. PuLMo co-cultures many different types of lung cells and replicates the conditions in an actual human lung, even the mechanical stresses of breathing. A PuLMo unit resembles the human organ in cellular function but not in appearance; the model is rectangular, about the size of a shoebox, and features dozens of

modular components, including the system's life support system of valves, tubes, pumps, and reservoirs.

Along with their interest in pharmaceutical applications, bioengineers at Los Alamos are working to adapt the PuLMo technology to identify and counter biological, chemical, and radiological threats. Work is underway to make the technology deployable in two modes depending on the scenario and threat. In one mode, the technology is brought to bear on the battlefield in broad sweeps (such as in a flyover) to "inhale" large amounts of air and characterize potential airborne contaminants before soldiers are exposed to the environment. This grants warfighters critical intelligence about airborne threats and allows them to utilize proper protective gear to prevent human exposure.

In the second mode, the technology operates in a lightweight, wearable device that continuously monitors the air that a soldier breathes, scanning and analyzing potential contaminants. The device would provide immediate actionable intelligence in life-or-death situations, allowing medical personnel to prioritize treatment of soldiers on the battlefield and apply countermeasures.

"To see lung cells grow and perform like they're supposed to in PuLMo is amazing," Harris says. As the technology evolves, it promises to serve as a sentinel for respiratory safety anywhere it is deployed. ★



SUPERCOMPUTING SCIENTIST GARY GRIDER

SUPERCOMPUTING



New ThunderX2 processors boost efficiency in nuclear stockpile simulations

BY KATHARINE COGGESHALL

In the world of supercomputers, “fastest” traditionally equates to “best.” But Los Alamos’ High Performance Supercomputing Division leader, Gary Grider, is shaking up tradition.

Rather than continuing to aspire to the fastest computers, Grider chooses to focus the division’s efforts on computing efficiency, a more relevant and timely consideration for U.S. national security applications.

For decades, the TOP500 list—a notable world ranking of supercomputers by speed—was the gold standard for determining who could boast the top computer. Los Alamos played prominently in the competition, earning first-place rankings several times over. A computer’s speed is assessed by the number of rapid calculations, or floating point operations per second (flops), it can execute for every watt of electricity it uses. Known as flops per watt, that criterion has influenced the supercomputing industry, but that benchmark has become less relevant for mission-centric computing: simulating nuclear weapon performance as part of the national program for monitoring the health and reliability of the U.S. nuclear stockpile. For those simulations—the bread and butter of the Laboratory’s national security mission—Grider explains, “the target of flops per watt has led to inefficient use of supercomputers—think 1 percent efficient for our needs.”

Supercomputing has reached a fork in the road, with the TOP500 chasers speeding in one direction and the Grider

team focusing on extreme-scale computing environments that achieve higher efficiency. Grider’s team calls itself the Efficient Mission-Centric Computing Consortium (EMC3) and, in addition to the Laboratory, it includes Mellanox Technologies, DDN Storage, nCorium, and Marvell.

EMC3 recently brought Marvell’s new ThunderX2 ARM processors to Los Alamos. Rather than focusing on speed, the ThunderX2 answers the call for more-efficient extreme-scale weapons simulations.

The ThunderX2 offers high memory bandwidth and tolerance of complex problem solving that’s strategically targeted to Laboratory and EMC3 needs. In addition to its efficiency, the ThunderX2 was also rapidly deployable—weapons applications were moved quickly from previous processors. This was a result of careful planning and execution, both in the design of the processor and in the deployment strategy.

The ThunderX2 is the first in Grider’s planned family of more efficient processors. Marvell and the Lab are allying to create a variety of new architectural components (pieces of hardware and software) that will focus on higher-efficiency, more stockpile-valuable computing in the coming decade. ★



GEOPHYSICIST PHIL BLOM

INFRASOUND



Infrasound for missile tracking

BY WHITNEY SPIVEY

If a tree falls and no one hears it, does it make a sound? That's the question Phil Blom of the Lab's seismoacoustics team is researching...but with a national security twist. Blom wants to know if a missile launches or a nuclear device explodes or a supersonic aircraft flies by, and no one hears, do those things make sound?

The answer, of course, is yes (anything that moves air creates sound, which travels in waves), and Blom researches the details using atmospheric acoustics—the study of how sound waves propagate in the atmosphere—and infrasound—the study of sound waves with frequencies too low for humans to hear. What type of missile

launched? How big was the nuclear explosion? Where did that supersonic aircraft go?

"Infrasound waves travel large distances," Blom says. "But they're detectable 24/7 by microbarometer sensors on the earth's surface that inexpensively and precisely measure fluctuations in air pressure." A large area can be monitored without a dense network of sensors, and sensors don't have to be near the source (of a missile launch, for example) to acquire data.

Groups of microbarometers can detect the direction sound moves from its source. But doing that for a fast-moving source can be tricky, so Blom turns to atmospheric acoustic

modeling—predicting how acoustic energy spreads through the atmosphere. "We use modeling to better understand how infrasonic waves propagate from the source to the sensor; then we can learn where the infrasonic signal came from and what produced it," Blom says. "This potentially enables us to discern the type of missile, how it was launched, and its trajectory."

Because of infrasound's relatively slow propagation speed, Blom's research will likely never be a warning system for incoming missiles. Instead, it can be used to retroactively detect, track, and characterize missiles that have already launched. "We can help characterize missile performance," he says, "what occurred during launch, flight, and reentry." Infrasound also has increasing battlefield applications, such as tracking aircraft, localizing the source of gunfire, and detecting tunnels.

Combined with seismic, electromagnetic, or other

data types, "infrasonic signatures contribute to a more complete picture and improve our confidence in characterizing foreign weapons systems," Blom explains.

Blom hopes to use supercomputers to improve modeling and characterization. "The future will bring even finer characterizations of missiles and supersonic aircraft, as well as explosions and other phenomena," he says. "Infrasound is proving very useful for national security and nuclear nonproliferation." ★

► Phil Blom is the Laboratory's lead scientist for infrasound research. He is a co-organizer of the annual Infrasound & Missiles Workshop, held each April at the Missile and Space Intelligence Center in Alabama.



► “We’re less the cops and more the detectives,” Pickett says. “Cybersecurity investigation is like the *CSI* television series, but with less gore.”

COMPUTER SCIENTIST NEALE PICKETT

CYBER SECURITY



Defending against the dark art of computer hacking

BY CRISTINA OLDS

Neale Pickett is the literal poster boy for cybersecurity at Los Alamos. On a flyer advertising a lecture about “defending yourself from the dark forces of the internet,” Pickett was illustrated as a superhero in body armor, wielding a sword and shield, to represent his role as a champion cybercrime fighter.

Much of Pickett’s work focuses on cybercrime, which he describes as a “cheaper, more covert way to disrupt a government than previous types of espionage.”

Cybercrime is any criminal activity involving a computer or

the internet. For example, a bad guy might send phishing emails with an attachment carrying a virus that, if opened, infects computer software and even hardware. Or worse, the virus may allow the bad guy to access information on a computer or its servers.

Nefarious characters keep coming up with new challenges. Part of Pickett’s job is training the good guys to be ready for anything. For the 10th year, Cyber Fire, a cybersecurity training program Pickett developed, will teach students hands-on techniques for dealing with cyberattacks. In 2019, four

sessions of Cyber Fire courses will be held to meet increased training demands.

“We’re developing a sense of teamwork by bringing together students from national laboratories, the military, the aerospace industry, U.S. government agencies, and even other governments,” Pickett says. “The bad guys are working in concert, so the defenders need to work in concert as well.”

Pickett’s Cyber Fire course, “Network Archaeology,” teaches analysts how to dig up and decipher digital evidence. “In archaeology, you don’t have manuals, just artifacts. If people stumble across a CD 300 years from now, they may wonder what we did with this technology, and they’ll have to figure out how they can access its data. That’s what we’re doing now: teaching techniques for deciphering other languages.”

Pickett also teaches middle school and high school students, showing them how to systematically analyze a computer’s defenses and vulnerabilities and how to think like the hackers they need to defend against.

Cybersecurity requires fundamental information technology skills such as systems design and computer architecture, as well as an understanding of programming languages for writing and deciphering code. Creativity is also an essential skill. “Computer programming is an inherently creative endeavor,” Pickett explains. “At Cyber Fire, we’re giving people an environment where creative thinking yields results, often wildly different results from one student to the next.” ★

PHYSICIST KATIE MUSSACK



Using teamwork to solve difficult national security challenges

BY WHITNEY SPIVEY

In 1945, the U.S. Navy had a question: Could its ships survive a nuclear blast? It turned to Los Alamos, which provided an answer after the 1946 Crossroads test series in the Pacific. (See p. 49 for more about Crossroads.) In 2018, the Navy had another question—a classified one—this time about nuclear weapons. Once again, it turned to Los Alamos for an answer.

“To answer the question, we started brainstorming,” says physicist Katie Mussack, who partnered with colleagues Omar Wooten and Guillermo

Terrones on what she calls “thought experiments.”

“We started by talking about the physics at play and how we wanted to change the dynamics of the system in the question,” she explains. The trio discussed and went back and forth on new ideas. Then they independently investigated different parts of the problem before continuing their conversation. Eventually, they began doing computer simulations, with actual experiments to come later.

“Our initial goal was to show the Navy that we could

be responsive when asked a question,” Mussack says. “Then we came up with ideas that could actually work.”

Mussack’s mentor, celebrated weapons designer John Pedicini, provided behind-the-scenes guidance and encouragement. “He pushed us, but he did it out of love: love for us, the science, the product, the nation,” Mussack says. “His encouragement gave us the freedom to explore and trust ourselves while also questioning ourselves. We needed to think deeply about what we were doing.”

They also needed to talk about what they were doing—to bounce ideas off colleagues not directly involved in the problem. “The Lab is not just a collaborative environment. It’s a collaborative environment full of experts,” Mussack says.

“Everyone’s door is open, and people are excited to talk about their work and thoughts.”

Mussack is quick to point out that her team’s ability to answer a challenging question builds on not only this collaborative environment but also on decades of previous Laboratory research. “I looked back though historical documents and saw ideas that were similar to the ideas we were brainstorming,” she says. “I was able to use some of those ideas and develop them further to finally answer the Navy’s question.”

“Innovation is slow steady progress that builds to one thing that people notice,” she continues, noting that progress is often the result of failure. “You come up with an idea, try it, and if it doesn’t work, try something else.” ★

► “Be flexible with the way you approach a problem,” says physicist Katie Mussack, paraphrasing advice from her mentor John Pedicini. “Be tied to the outcomes and not to the specific details of the process.”





ACOUSTIC SCIENTIST CRISTIAN PANTEA

BOMB IMAGING



Seeing into bombs with sound

BY H. KRIS FRONZAK

When bomb squads are called to check out a potential bomb, they need answers to critical questions. Is the bomb a fake? If it's real, is it stable enough to be defused, or could it explode at any second?

A Los Alamos–invented acoustic imaging device, called ACCObeam, is being repurposed to remove much of that uncertainty. Using ACCObeam's sound waves, bomb techs of the future may be able to build 3D images of bombs without physically looking inside them. Cristian Pantea, an acoustic scientist who helped create ACCObeam, or the Acoustic Collimated Beam, is working with a team to refine this device so that bomb squads can get all the data they need to make life-saving decisions in only a few minutes.

"The data ACCObeam gives us doesn't provide all the answers, but it can at least show techs whether they're dealing with a dud, something that could explode momentarily, or something that can be defused slowly and carefully," Pantea says.

An early version of ACCObeam was invented years ago to assess the stability of gas and oil pipelines. The device emits a low-frequency, acoustic beam that's ultra-narrow (collimated). Users can assess the makeup of almost any material in any medium, such as water, rock, or metal, simply by changing frequencies and seeing how the sound waves penetrate or reflect off different objects. The end result is a 3D image with excellent resolution. In action,

ACCObeam can show objects' imperfections and densities and even distinguish between different materials.

For all its power and precision, ACCObeam is also tiny—smaller than a human pinky fingernail. The device's portable nature and great resolution gave its inventors the idea of using it to "see" inside bombs on location.

In practical terms, this kind of data could help guide bomb techs who often have to make an urgent choice: whether to defuse a suspected explosive on site or try to move it to a safe detonation zone.

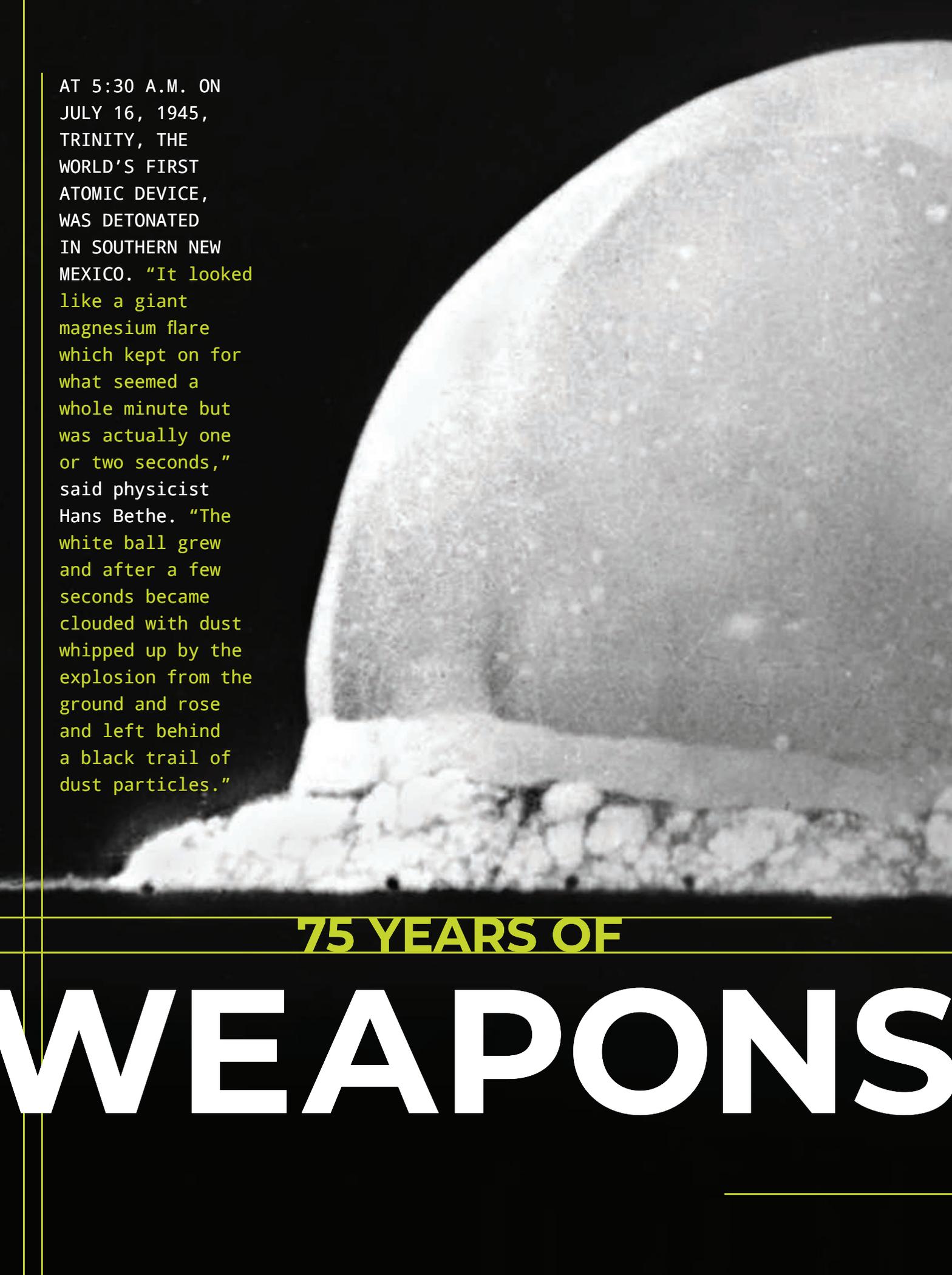
"Our goal is to make this device so precise and easy to use that bomb squads could get all the data they need to make life-saving decisions in 5–10 minutes from the time they approach," Pantea cautions that ACCObeam isn't ready for prime time yet. More work is being done to test how well the prototype can discriminate between types of explosives.

Depending on the outcome of that research, Pantea and his teammates at Los Alamos hope to license the device in about five years. For bomb squads and the many people they protect, the device would be lifesaving. ★

AT 5:30 A.M. ON
JULY 16, 1945,
TRINITY, THE
WORLD'S FIRST
ATOMIC DEVICE,
WAS DETONATED
IN SOUTHERN NEW
MEXICO. "It looked
like a giant
magnesium flare
which kept on for
what seemed a
whole minute but
was actually one
or two seconds,"
said physicist
Hans Bethe. "The
white ball grew
and after a few
seconds became
clouded with dust
whipped up by the
explosion from the
ground and rose
and left behind
a black trail of
dust particles."

75 YEARS OF

WEAPONS





**BETTER SCIENCE =
BETTER SECURITY**

As science advances, so do
America's **national security**
capabilities.



ADVANCES

In addition to creating the world's first nuclear device, Los Alamos has made nuclear weapons more effective, safe, and specific to military needs to support U.S. nuclear deterrence.

IN 1942, THE U.S. GOVERNMENT SELECTED LOS ALAMOS for Project Y of the top-secret Manhattan Project. Civilian and military men and women came to Los Alamos to solve a seemingly unsolvable problem: design and build an atomic fission bomb to end World War II.

On the morning of July 16, 1945, Manhattan Project scientists conducted a test that proved the feasibility of weaponizing energy from the atom. Trinity, as the test was known, was the detonation of the “Gadget”—the world’s first atomic device—near Alamogordo, New Mexico.

After the success of the Trinity test, two atomic bombs were sent to the Pacific for use in the war: Little Boy was dropped on Hiroshima on August 6, 1945, and Fat Man was dropped on Nagasaki three days later. World War II officially ended on September 2.

“It was a damn good thing

that the bomb was developed, that it was recognized as something important and new, and that it would have an effect on the course of history,” former Laboratory Director Robert Oppenheimer told *The New York Times Magazine* in 1965. **“In that world, in that war, it was the only thing to do.”**

In the decades since, Los Alamos has continued to pioneer weapons technology that is just as significant but perhaps not as well known as those first fission bombs. During the Cold War in particular, deterrence theory—the idea

that nuclear weapons deter attacks—became the dominant military strategy and drove the Laboratory to design and deliver increasingly more powerful and compact nuclear weapons for ever-improving delivery systems. With the development of these weapons came the responsibility to make them safer. Innovative science and engineering were—and still are—necessary in both the development and safety of these complex weapons.

Here’s a look at 10 Los Alamos-developed weapons advances that continue to impact America’s national security. ★

NUMBER ONE

Thermonuclear fusion and boosting



Fission bombs are the prerequisite for developing other types of nuclear weapons. Not long after the success of the Gadget, Fat Man, and Little Boy, scientists began learning to make even more powerful bombs using fission to initiate thermonuclear fusion, which occurs when atoms combine at high temperatures to produce tremendous amounts of energy—aka nuclear yield.

In April 1951, Los Alamos began the Greenhouse nuclear test series at Enewetok Atoll in the Pacific Ocean. The series consisted of four explosive experiments (called shots): Dog, Easy, George, and Item. George was the first experiment that produced thermonuclear fusion. With a 225-kiloton yield (the equivalent of 225,000 tons of TNT), George was the largest nuclear explosion up to that time.

“George was an important way station on the path to development of thermonuclear devices,” according to a 1951 report by the Defense Nuclear Agency. The report explained that George proved that a fission reaction could be used to start a sustained thermonuclear reaction, leading to the first test of a thermonuclear device in 1952.

On May 24, 1951, two weeks after George, the 45.5-kiloton test called Item was the first test of the principle of fusion “boosting”: the use of a thermonuclear fusion reaction to increase the rate of a fission reaction in order to boost efficiency and therefore, yield.

In 1956, the concept of hollow-boosted primary (first stage) designs was proved in Los Alamos’ Operation Teapot experiments. Hollow boosting used neutrons from the fusion of a gas mixture blown into a hollow core made of fissile materials, just before detonation to accelerate the chain reaction. ★



■ On May 8, 1951, George was the first experiment that produced thermonuclear fusion.

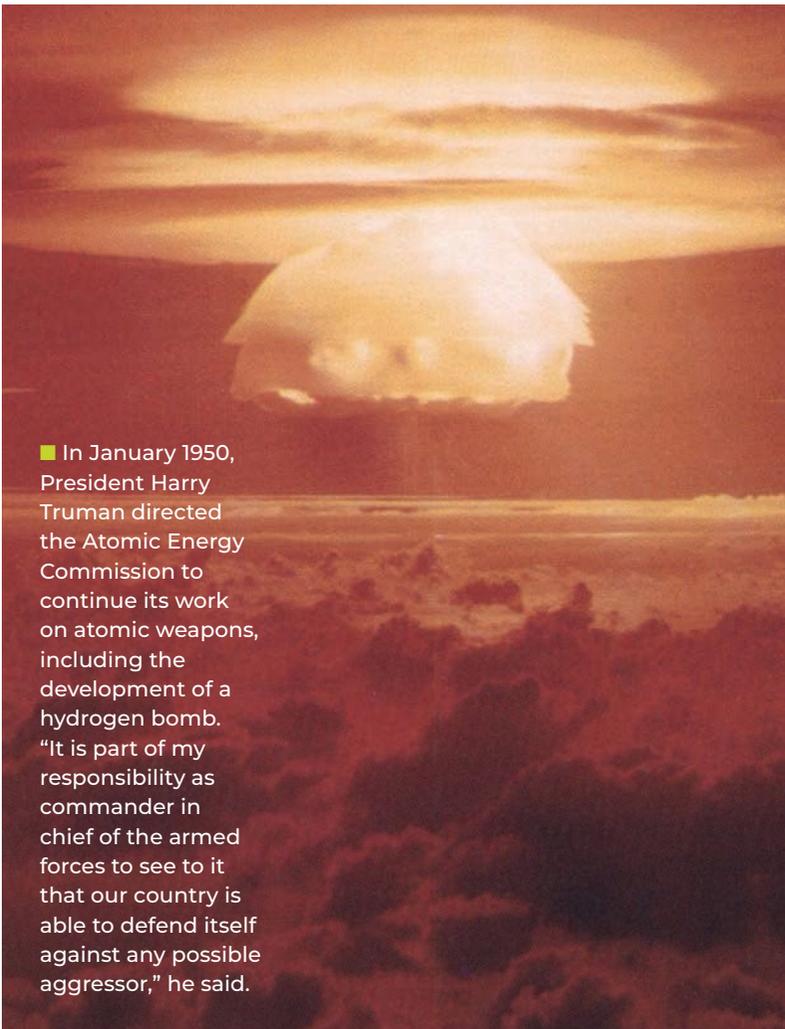
The hydrogen bomb



Thermonuclear weapons are colloquially called hydrogen bombs, or H-bombs, because they use the fusion of different forms (isotopes) of hydrogen. Using these isotopes—specifically deuterium and tritium—allows for yields in the megaton range. (A 1-megaton yield is the equivalent of 1 million tons of TNT.)

The **world's first megaton-class thermonuclear test was Mike**, a Los Alamos–designed test in the Ivy series at Enewetok Atoll on October 31, 1952. Mike was a two-stage test device that weighed 82 tons and used a fission bomb as the first, or primary, stage to initiate a thermonuclear-fueled secondary stage (the “Teller-Ulam” concept). The resulting 10.4-megaton test was, at that time, the highest-yield device ever exploded and created a crater 6,240 feet across and 164 feet deep.

In 1954, the Operation Castle series successfully **proved the U.S. could make a deliverable thermonuclear weapon.** “[The] Castle results can be described as sensational,” wrote Los Alamos weapons designer John Richter in his book, *Risk Versus Threat*. The two-stage designs tested in the Ivy and Castle series, together with the hollow-boosted primary designs, set the template for the subsequent U.S. stockpile. ★



■ In January 1950, President Harry Truman directed the Atomic Energy Commission to continue its work on atomic weapons, including the development of a hydrogen bomb. “It is part of my responsibility as commander in chief of the armed forces to see to it that our country is able to defend itself against any possible aggressor,” he said.



Battlefield nuclear weapons



Also called tactical or theater weapons, battlefield nuclear weapons are compact weapons designed to be used on the battlefield (to destroy 100 tanks, for example). In addition to designing nuclear bombs (dropped from planes) in the 1950s, Los Alamos designed nuclear missile warheads for the Army’s Honest John and Corporal short-range missiles and the Air Force’s Matador cruise missile. It also developed the Army’s 11-inch artillery-fired atomic projectile.

Battlefield nuclear weapons were a substantial part of the peak nuclear weapons stockpile levels during the Cold War. They **“changed the tactical calculus between the Soviet Union and the U.S. on the Eastern European front,”** says Jeremy Best of the Lab’s Office of Nuclear and Military Affairs. “Battlefield nuclear weapons were how we balanced the manpower and conventional force difference between us and the Soviet Union.” **Most of America’s battlefield nuclear weapons were either retired or dismantled after the Cold War.** ★

■ **Pictured:** Honest John battalions were deployed in Europe in early 1954.

One-point safety



The concept of one-point safety was developed in the mid-1950s after

physicist Harold Agnew, who would become the Laboratory's third director, visited an Air Force base. There, he saw how casually the airmen handled nuclear weapons and became alarmed about the possibility of an accident. He wondered if, for example, inadvertently dropping a weapon on the tarmac could produce a detonation with nuclear yield and, if so, how such a disaster could be prevented.

"It thus became a major design objective to assure that even when fissile and high-explosive components were fully assembled, there would be no nuclear yield if an accident resulted in detonation of the high explosive," wrote Los Alamos weapons designers Robert Thorn and Donald Westervelt in a 1987 report. "Since such a detonation might start at any single point on or in the explosive components, this design objective came to be known as 'one-point safety.'"

In the mid-to-late 1950s, multiple tests were devoted to studying one-point safety. The first of these was the Project 56 series in Nevada, followed quickly by the Project 58 series. After these two series, the one-point safety tests were integrated into many of the test series conducted at Nevada. One-point safety was a game-changer because it made the stockpile safer. ★

■ **Pictured:** One-point safety made transporting nuclear weapons—on planes such as this B-52 Stratofortress—safer because no nuclear yield would occur in the event of an accident.



One-point safety was a game changer because it made the stockpile safer.



■ When a B-52 crashed at Palomares, Spain, in 1966, the conventional explosives of a nuclear weapon detonated, but no nuclear yield occurred—due to modifications that were made as a result of the hydronuclear program.

NUMBER FIVE

Hydronuclear tests



When a nuclear testing moratorium went into effect on October 31, 1958, designers **“took advantage of the resulting opportunity to study in more detail the somewhat puzzling results of recent one-point safety tests,”** according to Thorn and Westervelt. “The safety behavior of a given design seemed to depend critically on the particular point at which detonation of the high explosive was initiated.” Because these designs could not be tested during the moratorium, Los Alamos developed a hydronuclear test program.

Hydronuclear tests are small-scale underground tests that use nuclear material and create fission but are engineered to generate no nuclear yield. These tests involve a combination of high explosive and fissile material (enriched uranium and/or plutonium) in quantities too low to generate a nuclear explosion.

Once the Atomic Energy Commission (the earliest predecessor of the Department of Energy) and President Eisenhower approved the hydronuclear test program, tests were conducted at Los Alamos rather than at the Nevada Test Site. Supposedly, this was so Los Alamos designers would not be tempted to create nuclear yield (because if they did, they risked contaminating the town in addition to violating the test moratorium).

The Laboratory’s first hydronuclear test was conducted on January 12, 1960, and after several series, “by April 1 the most urgent safety questions had been answered,” according to Thorn and Westervelt. “The hydronuclear experiments...made it possible to identify, and in some cases to resolve, otherwise

crippling safety issues.”

Ultimately, the tests generated the data needed to further study one-point safety while still fitting within the bounds of the test moratorium. They advanced the development of one-point safety design and engineering and improved the understanding of how much fissile material could be used in a pit and remain safe in almost any conceivable accident scenario. Located inside a weapon, the pit triggers nuclear fission when compressed by high explosives.

“The speed at which our scientists designed, built, and diagnosed the hydronuclear experiments was remarkable,” says Mark Chadwick, chief scientist and chief operating officer of the Laboratory’s Weapons Physics Directorate.

“These experiments allowed them to quickly identify and resolve safety concerns.” ★

Photo: Daniel Preston



NUMBER SIX

Plastic-bonded conventional high explosives

 High explosives trigger nuclear weapons that use an implosion process. By the early 1950s, **Los Alamos had developed the plastic-bonding process for conventional high explosives.** In a plastic-bonded explosive (PBX), explosive powder is bound together using a synthetic polymer, which allows the explosive to be formed into specific shapes. The PBX 9501 formulation, introduced in the 1960s, improved safety in handling and transportation scenarios, while maintaining performance and facilitating compact warhead designs. It allowed the Lab to retire the earlier, more sensitive (and less safe) PBX 9404 explosive. ★

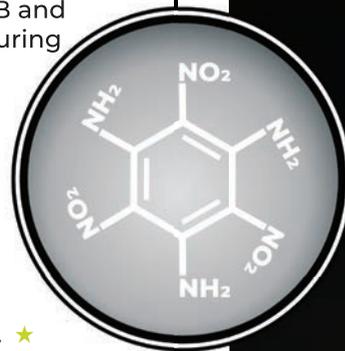
■ **Pictured:** PBX allowed scientists and engineers to adjust explosive properties to balance performance and safety.

NUMBER SEVEN

Insensitive high explosives



Los Alamos began researching insensitive high explosives in the 1950s, with the goal that no nuclear weapons would ever be unintentionally detonated. The Laboratory developed manufacturing and formulation methods for the explosive TATB (triaminotrinitrobenzene), a molecule that was first synthesized at Harvard University in the 19th century. TATB burns but does not explode when it's heated and does not react even when struck by bullets or shrapnel. Deliberately detonating this unique material requires a well-engineered initiation system. The Laboratory played a key role in refining TATB and patenting its manufacturing process. **Los Alamos also became the first national lab to use a TATB composition in stockpile nuclear weapons,** specifically in the B61 bomb, the W80 cruise missile, and the W85 Pershing II missile. ★



TATB is typically the main component of insensitive plastic-bonded explosives, including PBX 9502, an insensitive high explosive that the Lab produced for use in nuclear warheads. "PBX 9502 is uniquely suited for nuclear bombs," says Laboratory high-explosives expert Cary Skidmore.



■ A B-52 drops a B61 gravity bomb. Photo: U.S. Air Force



NUMBER EIGHT

ICBM and SLBM warheads

■ **Pictured:** An unarmed Minuteman III ICBM is test-launched from Vandenberg Air Force Base in California. Photo: U.S. Air Force



In the 1970s and '80s, Los Alamos designed the W76, W78, and W88 warheads to be used on intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs). A ballistic missile is rocket powered and is guided into outer space in a high, arching trajectory. It falls, unguided, with gravity until it reenters the Earth's atmosphere and descends to its target.

These powerful, small, accurate warheads can go anywhere in the world and are an essential component in deterring our adversaries. The warheads can be carried inside a multiple independently targetable reentry vehicle (MIRV) and can each be programmed to hit a different target.

These warheads remain the cornerstone of the U.S. deterrent—its stockpile of nuclear

weapons. Since 1979, Minuteman ICBMs have been armed with the W78 nuclear warhead. Ohio-class submarines can carry up to 24 Trident II D5 SLBM missiles, with each missile being capable of delivering up to 12 independently targetable W76 or eight W88 warheads with a range beyond 4,600 miles. ★

NUMBER NINE

Plutonium R&D and pit production



Early in its history, Los Alamos measured the critical mass of plutonium—the smallest amount of plutonium needed for a sustained nuclear chain reaction—and to this day, the Laboratory leads experimental and simulation work in nuclear criticality and criticality safety. Since 1943, Los Alamos has designed a variety of plutonium alloys and pit types to meet specific weapons requirements.

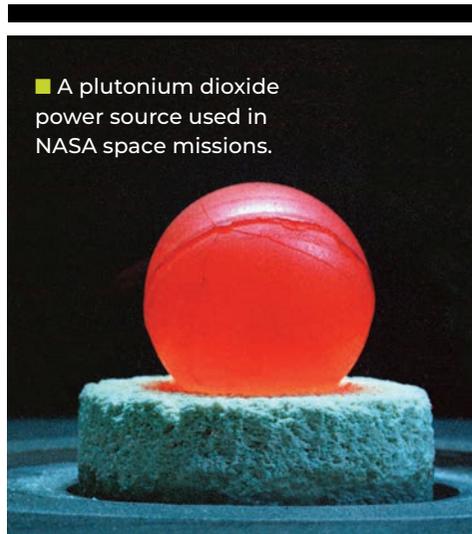
The Laboratory has the nation's only facility capable of handling large quantities of plutonium for manufacturing pits and power sources and for conducting basic R&D.

Plutonium pits are critical components of every nuclear warhead, but nearly all the pits in the current U.S. stockpile were produced from 1978 to 1989 at Colorado's Rocky Flats facility, before it was shut down. In the 2000s, Los Alamos demonstrated an ability to build war-reserve pits. A war-reserve pit is one that meets the engineering and physics standards for use in deployed nuclear weapons. In May 2018, the NNSA reconfirmed that Los Alamos will establish a safe, secure, reliable, and efficient capability to manufacture at least 30 war-reserve plutonium pits per year by 2026 (the Savannah River Site in South Carolina will develop the capability to manufacture 50 war-reserve pits per year by 2030).

"Make no mistake, Los Alamos is—and will remain—the nation's plutonium center of excellence," NNSA Administrator Lisa Gordon-Hagerty said during an April 2018 visit to Los Alamos. "The work that is done here is critical to our nation's nuclear security and central to our stockpile stewardship mission." ★



■ A worker uses a glovebox to handle plutonium.



■ A plutonium dioxide power source used in NASA space missions.

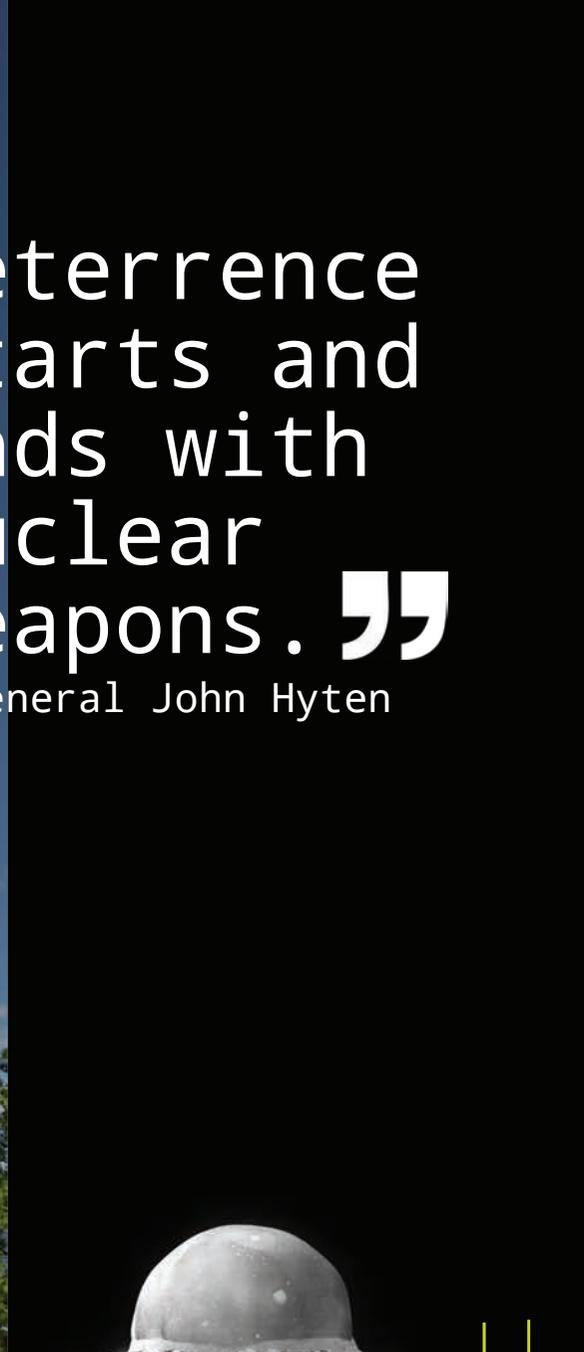
“Make no mistake, Los Alamos is—and will remain—the nation's plutonium center of excellence.”

—NNSA Administrator
Lisa Gordon-Hagerty

■ Science-based stockpile stewardship combines scientific and experimental capabilities (such as those at DARHT, pictured), with high-performance supercomputing simulations.



“Deterrence starts and ends with nuclear weapons.”
—General John Hyten



NUMBER TEN

The U.S. nuclear stockpile today

 Historically, of the 63 types of nuclear weapons entered into the U.S. stockpile, 46 were designed at Los Alamos. Of today's seven types of nuclear weapons, five are Los Alamos-designed: the B61 gravity bomb; the W80 cruise missile warhead; and the W76, W78, and W88 ballistic missile warheads.

Los Alamos continues to maintain the stockpiled variants of the B61, W76, W78, and W88 and is actively modernizing the W76, the W88, and the B61 to ensure that these nuclear weapons remain safe, secure, and reliable. Los Alamos is integral to ensuring a continued effective deterrent in the coming decades.

“What you do here is the most important work in the country,” General John Hyten, commander of U.S. Strategic Command (STRATCOM), told Laboratory employees during a visit last year. **“Deterrence starts and ends with nuclear weapons.”** ★

This article was inspired by a list compiled by Mark Chadwick and Michael Bernardin. Chadwick and Bernardin are the chief scientist/chief operating officer and the associate Laboratory director, respectively, of the Laboratory's Weapons Physics Directorate.



► This pressure vessel was built by layering metal powder—a process called additive manufacturing.

At the Laboratory's Sigma Complex, metal components are created with powder, layer by layer, to withstand extreme environments.

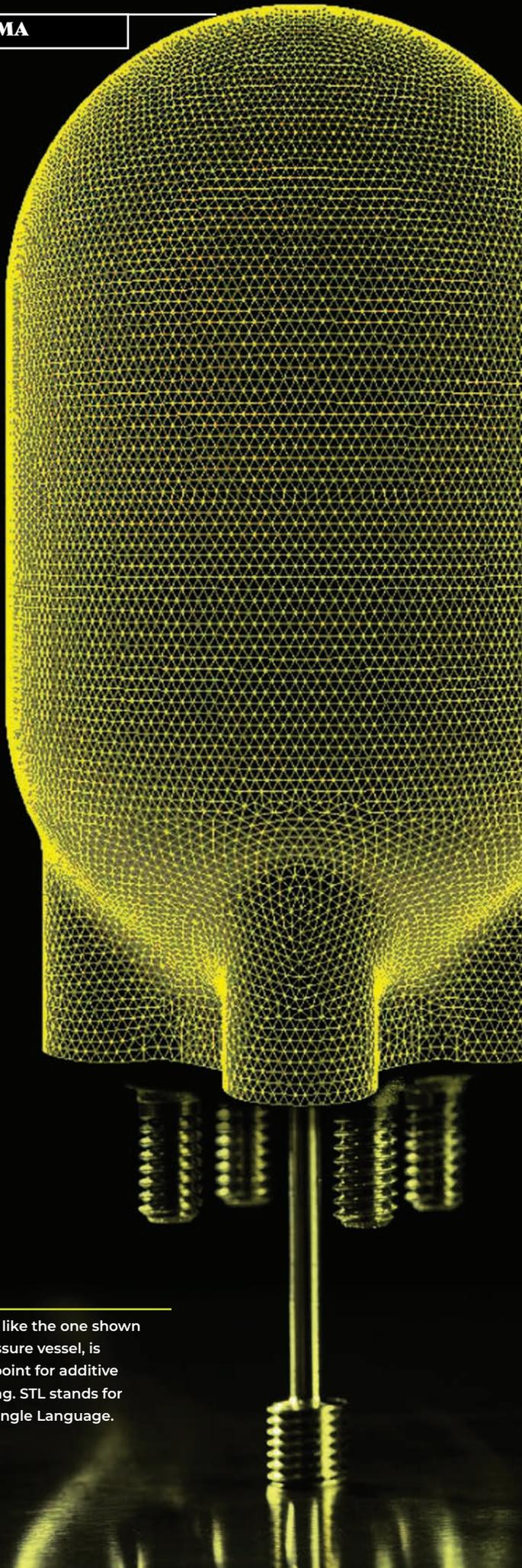


**BETTER SCIENCE =
BETTER SECURITY**

Innovative manufacturing techniques may result in higher-quality, safer, and less-expensive parts for nuclear weapons.

ADDITIVE MANUFACTURING: THE POWER OF POWDER

BY KATHARINE COGGESHALL



► A 3D STL file, like the one shown here of a pressure vessel, is the starting point for additive manufacturing. STL stands for Standard Triangle Language.

IN THE SIGMA COMPLEX at Los Alamos National Laboratory, John Carpenter—a materials scientist—sits quietly at his desk analyzing his latest data. Colorful line graphs and black-and-white images fill his computer screen. The glow of the images pulls him forward to investigate more closely, and he smiles at the success these data imply.

Since 2015, Carpenter has been a lead scientist for the NNSA-funded Pressure Vessel Project. Working with researchers at Sandia National Laboratories, Savannah River National Laboratory, Lawrence Livermore National Laboratory, and Kansas City National Security Campus, Carpenter guides this inter-laboratory collaboration.

This project is the first of its kind because it circumnavigates the linear “process leads to product” methodology to instead work with a chicken-or-egg scenario: What comes first, the manufacturing process or the product? For Carpenter, the answer is both. The initial process leads to a product, which is then analyzed to determine how that process can be improved, which leads to a better product, and so on. This is what Carpenter and the NNSA have termed science-based qualification, and it is at the crux of the Pressure Vessel Project’s purpose: Use the scientific method to prove, step by step, that a process known as additive manufacturing (AM) is suitable for building metal components.

“We are pioneering the pathway for additive manufacturing,” Carpenter explains, “and once this pathway is established for the pressure vessel, other metal components can be built.”

The point of the pressure vessel

The pressure vessel these scientists are making is a humble component no bigger than an average person’s palm. Made from stainless steel powder, its simple egg-like structure belies this component’s importance for national security—it is the model by which science-based qualification will be used to determine whether AM can reliably manufacture and repair metal components that are faced with extreme environmental conditions and are relevant to national security.

In particular, component repair is important for the aging U.S. nuclear stockpile. Over time, stockpile components suffer from age and need to be repaired or replaced, but often the knowledge and equipment for manufacturing those

components have disappeared with time. People retire, machines break, and life moves on, which is why scientists such as Carpenter are exploring AM as the technology for filling in the gaps.

The AM process produces real-world products from powdered materials such as metals, polymers, and ceramics. AM is similar to 3D printing but with two key differences: the scale and the materials. In terms of scale, 3D printing is at one end (for everyday consumers) and AM is far at the other (industrial). The materials can be far more exotic in AM, and AM can build products that are far more useful as compared with 3D printing. For weapons, AM provides an alternative way to build, repair, or refurbish critical components.

Carpenter's team is materializing a small army of pressure vessels from metal powder, with each new vessel slightly better than the one before. The army will continue to grow until NNSA requirements have been met and characteristics such as material strength and ductility, burst pressure, resistance to leakage, and performance in extreme environments are assessed.

The data from this latest pressure vessel are what splash Carpenter's screen with color. Coming full circle—process to product and back to process again—these new data put proof behind the science-based qualification method.

Where additive manufacturing fits in

Different from traditional forms of manufacturing, such as molding and casting, AM is a solution for building uniquely challenging components, such as components with complex architectures. For example, nature's intricately fashioned honeycomb is a structure that cannot be realized by traditional machining methods but can easily come to life using AM. This is one niche that AM can serve without completely replacing other manufacturing

methods. "Additive manufacturing is not going to replace traditional machining, but it allows for the expansion of capabilities," says Colt Montgomery, an AM postdoc at Sigma.

As of yet, there is no certification process for AM, but in the opinion of Michael Brand (an AM engineer at Sigma who has played a role in developing the technique from its beginning), a certification process is needed for the future. This is because the success of the technique is still somewhat dependent on the skill and experience of the operator and because AM technology changes rapidly over short amounts of time. "It has blown my mind how far additive manufacturing has gone in the five years since I started," Brand says.

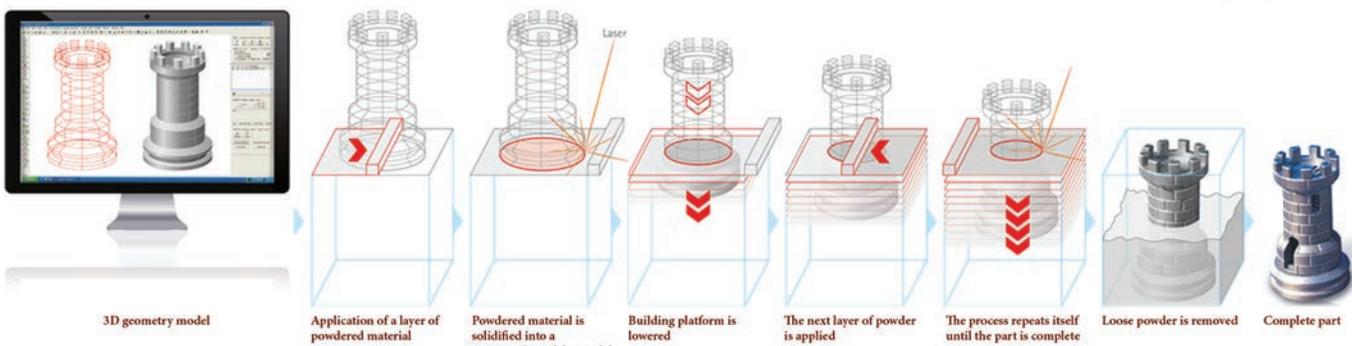
How additive manufacturing works

Essentially, AM takes a 2D drawing and brings it to life as a 3D component. Computer software takes the first step in initiating this process by modeling a drawing out of tiny triangles. These triangles spread over the drawing to form a net-like 3D image—an STL file. From there, the file can be customized to add labels to the 3D component, insert holes, or delete portions.

The STL file encompasses all of the program instruction details required to physically build the component, but first the file must be sliced. For powder-bed AM (the type used in the Pressure Vessel Project), slicing software cuts the STL file into 40-micrometer horizontal layers; this is the thickness each physical layer will possess. Note that the diameter of a human hair is 60 micrometers and a single micrometer is a millionth of a meter, so these AM slices are quite thin. The sliced file is fed by a computer to the AM machine, communicating how to actually build the pressure vessel layer by layer.

In the Sigma Complex, the AM shop houses a single computer atop a modest desk, which

▼ During the additive manufacturing process, digital 3D design data is used to build up a component in layers by depositing metal powder.
Illustration: EOS North America



is in stark contrast to the considerable AM machine that dominates the middle of the room. The rectangular 14-foot-long by 8-feet-tall by 5-feet-deep machine offers only a small window for viewing the “build” chamber, which is equipped with four infrared lasers. Brand explains that four lasers as compared to the traditional one laser reduces the component build time substantially (which is still on the order of 80–100 hours).

Carpenter’s AM team uses stainless steel powder between 20 and 60 micrometers in particle size, adding it to the argon-filled AM chamber one layer of powder at a time. Stainless steel is the material of choice for this project because it is relatively inexpensive, readily available, easy to work with, and well-characterized in terms of properties for non-AM applications. This allows Carpenter’s team to focus on the process variables at play rather than being surprised by an unexpected result due to a lesser-understood material.

Inside the argon-filled AM chamber, the first layer of stainless steel powder is spread on a build plate. The sliced STL file tells the laser where to strike in order to melt w powder together, according to what is needed for that layer of the pressure vessel. To an observer, the laser is invisible, until it strikes the metal and a bright spark of light appears. Not all of the powder in a given layer is melted, some remains loose.

Before another layer of powder is added on top of the first, the build plate moves down

For weapons, additive manufacturing provides an alternative way to build, repair, or refurbish critical components.

40 micrometers (equal to the thickness of the layer that will be added). The pressure vessel is built from the bottom up and is constantly lowering deeper into the chamber below. After 4,000–5,000 layers, the finished component is below the starting place of the first layer and buried within the excess loose powder that wasn’t melted by the laser. Like an archaeologist excavating a bone, the component is carefully removed from the chamber using a vacuum and brushes.

Much of that excess powder can be recycled for the next build. Careful post-processing of the excess powder removes any particles that have been sintered (or glued) together because these particles would be difficult to spread while building the next pressure vessel.

The process-product feedback loop

At the crux of the Pressure Vessel Project is the desire to link the AM process variables to the final performance of the component (or the product), which leads to informed decisions on how to tweak the process in order to make a better product.

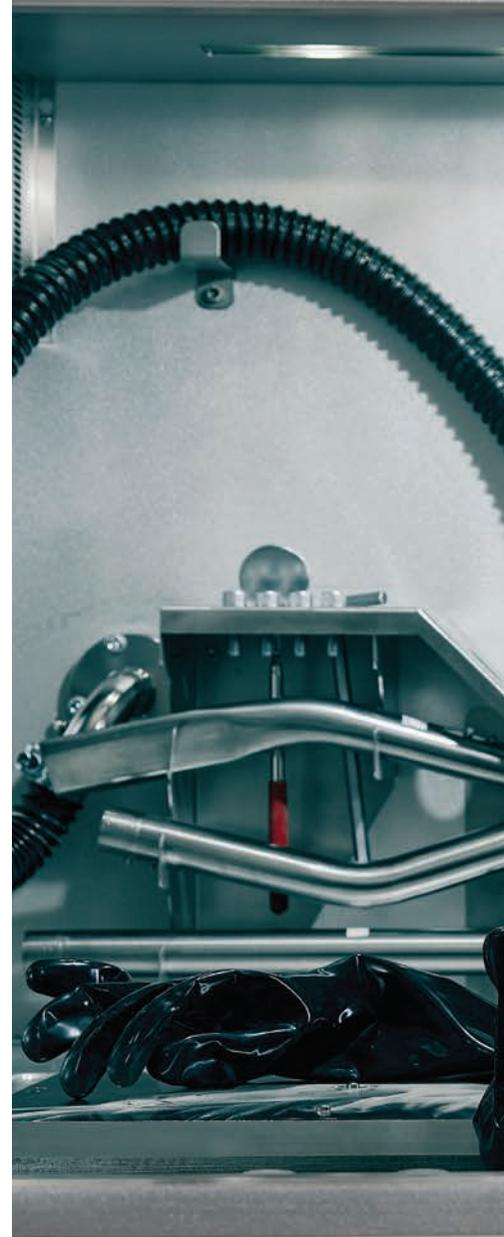
In the world of science, form is related to function. For example, a fish is equipped with fins to help it swim, and lung cells are quite thin to allow gas transfer for breathing. On any scale, form couples with function. In a pressure vessel, its form on a microscale is coupled with its function (performance).

The pressure vessel’s microstructure is predictive of certain properties, such as strength and toughness. So, when Sigma scientists and engineers identify a specific microstructure (called characterizing) in a pressure vessel, they are able to associate a list of predictable properties that go with it. They can tweak the process variables in order to tweak the microstructure, which results in a change in performance. This is science-based qualification, and it gives the

scientists greater control over the product. Science-based qualification is not a guess-and-check process; rather, it is a fundamentally different way of qualifying components. By linking structure to properties, a component can be qualified based on whether it has the right microstructure, regardless of the synthesis or production route.

However, AM is a unique form of manufacturing and produces microstructures that are considerably different from what would be seen if casting or forming methods were used. Everything scientists know about how microstructure from those latter methods relates to performance must be tossed out when considering AM, and new form-function links must be forged. “This necessitates creating new linkages between microstructure and properties,” Carpenter says, “and this is one of the reasons this project is so important.”

► Materials scientist John Carpenter is confident in the additive manufacturing pathway being forged by science-based qualification.



Sigma: a manufacturing powerhouse

The Sigma Complex was the obvious choice to headquarter the Pressure Vessel Project because Sigma houses many of the world's top manufacturing and metallurgical scientists under one roof. Working elbow-to-elbow, these experts can put their heads together at a moment's notice and offer instant feedback on the project.

Carpenter took advantage of this perk when one of the machines used in the Pressure Vessel Project went down. Between the resources at Sigma (both people and equipment) and the rapid learning from science-based qualification, Carpenter's team was able to continue to make headway. "We did have machines go down over the course of the project," Carpenter explains. "Our efforts in science-based qualification smoothed over this speedbump rather than causing us to start over."

A substitute for the downed machine was put in place and produced quality pressure vessels. This highlights the importance of science-based qualification—understanding why a process works and how it produces a component with specific performance characteristics unchains the scientists from having to always replicate the same process on the same machines. In real life, things break while deadlines still

loom. Carpenter's team members showed their newly learned links between microstructure and properties allowed them to change their process while still producing a pressure vessel of predictable performance. The applications of this strategy are far-reaching.

"It has blown my mind how far additive manufacturing has gone in the five years since I started."

—MICHAEL BRAND

Jumping on the bandwagon

Scientists and engineers at Sandia, Savannah River, Lawrence Livermore, and Kansas City collaborate with the folks at Los Alamos on the Pressure Vessel Project. It is clear there is more to this project than meets the eye; the applications of AM and the science-based qualification process entice researchers from all walks of life.

With this level of inter-laboratory collaboration came the need for a biannual technical exchange, so everyone can be kept up to speed



and contribute to the project in a timely and useful manner. Twice a year, everyone gathers in one location to hash out the latest data and analyses and contribute their ideas for reaching the NNSA objectives.

Altogether, there are seven deliverable categories for the AM project: vessel design, a qualification plan, AM building, material and processing assurance, modeling and simulation, inspection and metrology, and characterization/performance/function testing.

These categories are discussed both independently and as they relate to each other. For instance, the vessel design and AM building teams ensure that what is designed is buildable and what is buildable will meet the prescribed requirements.

The five institutions will continue to collaborate as the Pressure Vessel Project reaches a critical turning point—a change in focus from meeting NNSA performance objectives to scaling up and perfecting the process in order to build other components.

The future of AM

Three years of hard work have led to the successful data on Carpenter's computer screen (which proves the NNSA objectives have been met), but the Pressure Vessel Project is far from

complete. Now that the initial process has been determined through science-based qualification, the next phase of the project will focus on scaling up and transitioning AM to programs.

All eyes will be on the technology readiness level (TRL), a numerical estimation of the technology's maturity. The scale is from 1 to 9, with 9 being the most mature. The pressure vessel is considered to be at a TRL level of 3 right now, with the hopes that it will be at a TRL level of 5 by the year 2020. Most programs require a TRL level of 5 (along with a possible pathway to TRL level of 9) before adopting a process.

Thanks to the science-based qualification method, the scale-up for AM is expected to be straightforward, as compared to more traditional manufacturing techniques. Scale-up inherently causes changes in a manufacturing process, which can cause unexpected problems, but Carpenter is already well-versed in overcoming these challenges.

Carpenter and his team view the future of AM as very bright, with many collaborations expected in the coming years. Innovations in the AM materials used, the components produced, and streamlining the process as well as the characterization are all anticipated. Along with powder-bed AM, other types of AM will be investigated, and modeling and simulation tools will be developed to further enable science-based qualification.

Not only is the Pressure Vessel Project pertinent to national security, particularly as it relates to

the aging stockpile, but AM is also predicted to replace older, less-efficient manufacturing techniques. AM is expected to be a "greener," more sustainable technique that will reduce the production footprint as well as the cost of fabrication within the NNSA plants (as compared to other manufacturing methods).

Carpenter's team is cognizant of its position on the frontlines of AM development. "We're in an exciting area," Montgomery says, "we're seeing the innovation take place." His team is also aware that staying ahead of AM innovations is important for national security, as other countries are beginning to adopt this technology. No others, however, are as adept at science-based qualification as the researchers at Sigma and their collaborators at the four other national laboratories. ★

► A partially manufactured pressure vessel.

At the Sigma Complex, a part is heated in preparation to be formed by a press.

INSIDE THE SIGMA COMPLEX

At Los Alamos, material design, manufacturing, and testing is all under one roof. Since the late 1950s, Sigma's mission has been to make products (for weapons or otherwise) efficiently, predict a product's functionality, and guarantee a product's quality. These products are not only complicated—structurally and materially complex—but also essential to national and global security. Sigma products can be found in nuclear warheads, in outer space, and in models that predict material aging driven by radiation and heat.



Creating alloys

(mixtures of metals), such as Nambé, a lustrous silver-looking alloy of eight metals that was adopted by dishware artisans because of its resistance to tarnish and chipping. Additionally, depleted U6Nb is a mixture of depleted uranium and niobium that can be cast into weapon parts and used for radiation shielding



Contributing to the field of radio pharmacy

by developing thorium targets that recover radium isotopes for cancer treatment and creating SHINE, a system that diagnoses a multitude of diseases, such as cancer and heart disease, through the use of the molybdenum-99 isotope



Building components for space

, such as those in Cassini (a robotic spacecraft sent to study Saturn) and the A-10 Warthog (a U.S. military fighter plane). Sigma has also produced uranium-impregnated graphite fuel components for the Rover II and Mars Rover



Studying the simulation of oil and natural gas

in deep geological reserves as well as crack formation and seismic wave propagation via a 5,000-ton high-pressure press, called the Sigma Press



Developing a series of four reactors

(Kiwi, Phoebus, Peewee-1, and Nuclear Furnace-1) to understand the principles needed to create a nuclear-powered rocket (Project Rover)



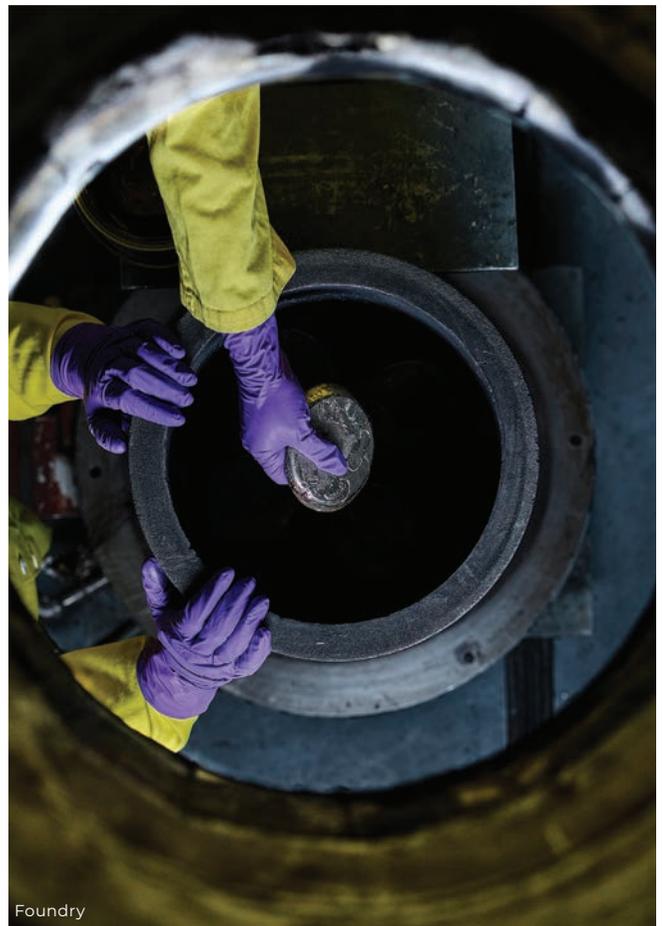
The Sigma Complex consists of seven shops

These shops work separately or together to create solutions for their clients.

- Foundry and Solidification Science
- Deformation Processing
- Powder Materials Processing (includes Additive Manufacturing)
- Machining and Inspection
- Electrochemistry and Corrosion
- Welding and Joining
- Characterization and Special Projects



Machining and Inspection



Foundry



Processing beryllium and radioactive parts and manufacturing custom uranium components for stockpile stewardship experiments



Supporting the Lab's Weapons program. For example, Sigma produces critical components of the test devices used at the Dual-Axis Radiographic Hydrodynamic Test facility

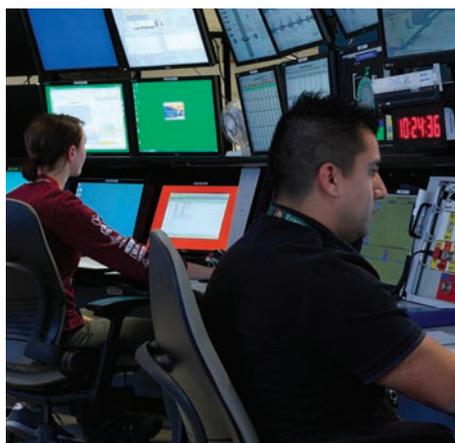
The Science of Policy

Three NNSA officials—who used to work at Los Alamos—share their thoughts on innovation and an ever-evolving stockpile.

AS TOLD TO WHITNEY SPIVEY

Kathleen Alexander

Assistant Deputy Administrator for Research, Development, Test, and Evaluation in NNSA's Office of Defense Programs



I oversee what is traditionally viewed as the science-based stockpile stewardship portfolio—theoretical, analytical, experimental, and computational capabilities. The organization also oversees all of our academic programs, as well as Laboratory Directed Research and Development, which is where a lot of innovation actually originates.

While providing oversight for our academic programs, I take the opportunity to speak with students about how compelling our mission is. I also emphasize that working on our mission requires a “we” perspective because we work in teams to

We still have to make sure staff members receive sufficiently challenging experiences so that they are prepared for the future. Additionally, it is important that we allow staff to take risks and recognize that when you allow for that risk taking, sometimes the good results don't happen immediately.

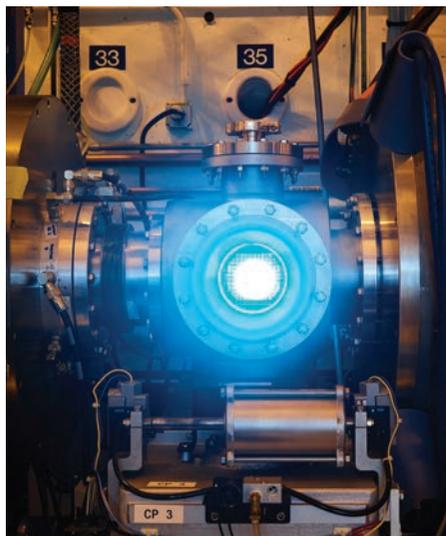
We don't want to be so success oriented that we start designing experiments to confirm what we already know. I often say to team members, “**Tell me the experiment that might prove you're wrong—and do it.**”

In our experiments, we often require very fast diagnostics with high resolution to obtain the information we need. We've learned a lot from the hydrodynamic test facilities at the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at Los Alamos National Laboratory and Flash X-ray Induction Linear Accelerator (FXR) at Lawrence Livermore National Laboratory. The time is right to apply that knowledge to the subcritical experiment program using state-of-the-art diagnostics at the NNSS (see p. 12). **Subcritical experiments are a key tool in our toolkit**, and it's very important to collect as much information as we can from these experiments.

You can see and feel the enthusiasm and energy of the Nevada and laboratory workforces when they're performing subcritical experiments and especially when they're implementing new diagnostics. It's all about the data and results—that is what energizes the workforce. ★

■ **Pictured:** Facilities such as DARHT provide data that increases scientists' confidence in the weapons in the U.S. nuclear stockpile.

“It's all about the data and results—that is what energizes the workforce.”



contribute to the security of the nation.

We've been doing science-based stewardship for well over 20 years now. Materials continue to age while threats continue to surface and evolve. **We must remain prepared to respond to new technical challenges and surprises.** The questions we need to answer grow more challenging. Yet, we must continue to be responsive, agile, and resilient. We have to think outside our current set of acquisition programs so that we can challenge people beyond their current knowledge base.

In the past, our designers and engineers conducted a certain number of experiments as part of the journey to becoming experts. So how do we create experts in an era in which we're not doing as many experiments?

Mark Anderson

Director for the Office of Advanced Simulation and Computing and Institutional R&D



I run the advanced simulation and computing program at NNSA. Advanced simulation and computing is a major federal program that pushes the boundaries of computing and has been doing that since the beginning of stockpile stewardship.

Advanced simulation and computing has been at the forefront of high-performance computing R&D for over two decades since the first teraflop computer at Sandia and the first petaflop computer—Roadrunner—at Los Alamos, and we're going to put an exaflop computer at Livermore in 2023. So we have gone up by six orders of magnitude in computing power, a million times. That's a big jump in two decades.

After 20 years we are reevaluating what it means to be a leader in this field. We've been chasing the flops—floating point operations per second—ever since the beginning, with good reason. The laboratories and the designers initially thought that we could handle stockpile stewardship by higher-resolution calculations of weapons. We got to a point where we could do those higher-resolution calculations and we realized that at these higher resolutions, we need better physics. Whenever we reach a new

threshold in computing power, we uncover new science issues that need to be resolved.

We're not able to increase the density of transistors on a chip at the rate we were anymore. And so we're looking at other methods of enhancing performance that may translate into more flops and may not. NNSA needs to pursue efficiency over flops from here on out.

The communication angle is actually extremely important. Any hint of science in a conversation can put certain people off, even if it's necessary to truly answer the question. So it makes it a real challenge to communicate in terms that your audience can understand or is willing to accept.

It's easier to work with the laboratories if they respect your background a little bit. I can participate in the discussions about how to solve problems in a way that federal program managers who don't have that background cannot. Policy sets constraints, but being able to argue the value proposition pro or con is really important, and that means understanding the technical issues.

Anybody who has a technical background understands that you cannot demonstrate weapons are going

to work without testing them. The question is: Can you build up a body of evidence that's convincing and compelling enough that you do not need to test? That's the Holy Grail we've been chasing for the past 25 years almost.

Originally, stockpile stewardship was this: We're not going to change anything. We're going to keep the weapons we have and just make sure they're good. Then we started to realize, well, good forever? What does that mean? You start trying to refresh these weapons so they live longer, and all of a sudden things aren't available that used to be. So you have to turn to additive manufacturing (see p. 34) or to other materials, and all of a sudden, you've made changes, and you have to deal with those changes. ★

Kevin Greenaugh

Assistant Deputy Administrator for Strategic Partnership Programs



I worked at Los Alamos National Laboratory as a scientist and engineer, and when I came to the D.C. area to manage technical programs, it was a smoother transition. If you understand the science and engineering that you're trying to manage, it's helpful.

There's an intersection between science and policy. For example, there's a policy that established a moratorium on underground nuclear testing. So, what does that mean technically? What do you need to do in weapon programs to be able to certify that weapons will work as a result of that policy decision?

Another example of where policy intersects technology is nuclear weapons materials. The policy is to no longer use some hazardous materials in weapons,

which results in qualification changes. You have to be able to qualify that components made from new materials will not impact weapon performance. You need scientific understanding to determine how policy can change technology, which can change weapon performance.

We want to be responsive to the stockpile. As we execute life extension programs, we consider certifiability and manufacturability. When you go down the path of manufacturability, you ask, how can I manufacture this component quicker, with improved performance and with minimal waste? **That takes us down the path of new manufacturing approaches, such as additive manufacturing** (see p. 34). Then we have to ask, how can we

qualify something that introduces different material properties, such as grain structures, while not impacting performance?

Lastly, strategic partnership projects and technology transfer enable weapons activities. In both programs, capabilities at our sites are used to help other agencies meet their missions, while exercising NNSA site core capabilities. Technology transfer, resourced by programs such as Cooperative Research and Development Agreements, often results in technologies that support weapon activities while improving local and global markets through commercialization. These are valuable by-products of the weapons program that normally are unappreciated. ★

THE NEED FOR SPEED

A dedicated “gearhead,” Jeffrey Luehring is all about parts—weapons parts for executing his job in materials management and boat parts for the jet boat he drag races.

BY OCTAVIO RAMOS

PHOTOGRAPHS BY MICHAEL PIERCE

Jeffrey Luehring of the Laboratory’s Material Management and Business Services group can’t help but embrace the need for speed. On any given weekend, Luehring takes to a lake or a river, not to fish, water ski, or casually drive around in a motorboat but rather to experience an adrenaline rush and test his nerves. Drag racing against a competitor, he eases his hydro boat Sucker Punch into a short rolling start, checking the stillness of the water while watching for the green “start” light to illuminate. Once the light signals “go,” Luehring slams down the boat’s throttle. In six or so seconds, Luehring and his jet boat attain speeds in excess of 150 miles per hour. “I’ve always enjoyed speed,” Luehring explains. “I started racing bicycle motocross—BMX—at an early age while growing up in White Rock, New Mexico. From there, I progressed to racing dirt bikes, which I still do occasionally. But jet-boat drag racing—there’s nothing quite like it in all of racing.”

THE MECHANICAL GENE

Luehring’s father worked as a mechanical engineer for the Laboratory’s Weapons Experimental Division for 18 years. “I definitely picked up his mechanical gene,” Luehring says. “I’ve been a ‘gearhead’ my whole life—I was always out in the garage messing around and helping him work on my older brother’s car when I was younger.”

Luehring’s interest in all things mechanical led him to machining, which he practiced in industry for 16 years before he came to the Laboratory, where for the first eight years he built hydro assemblies. These assemblies are used for hydrotesting, a special type of testing in which materials flow like water (“hydro”) under high temperatures and pressures. He then spent time as an explosives assembly technician before taking on his current position as a production control specialist.

“My background in machining has proved essential in my current job,” Luehring says. “Basically, I am responsible for materials management,

receiving high-profile and, often,

classified parts used by weapons designers and production agencies. It’s a challenging and rewarding job—I get to see the other side, tracking where materials and parts come from, how they move through the processing system, and how finished parts are moved and tracked to their end users. These parts play a huge role in the Laboratory’s number one national security mission, and I’m a big part of that.”

THE SPEED GENE

Luehring’s machining background has also served to feed his need for speed. “What I learned from precision machining enables me to build and modify my own race engines at home,” Luehring says. “At work, I’m always looking for ways to improve and streamline materials management. The techniques I come up with while doing my job emphasize precision and efficiency. It’s the same when I work on my jet boat—I’m always refining engines so that they can achieve 2,000 horsepower, which translates to speeds of 150 miles per hour across a water track of only 1,000 feet.”

Luehring says that he inherited his need for speed from his mother’s side of the family. “On my mother’s side, I have a cousin who races sprint cars and another cousin who races flat-track motorcycles. It’s obvious I got my mother’s speed gene when it comes to racing.”

In late 2018, Luehring earned season wins in both the Lucas Oil Drag Boat Division 1 Quick Eliminator Class Championship and the Arizona Drag Boat Association Division 1 Quick Eliminator Championship. He previously earned back-to-back championships in 2017.

“It’s funny, but I’ve found that the organization skills I’ve acquired in my job at the Lab have really helped me when I’m working on my jet boat,” Luehring says. “I handle all kinds of classified parts that you simply cannot misplace or lose. The same is true when it comes to building and modifying motors, as some of the components are customized and difficult to replace quickly. At work or on the water, successful organization is what lets you bring home the big win.” ★





““ When you're on the water, moving along at 20 miles per hour feels like 50 miles per hour—imagine what it feels like in excess of 100 miles per hour. **””**

THE DISTINGUISHED ACHIEVEMENTS OF LOS ALAMOS EMPLOYEES

NNSA Administrator **Lisa Gordon-Hagerty** presented outgoing Lab Director **Terry Wallace** with the Gold Award, the highest honor that an NNSA administrator can bestow. “Terry and I are of the belief that the work we do is not about ‘us.’ It is about the nation,” she said. “I saw that from him time and again.”

Marc Kippen was awarded the inaugural Los Alamos Global Security Medal. Established in 2018, the medal honors the achievements of active or recently retired Lab employees who have made significant contributions to the Lab’s global security mission. Kippen was recognized for his leadership and achievements in developing, promoting, and sustaining national security capabilities and programs in space-based sensing and nuclear detonation detection.

In September 2018, for the third year in a row, the Laboratory was recognized **as one of the 50 best companies for Latinas to work for in the United States**. The Lab ranked at No. 41 on the list, which is the same spot it held in 2017. It is the only national laboratory that ranked in the top 50.

On October 25, 2018, **Cynthia Reichardt** and **Hari Viswanathan** received the Laboratory’s annual Fellows Prize for Research, and **Kevin John** received the Fellows Prize for Leadership. “The Fellows Prizes recognize both exemplary research and leadership activities in support of the Laboratory’s mission and national needs,” says John Sarrao, deputy director for Science, Technology and Engineering.

The American Physical Society selected its 2018 Fellows, four of whom are Los Alamos scientists:

Brian Albright of XTD Primary Physics, **Jennifer Hollingsworth** of the Center for Integrated Nanotechnologies, **Brian Jensen** of Shock and Detonation Physics, and **Brian Kendrick** of Physics and Chemistry of Materials.

R&D Magazine selected theoretical biologist **Bette Korber** as its 2018 Scientist of the Year. Korber’s innovative HIV “mosaic” vaccine design—sembled from fragments of natural sequences through a computational optimization method—led to a first-in-class preventative HIV vaccine now being tested for efficacy in humans with support from the NIH and the Bill & Melinda Gates Foundation.

John Pedicini, **Paul Whalen**, and **Geoffrey West** were awarded the Los Alamos Medal, the Laboratory’s highest honor, for their achievements that contributed to the success of the Laboratory. Pedicini is a weapons designer, weapons scientist, and assessor of foreign threats. His major contributions include pushing the frontiers of weapons design with five innovative designs during the mid-1980s to early 1990s. Whalen is renowned for his pioneering work that fundamentally changed the test and evaluation of computational physics codes used for nuclear weapons simulation. West’s ability to find broad patterns in complex systems and develop an understanding of the underlying principles of these patterns resulted in discoveries that proved important in nuclear, atomic, and condensed-matter physics.

Five Laboratory scientists were honored as Laboratory Fellows in October 2018. **James Boncella** of the Chemistry Division made the seminal discovery of the first set

of nitrogen analogs of the ubiquitous uranyl ion. **Angel Garcia** of the Center for Nonlinear Studies has earned international recognition as a theoretical and computational biophysicist. **Lawrence Hull** of the Integrated Weapons Experiments Division is the leading authority in understanding the complex mechanisms and physics underlying high-explosive–metal interactions. **Dave Jablonski** of the X-Theoretical Design Division is a recognized authority in stewardship, weapons physics, and design. Chemical physicist **Sergei Tretiak** of the Theoretical Division develops theoretical frameworks for electronic properties in complex molecular structures.

George (Rusty) Gray III is the 2019 recipient of the American Physical Society’s George E. Duvall Shock Compression Science Award. Gray was cited for “pioneering contributions in dynamic constitutive and damage response of materials; for leadership in developing programs and tools to advance our understanding of materials and structures in response to high-strain-rate and shock deformation; and for leadership in the technical community.”



John Pedicini, **Paul Whalen**, and **Geoffrey West** were awarded the Los Alamos Medal at a ceremony on February 7, 2019.

BETTER SCIENCE = BETTER SECURITY

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

In its winter issue, *Careers and the Disabled* magazine named Los Alamos as **one of the top 20 government employers in the country** for people with disabilities. Los Alamos is the only national laboratory to make the list, ranking at No. 13. (Last year, the Lab was No. 19.)

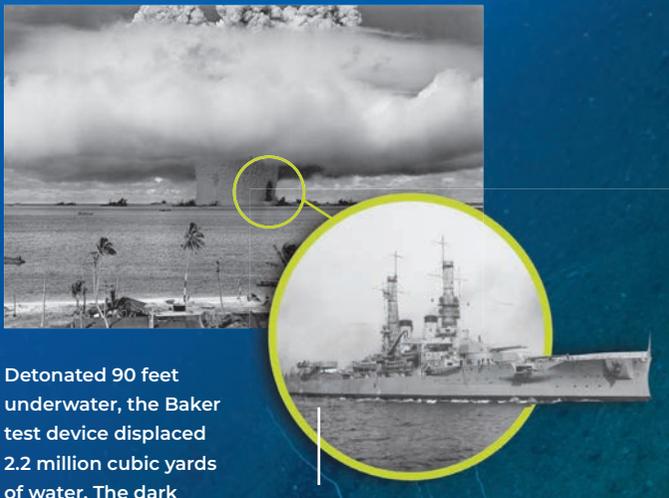
Soft-matter physicist **Stacy Copp** was one of five recipients of the 2018 L’Oreal for Women in Science Fellowship. Copp uses soft molecules to research the creation of materials that emit or interact with light. The resulting materials have potential applications in biomedical diagnostics, solar energy, and energy-efficient lighting.

The National Academy of Sciences awarded physicist **Michelle Thomsen** the Arctowski Medal, which includes a \$100,000 cash prize. The Arctowski Medal is presented every two years and recognizes outstanding contributions to the study of solar physics and solar–terrestrial relationships.

11 YEARS AGO

Photographed in 2008, the *USS Arkansas* lies upside down in 180 feet of water at the bottom of Bikini Atoll in the Pacific Ocean. The Wyoming-class battleship was sunk on July 25, 1946, during the Baker test of Operation Crossroads. The Los Alamos–designed test was used to study the effects of nuclear weapons on naval vessels. Placed approximately 500 feet from ground zero, “the 26,000-ton battleship *Arkansas* sank almost at once,” according to *Bombs at Bikini*, the official report of Operation Crossroads. “In sinking, she carried with her the dubious honor of being the first battleship to be sunk by an atomic bomb and the first battleship to be sunk by a bomb which never touched her.”

Photo: Reinhard Dirscherl/Getty Images



Detonated 90 feet underwater, the Baker test device displaced 2.2 million cubic yards of water. The dark area on the right of the upward-sweeping column is believed to be a cavity formed by the *USS Arkansas*.

Commissioned in 1912, the *USS Arkansas* served in both world wars before being used as a target in Operation Crossroads.



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THEN & NOW

Built in 1928, Fuller Lodge was one of the main structures at the Los Alamos Ranch School. Above, students, staff, and community members gather for a graduation ceremony. When Los Alamos was acquired for the Manhattan Project in 1943, Fuller Lodge was used as a dining hall and for social events. In June 2018, the building was used during the Laboratory's 75th anniversary celebration.

