LOS ALAMOS NATIONAL LABORATORY ◇ WINTER 2019

NATIONAL ★ SECURITY SCIENCE

THE EXPLOSIVES ISSUE

Devils in the details: the tricky business of making detonators

Eco boom: creating a safer, greener alternative to TNT

Entering the realm of augmented reality: dismantling IEDs from the safety of the computer world

PLUS:

The anatomy of a mushroom cloud

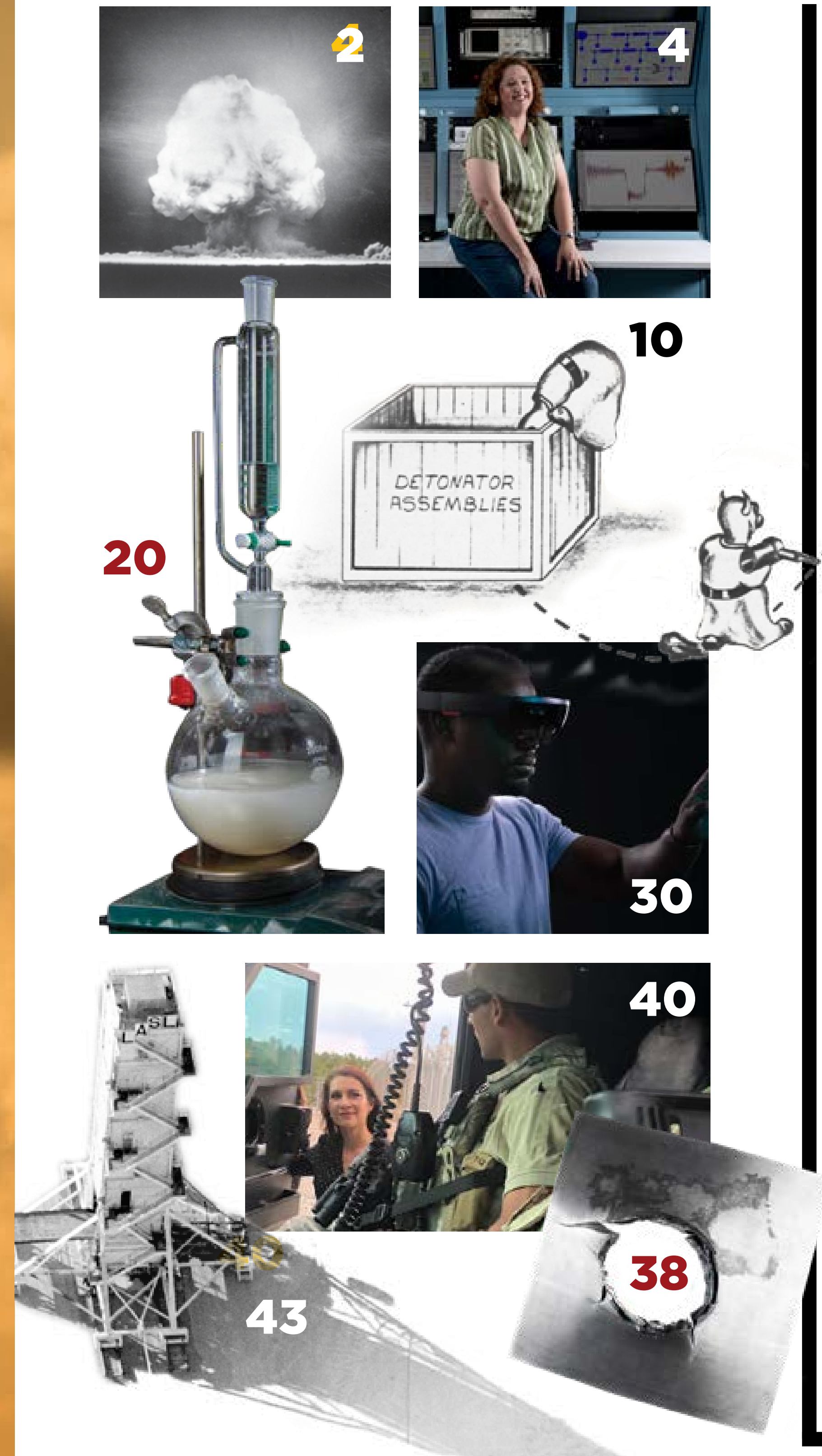
National security depends on scientific superiority

Safeguarding the Los Alamos campus

PHOTOBOMB

▼

A B-2 Spirit bomber flies on its first sortie from Joint Base Pearl Harbor-Hickam in Hawaii on January 14, 2019, in support of U.S. Strategic Command's bomber task force mission. The B-2, which is capable of carrying the Los Alamos–designed B61 gravity bomb, has been in service since 1989; this year, the Air Force celebrates the 30th anniversary of the plane's inaugural flight.
Photo: U.S. Air Force/Thomas Barley



IN THIS ISSUE

FEATURES

ABOUT THE COVER:
In February 2018, an explosives experiment at the Lab's Lower Slobbovia firing site provided data that helped validate calculations in a subsequent experiment at the Lab's Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility. The test object for this experiment contained pyrophoric materials similar to those found in some fireworks. Photo: Isaac Martinez

EXPLOSIVES

AFTER 76 YEARS IN BUSINESS, WE KNOW A THING OR TWO ABOUT THINGS THAT GO "BOOM."

BY BOB WEBSTER
DEPUTY DIRECTOR, WEAPONS

Project Y, the Los Alamos branch of the Manhattan Project, began taking shape on Northern New Mexico's Pajarito Plateau in February 1943. Just 29 months later, the scientists who'd been secretly transported to Los Alamos had created the world's first atomic device.

In other words, the Laboratory has been in the explosives business since Day 1. The successful implosion weapons of the Trinity Test (pictured) on July 16, 1945, and the Nagasaki mission on August 9, 1945, used detonators to ignite explosives that compressed a plutonium core (pit). If you've never seen a 1940s-era detonator, flip to p. 10 to learn more about these tiny devices and why they are so devilishly difficult to make.

Our explosives work comes with very strict safety and environmental regulations that we are eager to comply with. Operating a weapons laboratory while respecting the environment is something we've been doing for decades. High-explosives scientist David Chavez took this to heart with his invention of BOM, a "green" explosive more powerful than TNT but much healthier for the environment—not just in Northern New Mexico but around the world. Turn to p. 20 to learn more.

Our last feature article (see p. 30) in this issue of *National Security Science* highlights how augmented reality can protect warfighters, specifically, explosive ordinance disposal (EOD) technicians, who dismantle improvised explosive devices (IEDs). Thanks to augmented reality technology developed at Los Alamos, EOD techs can train using virtual IEDs, which makes for a much safer learning environment.

So, whether we are maintaining the detonators, pits, and other components of U.S. nuclear weapons or determining what's inside someone else's bomb, Los Alamos scientists are among the best explosives scientists in the world. By working hard to support our national security mission, we have helped keep the peace for more than 76 years, and we are confident we'll help keep the peace for another 76 years or more. ★

MASTHEAD

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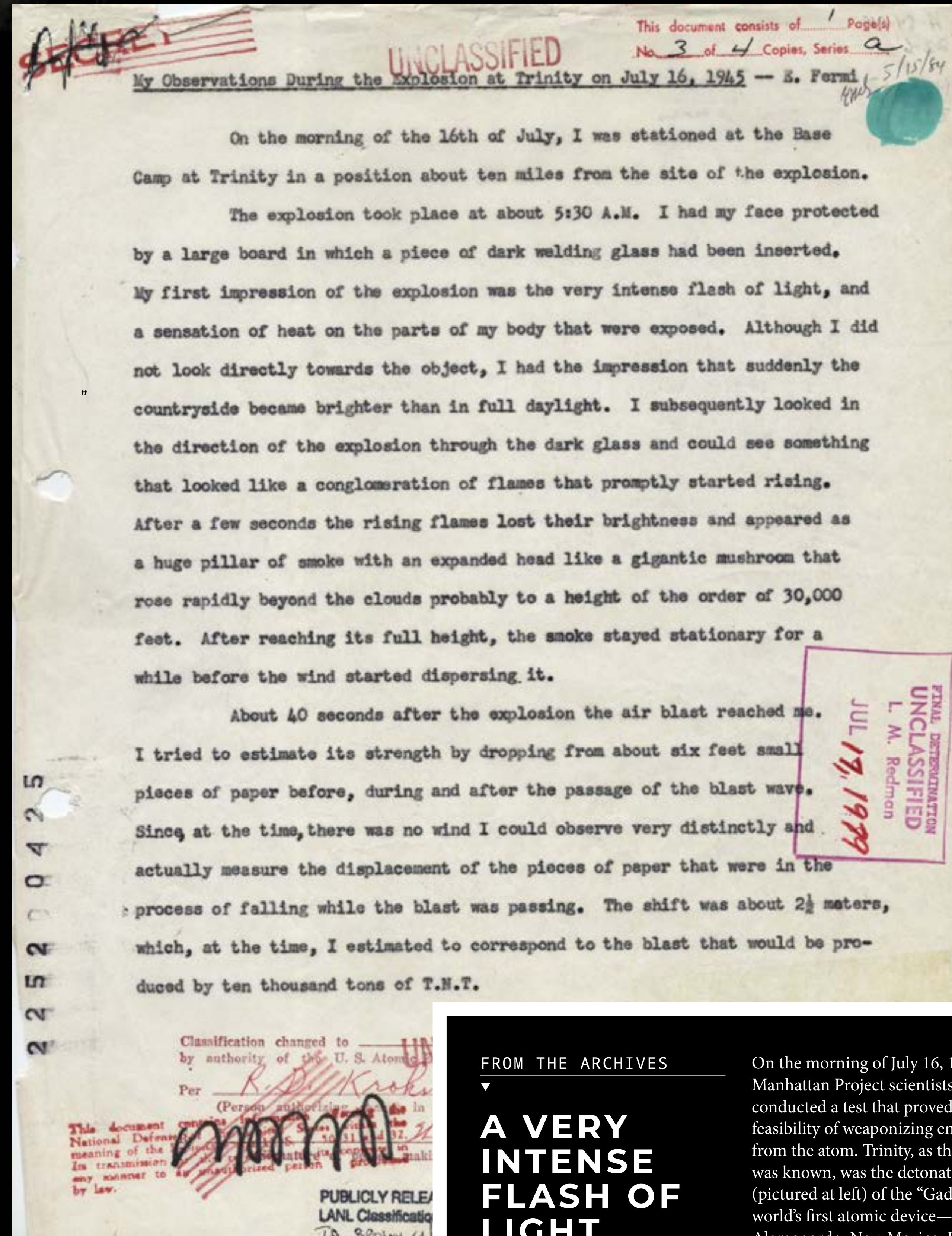
NSS STAFF SPOTLIGHT

In addition to serving as an editorial advisor for *National Security Science*, Jon Ventura leads the Lab's Office of Nuclear and Military Affairs, which builds and maintains relationships with military operational commands and the military service academies. After 15 years at Los Alamos, Ventura will retire in December 2019. He and his wife, Donna (also retired from Los Alamos), will move to Bozeman, Montana, where you'll find him on the slopes at Big Sky Resort.



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UNCLASSIFIED

My Observations During the Explosion at Trinity on July 16, 1945 — E. Fermi

On the morning of the 16th of July, I was stationed at the Base Camp at Trinity in a position about ten miles from the site of the explosion.

The explosion took place at about 5:30 A.M. I had my face protected by a large board in which a piece of dark welding glass had been inserted. My first impression of the explosion was the very intense flash of light, and a sensation of heat on the parts of my body that were exposed. Although I did not look directly towards the object, I had the impression that suddenly the countryside became brighter than in full daylight. I subsequently looked in the direction of the explosion through the dark glass and could see something that looked like a conglomeration of flames that promptly started rising. After a few seconds the rising flames lost their brightness and appeared as a huge pillar of smoke with an expanded head like a gigantic mushroom that rose rapidly beyond the clouds probably to a height of the order of 30,000 feet. After reaching its full height, the smoke stayed stationary for a while before the wind started dispersing it.

About 40 seconds after the explosion the air blast reached me. I tried to estimate its strength by dropping from about six feet small pieces of paper before, during and after the passage of the blast wave. Since, at the time, there was no wind I could observe very distinctly and actually measure the displacement of the pieces of paper that were in the process of falling while the blast was passing. The shift was about 2½ meters, which, at the time, I estimated to correspond to the blast that would be produced by ten thousand tons of T.N.T.

FINAL DETERMINATION
UNCLASSIFIED
L. M. Redman
JUL 17, 1979

Classification changed to UN
by authority of the U. S. Atom
Per R. D. Kroh
(Person authorizing ... in

PUBLICLY RELEA
LANL Classificatio
J.A. Brown

FROM THE ARCHIVES

A VERY INTENSE FLASH OF LIGHT

Physicist Enrico Fermi recounts the Trinity Test.

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 (pictured at left) of the "Gadget"—the world's first atomic device—near Alamogordo, New Mexico. Here, Nobel Laureate Enrico Fermi describes the test. This document is preserved in the Laboratory's National Security Research Center.

INFOGRAPHIC

THE INTERSECTION

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

The National Museum of NUCLEAR Science & History

In June, the Atomic Heritage Foundation (AHF) and the National Museum of Nuclear Science and History partnered to continue preserving Manhattan Project history. The partnership ensures AHF's extensive collection of oral histories will be available to the public for the foreseeable future.

In the late 1990s, the smoke from Disneyland's nightly fireworks bothered some folks in the Anaheim area. Los Alamos scientists were able to develop low-smoke pyrotechnics to solve the problem. The technology won an R&D 100 Award in 1998. Read more about new explosives technology on p. 20.

New Mexico will provide the Capitol Christmas tree and 75 other Christmas trees and tree skirts for government buildings in Washington, D.C. The Los Alamos Piecemakers Quilt Guild created the skirt for the tree destined for the U.S. Department of Agriculture building.

On August 9, former First Lady Michelle Obama Instagrammed a photo of Oscar McClain, a Laboratory summer student who works for the Materials Synthesis and Integrated Devices group. "What I love about Oscar's story is that no matter how many ups and downs he's been through, he's always remained resilient on his journey of becoming," Obama wrote. "This May, he graduated [from Southern University and Agricultural and Mechanical College] with a degree in chemistry and a 3.7 GPA. Because, as he told me this summer, 'Overcoming obstacles is what causes success to be worth achieving.' I'm so proud of you, Oscar! #BetterMakeRoom"

CULTURE

SCIENCE

WEAPONS INFRASTRUCTURE

COVERING UP

A new weather enclosure at the Lab's DARHT facility will keep experiments on schedule and boost worker safety.

The Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility is an essential scientific tool that supports stockpile stewardship at the Laboratory. DARHT consists of two large x-ray machines that produce radiographs (high-powered x-ray images) of mock nuclear weapons that implode at speeds greater than 10,000 miles an hour. Such radiographs help scientists ensure that weapons in the stockpile are safe and effective and that—if ever necessary—they will perform as designed.

The area where the mock nuclear weapon is detonated inside a large, spherical confinement vessel is called the firing point, and until recently, the firing point has always been outside. Because of this exposure to the elements, DARHT tests have sometimes been delayed because of weather.

But no more. A new weather enclosure, currently under construction and scheduled for completion in April 2020, will encompass the firing point, creating a predictable and consistent environment for experiments. At the same time, it will shield the facility's high-tech camera system and its other complex diagnostic equipment from rain, snow, wind, and other weather-related conditions.

"This project has multiple benefits—an increase in the number of experiments, a much safer work environment for our dedicated workforce, a better environment for our state-of-the-art equipment, and an environment conducive to higher-quality results, all of which support our essential stockpile stewardship mission," says Terry Priestley, retired group leader for DARHT Operations. "We have a powerhouse team to ensure the project is completed on time and meets our objectives." ★

Pictured: A rendering shows the completed DARHT weather enclosure.

QUOTED

"The Department of Energy and NNSA [National Nuclear Security Administration] appreciate Congress's steadfast support of the national labs. Los Alamos and Sandia are world-class scientific institutions that have played a pivotal role in American security and prosperity for decades. The nation needs to continue to invest in them to strengthen our national security and drive innovation and economic growth."

–NNSA Administrator Lisa Gordon-Hagerty, during a tour of Los Alamos on July 29 with members of the House Science and National Labs Caucus, a bipartisan congressional body that advocates for federal investment in the national laboratories. ★

WEAPONS

EXPLOSIVES TRAIN

BY KATHARINE COGGESHALL

A nuclear weapon can produce nuclear yield only if the weapon is detonated in a carefully choreographed sequence: a perfectly timed detonation triggers an explosion that implodes the nuclear pit.

SERVICE ANNIVERSARIES

HAPPY ANNIVERSARY!

In 2019, 31 employees in the Laboratory's weapons program celebrated 30, 35, 40, 45, and even 50 years of service to the national laboratories.

>> Remembers Los Alamos—where she was born and raised—when it was still a closed community. She jokes that

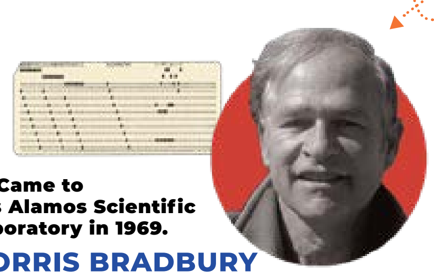
"IT WASN'T EASY BEING BORN IN A POST OFFICE BOX."

Vera Aguino	30 YEARS
Sheila Armstrong	45 YEARS
Guy Baker	30 YEARS
Brian Bartram	35 YEARS
Lawrence Bronisz	30 YEARS
Mark Byers	40 YEARS
Rendell Carver	35 YEARS
Anthony Chavez	30 YEARS
Mark Dinehart	35 YEARS
Lorraine Dominguez	30 YEARS
Darryl Gardner	30 YEARS
Rowena Gibson	30 YEARS
Mary Gonzales	35 YEARS
David Huerta	35 YEARS

>> Helped create and steward the modern subcritical experiments program, which is based at the Nevada National Security Site's U1a underground complex.

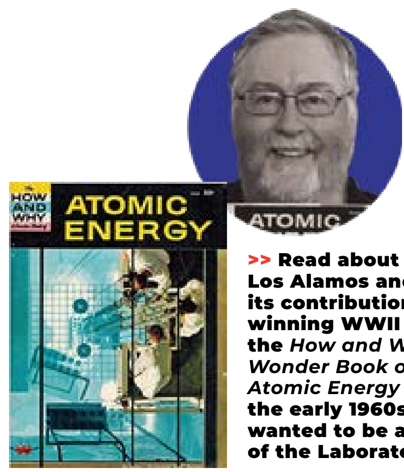
Diane Lamkin	30 YEARS
Aaron Lopez	30 YEARS
Dennis Lujan	35 YEARS
Len Margolin	50 YEARS
Deborah Martinez	35 YEARS
Paul Montaño	35 YEARS
Robert Montoya	30 YEARS
Charles Richardson	30 YEARS
Patrick Rodriguez	30 YEARS
Jeffrey Paisner	45 YEARS
Stanley Pierce	35 YEARS
Michael Shinas	30 YEARS
Clinton Shonrock	40 YEARS
Mike Stevens	35 YEARS
Robert Sutherland	30 YEARS
William Ward	30 YEARS
Laura Worl	30 YEARS

>> Followed in the footsteps of his grandfather, who was a machinist during the Manhattan Project. Now, his sons are fourth-generation Los Alamos employees.



>> Came to Los Alamos Scientific Laboratory in 1969.

"NORRIS BRADBURY WAS THE DIRECTOR. YOU COULD FIND PARKING ANY TIME OF THE DAY. COMPUTERS WERE SLOW, AND PUNCH CARDS WERE STILL IN USE."



>> Read about Los Alamos and its contribution to winning WWII in the *How and Why Wonder Book of Atomic Energy* in the early 1960s and wanted to be a part of the Laboratory.

QUOTED

"I think that the greatest tribute to Los Alamos and its continuing work is the fact that there have been no wars between major powers since 1945. I'm certainly glad to be known as part of that Los Alamos tradition."

—Los Alamos physicist Lawrence Johnston in an August 2006 speech to Laboratory employees. Johnston invented the exploding-bridgewire detonator in 1945. Turn to p. 10 to learn more about detonators.

EDUCATION

LEARNING FROM THE BEST

The Lab's Deputy Director for Weapons teaches students at Texas A&M University.

BY SIERRA SWEENEY

For Texas A&M nuclear engineering doctoral student Alexander Perry, running into one of the country's leading weapons experts—Laboratory Deputy Director for Weapons Bob Webster—has become common. Found in lecture halls, across A&M's Zachary Engineering complex, and at the occasional breakfast meeting, Webster has been a notably available and approachable resource for nuclear engineering students.

Perry's first encounter with Webster was when he was a junior and attended Webster's guest lecture in the nuclear criticality safety course. Perry says Webster's passion for the field of nuclear engineering is contagious. "Once I sat in a room and listened to Dr. Webster lecture, I felt as enthusiastic and motivated about nuclear engineering as I was during my first days in the department." Webster's ability to "make the most difficult concepts consumable" is what Perry believes makes Webster such a unique and notable educator. "He has the ability to make complicated information both simple and elegant."

A former Los Alamos intern, Perry is familiar with the legacy of the Lab and Webster's role in the Laboratory's national security mission. "I remember sitting through one of his unclassified lectures on the fundamental physics of nuclear weapons thinking that he is one of the most valuable assets to this country, and I got to shake his hand," Perry says.

Perry is interested in nuclear medicine and in the medical applications of nuclear engineering. He hopes to complete his doctorate at A&M, with an emphasis on image reconstruction and dosimetry in the field of nuclear engineering. As he works toward this goal, Perry says he will always remember Webster's most valuable lesson: "No matter how much you think you know, you can always learn more." ★

Pictured: Bob Webster (left) chats with Alexander Perry at Texas A&M University in College Station, Texas. Photo: Texas A&M University College of Engineering

CAREERS

ON THE ROAD TO LOS ALAMOS

Students at Northern New Mexico College now have a path to careers as radiation control technicians at the Laboratory.

BY SIERRA SWEENEY

As the Laboratory expands and takes on new responsibilities to support its national security mission, the demand for qualified employees is rising. The Lab's Plutonium Facility, in particular, needs radiation control technicians (RCTs), who play a role in all Laboratory activities above a certain hazard level. RCTs actively monitor contamination levels, verify dose rates for areas and people, ensure compliance with federal and Laboratory policies and procedures, and complete the associated documentation.

This is where Northern New Mexico College (NNMC) comes in. Working closely with the Laboratory, NNMC, about 30 minutes away in Española, recently launched a two-year program that will train students to become RCTs. After graduating with an associate degree in radiation protection, these students will be ready for an entry-level position at the Laboratory. The curriculum will follow Los Alamos and U.S. Department of Energy training requirements for RCTs, with the Laboratory providing technical staff to take part in instruction. The Laboratory, which is funding the program, will also offer internships for students to work at the Laboratory while they are pursuing their degrees.

"Student response has been wonderful," says Joaquin Gallegos, who chairs NNMC's Biology, Chemistry, and Environmental Sciences departments. "The Laboratory is often these students' first choice for employment. We are excited that this partnership is a win-win—for Los Alamos in meeting its workforce needs and for our students in finding meaningful local employment." ★

Q&A

ASK A PHYSICIST

Tina McKee answers four questions about her work on a recent hydrodynamic experiment.

BY WHITNEY SPIVEY

Tina McKee was the lead experimenter on a recent hydrotest at the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility. In a DARHT experiment, scientists detonate a mock nuclear weapon and take radiographs of the resulting implosion. The heat and pressure created by the implosion cause the weapon's nonnuclear core to melt and flow like water. This change from solid metal to liquid is why the experiment is considered "hydrodynamic" and often called a "hydrotest."

NSS caught up with McKee recently to ask her about her work on these tests.

What is a lead experimenter?
The lead experimenter is responsible for all aspects of a hydrotest at DARHT and has the technical knowledge to make the right decisions and troubleshoot along the way. As lead experimenter, I coordinated with everyone—physicists, engineers, accelerator operators, and others—to ensure we got the best data we could get from the hydrotest. I had a blast working with so many different people at the Lab. Everyone works together as a team because we all have a common goal: a successful hydrotest with excellent data collection.

What was your reaction when you were named lead experimenter?
I was honored. It is an incredible amount of responsibility, and the fact that my team trusted me to do the job is very humbling. And, in a happy coincidence, all of the subject matter experts for this hydrotest were women. It is excellent to see the technical opportunities available for women at the Lab, and it was a privilege to be given the chance to work with this group of esteemed scientists.

What's the atmosphere like at DARHT on test day?
It's electric! Everyone is excited to finally be executing the test, but test day is very much "hurry up and wait." People all bring food to share, and there is usually a big box of breakfast burritos, which go fast. Everyone knows their job, so suddenly the lead experimenter is trying to stay out of people's way and let them work. It is incredible to see over a year's worth of work come down to a final countdown of 3…2…1…BANG!

How were the results of the test?
The results were excellent. I think everyone was impressed with how detailed the radiographs were. This test was first proposed more than 10 years ago to answer a safety question for the B61 gravity bomb. DARHT's radiographic capabilities made DARHT the only tool to answer that question. We were able to get the best data achievable; in fact, one of my managers called it a "textbook radiograph." ★

VOCABULARY

ANATOMY OF A MUSHROOM CLOUD

Think "nuclear weapon," and you probably picture a mushroom cloud—a stem supporting a puffy head. But photos from U.S. atmospheric nuclear tests (1945–1963) show more than the basic stem-and-head structure. The detonations produced different, sometimes odd, effects. **BY EILEEN PATTERSON**

FIREBALL
The fireball was gone in seconds, so photographing it during the tests required a rapid electronic camera, called a rapatronic camera. Rapatronic photos of a test detonated on a tower showed a fireball with **"legs"**—the tower's guy-wires becoming a glowing plasma in the fireball's heat. The phenomenon was called a **rope trick.**

TUMBLER-SNAPPER HOW
JUNE 5, 1952
NEVADA TEST SITE

CAPS
A high-yield test in the South Pacific created a swiftly rising cloud that might push warm water vapor ahead of it to great, cold heights, where the water vapor froze into one or more ice caps.

CASTLE BRAVO
FEBRUARY 28, 1954
BIKINI ATOLL

DOMINIC TRUCKEE
JUNE 9, 1962
NEAR CHRISTMAS ISLAND

SKIRTS AND BELLS
Some tests produced "skirts" or "bells," cone-shaped phenomena descending along the mushroom's stem. These occurred when the dropping pressure and temperature of the high altitude caused humid air around the stem to condense into water droplets heavy enough to fall.

THE BASIC MUSHROOM
The iconic mushroom cloud begins as a fireball, a luminous bubble of extremely hot air and vaporized weapon residues. The fireball rises like a hot-air balloon, pulling air, water vapor, and debris into its base to form the mushroom stem. As the fireball rises, it cools, losing its glow, and the vaporized material and water vapor condense and spread, forming the mushroom head.

BUSTER CHARLIE
OCTOBER 30, 1951
NEVADA TEST SITE

DOMINIC SUNSET
JULY 10, 1962
NEAR CHRISTMAS ISLAND

ABOUT TEST NAMES
Nuclear tests were done in series. A test's name had two parts: series title first, test name second.

RINGS
A test in a warm, wet environment like the South Pacific sometimes produced rings of vapor instead of the type of vapor cloud seen in photos of Crossroads Baker. The rings were caused by the layers of humidity in the air.

SLICK AND CRACK
Crossroads Baker produced a "slick" and a "crack," both caused by the underwater test's shock wave's first contact with the surface. The slick was an expanding circle of dark water resembling an oil slick, the source of its name. The crack was the shock wave's disturbance of the water—a circle of white, ruffled water.

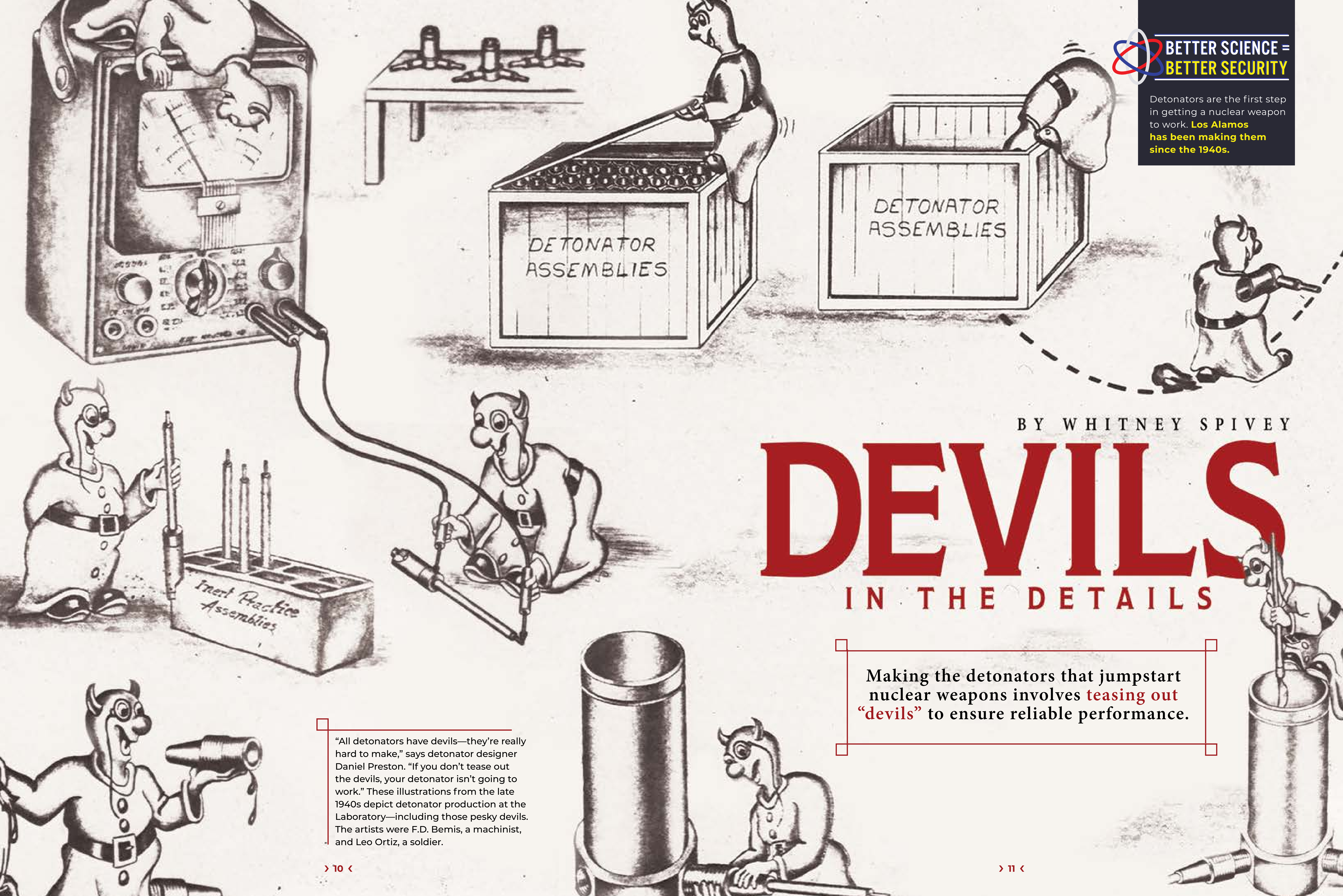
A FAKE MUSHROOM
Here, Crossroads Baker seems to be a mushroom cloud but is not. Baker was detonated under water, so the "stem" is a hollow pillar of water, and the "head" is short-lived (seconds) vapor.

CROSSROADS BAKER
JULY 24, 1946
BIKINI ATOLL

TEAPOT MET (MILITARY EFFECTS TEST)
APRIL, 15, 1955
NEVADA TEST SITE

LINES
The vertical lines in many nuclear test photos are smoke trails from rockets. The rockets were fired so the progress of the test's shock wave could be recorded against the pattern of lines provided by the smoke trails.

CROSSROADS BAKER
JULY 24, 1946
BIKINI ATOLL



BETTER SCIENCE = BETTER SECURITY

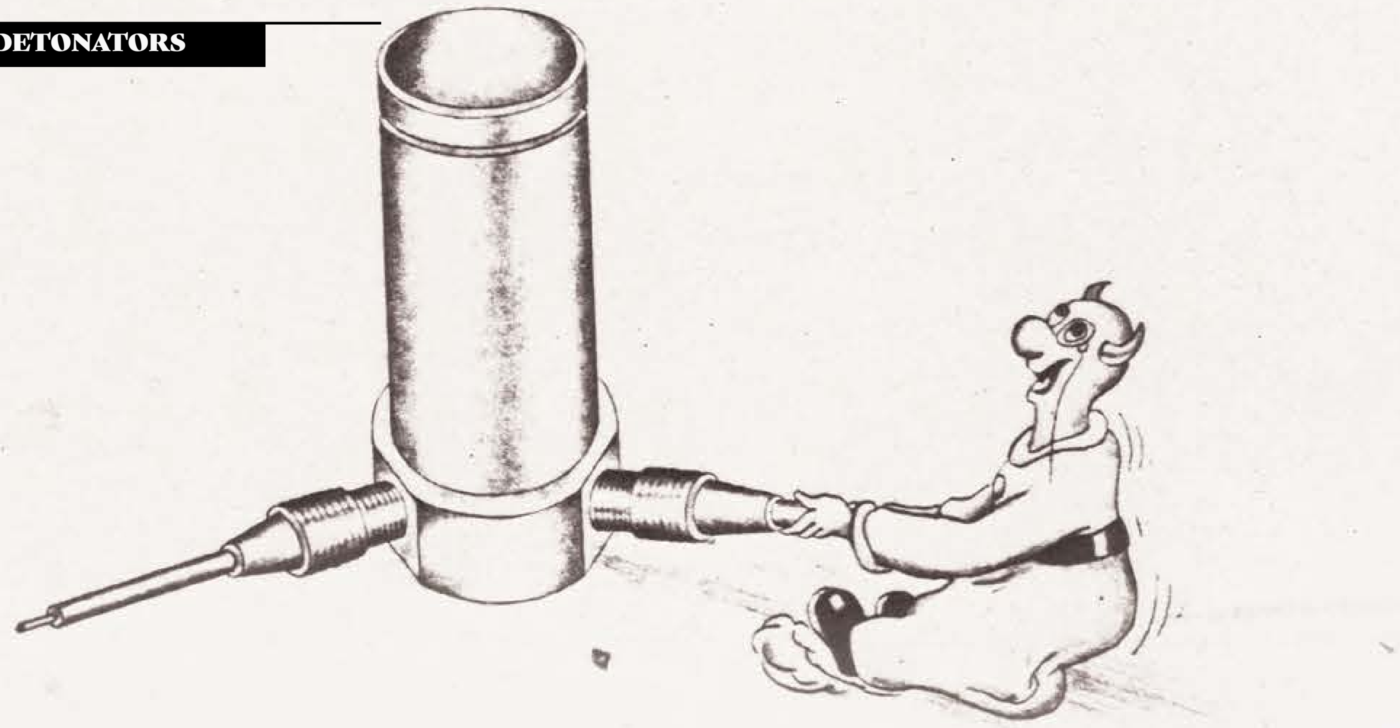
Detonators are the first step in getting a nuclear weapon to work. **Los Alamos has been making them since the 1940s.**

BY WHITNEY SPIVEY

DEVILS IN THE DETAILS

Making the detonators that jumpstart nuclear weapons involves teasing out "devils" to ensure reliable performance.

"All detonators have devils—they're really hard to make," says detonator designer Daniel Preston. "If you don't tease out the devils, your detonator isn't going to work." These illustrations from the late 1940s depict detonator production at the Laboratory—including those pesky devils. The artists were F.D. Bemis, a machinist, and Leo Ortiz, a soldier.



In July 2016, Wendy Strohmeyer, the Bradbury Science Museum's then-newly hired collections specialist, was sorting through a backlog of artifacts in the museum's warehouse. "A small stack of plain brown boxes full of donations had piled up," she remembers. "As soon as I felt ready, I began going through them."

In the bottom of one box was a large ziplock bag. Inside the bag were 13 corroded, dirty, hollow metal cylinders with "handlebars" protruding perpendicularly from one end.

Unsure of what the roughly baseball-sized artifacts were, Strohmeyer called weapons engineer Glen McDuff. "Wendy calls me about anything strange she finds," McDuff explains. "I'll go over and see it. If I can, I'll tell her what it is."

In this case, McDuff was able to tell Strohmeyer that she was in possession of 13 empty (no explosives) exploding-bridgewire detonators from the Manhattan Project—yes, that 1940s top-secret effort to build the world's first atomic bomb. These handlebar detonators or 1773 detonators, as they're also called, were the same type of detonators used in 1945 in the Gadget, the atomic device detonated in the Trinity Test, and in Fat Man, the atomic bomb used on Nagasaki, Japan.

"I think they represent something bigger than being part of a weapons assembly," says Laboratory engineer Daniel Preston, who has worked for the Lab's Detonator Science and Technology group. "If you apply the right historical lens, they show how special Los Alamos is."

Finding the correct historical lens was tricky, even for Preston, who is both an accomplished detonator designer and a history buff. "At first glance, these artifacts look like empty detonator bodies," he explains. "A closer inspection reveals that these parts were once filled with explosives and fired."

But wait a minute. Detonators are supposed to detonate, destroying themselves; how did these 13 remain intact? Preston believes they are the remains of classic detonator threshold testing. "Threshold testing is performed by firing a series of detonators at a variety of voltage potentials (electricity sources) and observing whether the detonator 'goes,'" he says. "In threshold testing, by design, half of the detonators do not fire properly because they do not get enough energy; we call these NoGos." Often, NoGos will burn all their explosives, leaving an empty detonator with the faintest trace of deformed metal.

If the Bradbury's detonators are in fact remnants of Manhattan Project–era threshold testing, then they directly supported the Trinity Test and the Nagasaki mission by helping scientists dial in the appropriate voltage for the detonators on the Gadget and Fat Man.

"Holding these detonator parts is like holding little time machines," Preston says. "Their existence highlights how Los Alamos and its workforce changed the world."

"To get a uniform implosion, you needed to start it detonating in a large number of places with a very high degree of simultaneity."

Lawrence Johnston

◆ Thirteen Manhattan Project–era exploding-bridgewire detonators were discovered in a backlog of artifacts at the Bradbury Science Museum. "We have less Manhattan Project artifacts than you'd think," says collections specialist Wendy Strohmeyer. "I think it has to do with the ration-conserve reuse mentality at the time...anything that is a direct relic of that time is very valuable to the museum.

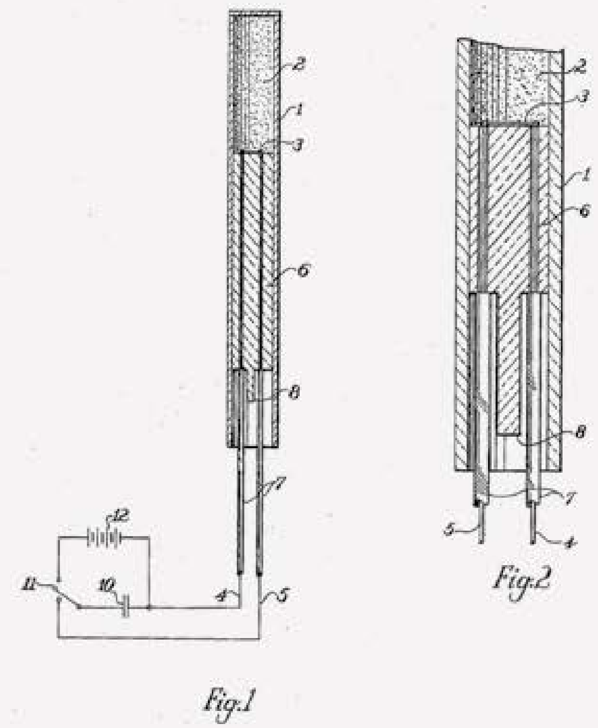
“Holding these detonator parts is like holding little time machines. Their existence highlights how Los Alamos and its workforce changed the world.”
—Daniel Preston

◆ Detonator specialist Daniel Preston examines the 13 exploding bridgewire detonators from the Bradbury Science Museum.

June 26, 1962 L. H. JOHNSTON 3,040,660

ELECTRIC INITIATOR WITH EXPLODING BRIDGE WIRE

Filed Nov. 8, 1944



What is a detonator?

Detonators are small devices used for detonating a high explosive. In a nuclear weapon, the nuclear part (called the core or the pit) is surrounded by high explosives. The detonation of those high explosives is what causes the pit to implode (compress) and create nuclear yield. To ensure this compression happens evenly around the pit, the detonators (there are many per weapon) must go off at exactly the same time.

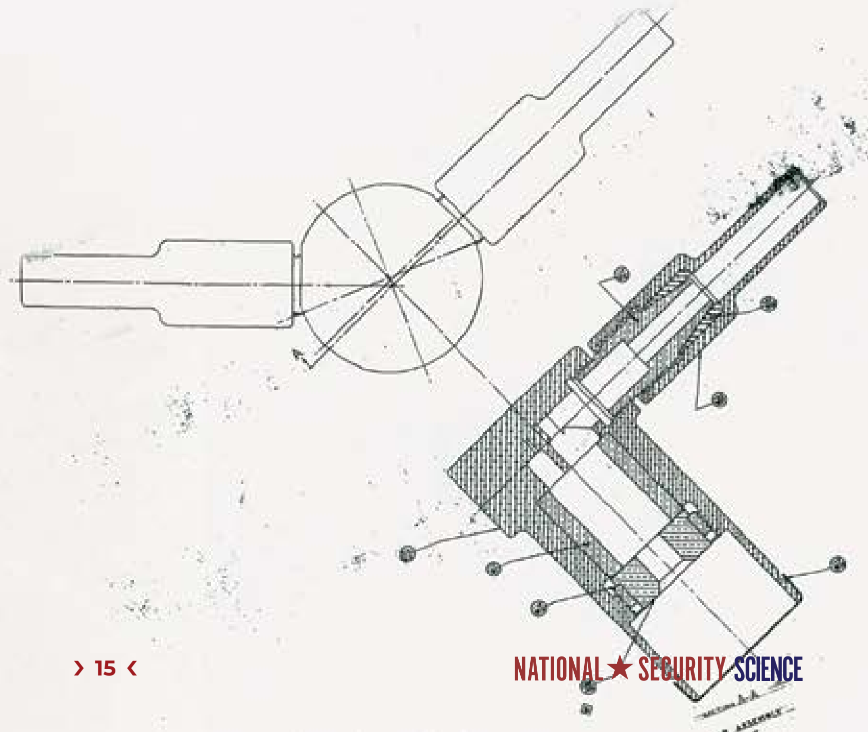
“To get a uniform implosion, you needed to start it detonating in a large number of places with a very high degree of simultaneity,” now-deceased physicist Lawrence Johnston explained during an interview at the Institute of Electrical and Electronics Engineers in 1991.

During the Manhattan Project, Johnston and his mentor, Luis Alvarez (who would go on to win the Nobel Prize in 1968), designed a new type of detonator, the safe and reliable exploding-bridgewire (EBW) detonator—the same kind that McDuff identified for the Bradbury.

Although Johnston and Alvarez were the brains behind the detonators, the devices were built mostly by women because of the dexterity required for detonator construction. “Women were brought in from nearby pueblos to do the assembling and loading, and SED [Special Engineering Detachment] soldiers were in charge,” Johnston explained. “Those women got real good at soldering the bridgewires on the entrance plugs and loading the explosives.”

◆ Above: According to Lawrence Johnston, “when the time came in 1944 to patent the EBW detonator, Alvarez said that the patent should be in my name only, since I had done all the work. He could have taken the view that I was only the technician who carried out his ideas. Patent 3,040,660 was granted in 1962.”

◆ Below: The original EBWs (as drawn here) are often called 1773 detonators. 1773 refers to the drawing number.



◆ A modern EBW (left) is much smaller than a 1940s-era EBW (right).

In this type of detonator, an electrical charge from a capacitor heats a bridgewire—a hair-thin wire that's tucked into an explosive inside the detonator's handlebar. Preston says there's still some mystery to what's going on inside an EBW detonator, but the current theory is that the bridgewire heats up so quickly that it vaporizes and creates a shock wave that detonates the explosive inside the handlebar. Combined with all the other small but powerful explosions from the other detonators, this explosion, in turn, detonates the adjacent high explosives that surround the weapon's plutonium pit. The pit implodes, creating nuclear yield.

The EBW design was critical to the safety of nuclear weapons because an EBW requires a specific energy source (electricity) to detonate, reducing the possibility of an accidental explosion.

EBW detonators were used on the Gadget, the world's first nuclear test, on July 16, 1945, near Alamogordo, New Mexico. "Praise the Lord, my detonators worked!" Johnston exclaimed after the Trinity Test. "I'm sure there were a number of people there who had been responsible for some essential component of the bomb, who felt the same elation. If the bomb had fizzled, [each man] would have had dark thoughts that maybe it was his fault."

"Praise the Lord, my detonators worked!"

—Lawrence Johnston

"It's a hard problem to put a new technology into an existing weapons system."

—Daniel Preston

After the Gadget's demonstrated success, EBW detonators were used on Fat Man, the atomic bomb that was dropped on Nagasaki on August 9, 1945, to help end World War II.

"We saw the flash of the Fat Man bomb come in through the window," remembered Johnston, who saw the explosion from a nearby observation plane. "Again, my detonators must have worked!"

Detonators today

After World War II, the Atomic Energy Commission moved detonator production from Los Alamos to Mound Laboratories, in Miamisburg, Ohio. But when Mound was declared a Superfund (contaminated) site in 1989, detonator production was moved back to Los Alamos.

After all these years, the EBW design is still used, although today's EBWs are about the size of a pencil eraser.

The Laboratory's newest detonators are called chip slappers. Like EBWs, chip slappers use an electrical charge to vaporize material and a shock wave to initiate an explosive. Whereas an EBW has the bridgewire embedded in the explosive, slappers separate the bridge from the explosive with an air gap and an insulating film. The vaporization of the bridge throws the film across the air gap into the explosive, "slapping" it. This separation of explosive and electrical components improves safety.

◆ Chase Gibson inspects a sheet of cables (electrical current wires that will become part of the detonator cable assembly) for defects. The cables will be individualized when their final profiles are cut out with a laser.

◆ Presses are used to progressively bend or cut features in a sheet of aluminum until it forms a three dimensional cup that will ultimately be loaded with high explosives and placed inside a detonator.

◆ Daniel Byers glues soldered connectors onto cables that will eventually become part of detonator cable assembly.

"Chip slappers are very efficient and very safe," Preston says. "They need a specific signal for the chip to vaporize and slap the explosive." Chip slappers are also more manufacturable and smaller than EBWs.

In fact, because chip slappers are so safe, they are replacing EBWs in America's B61 nuclear gravity bombs. "It's not a trivial thing to change the detonator in a nuclear weapon," Preston says. "It's a hard problem to put a new technology into an existing weapons system." But as the B61 gets upgraded for another 20 years of service, it's important to have components that age well and are resistant to temperature fluctuations.

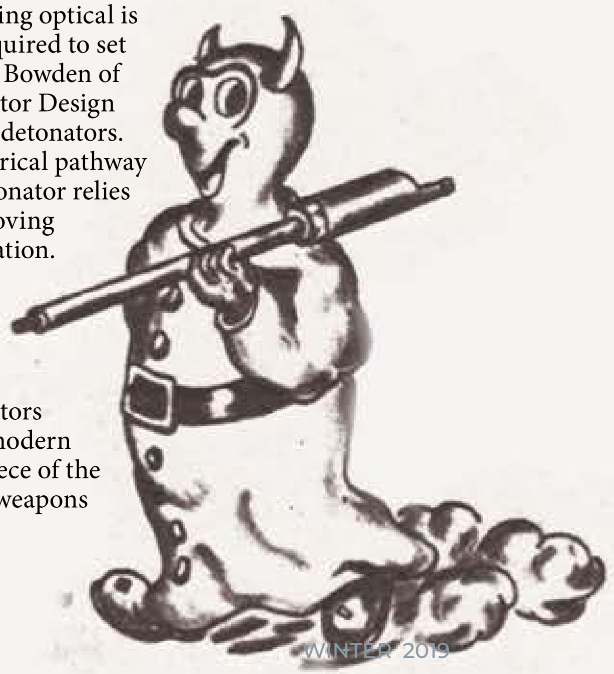
"Having the right kind of detonators to use in nuclear weapons is a high bar to meet, and Los Alamos continues to 'answer the mail' on them," says Preston, meaning that the Laboratory is continually inventing better—safer—detonators.

Preston is also quick to point out that "it takes an elegant engineer to make a good detonator," referring to how devilishly hard it is to design and build this tricky little piece of equipment. "The devils are in the details."

Because electricity has always been the riskiest element in a detonator, Los Alamos has started creating detonators in which the electrical energy is replaced by high-intensity laser energy. These detonators are known as optical detonators.

"The biggest advantage of going optical is the unique energy source required to set off the detonator," says Mike Bowden of Q-6, the Los Alamos Detonator Design Agency, who designs optical detonators. "Rather than having an electrical pathway to detonation, an optical detonator relies on a small, robust laser, removing all electrical means of detonation. Los Alamos will produce the safest and most robust and reliable detonators the world has ever seen."

Not only that, optical detonators will be even smaller than a modern EBW, making them a tiny piece of the safest, most reliable nuclear weapons in the world. ★



WHAT DO ROCKS AND EXPLOSIVES HAVE IN COMMON?

Two scientists are applying what they know about the granular microstructure of rocks to high explosives—a novel approach that could predict how explosives age.

BY J. WESTON PHIPPEN

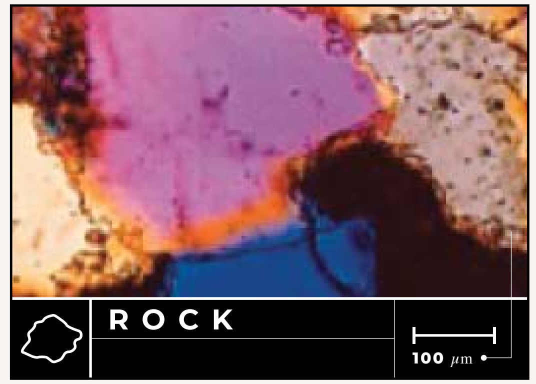


Photo: James Ten Cate

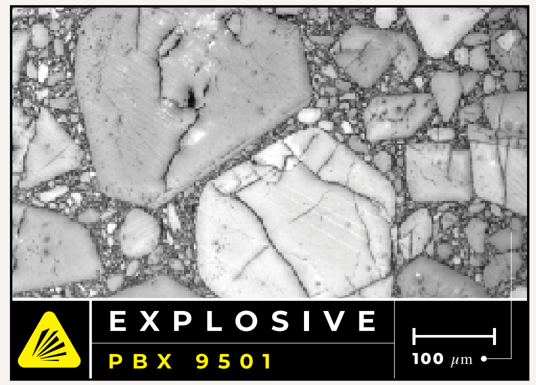


Photo: Cary Skidmore

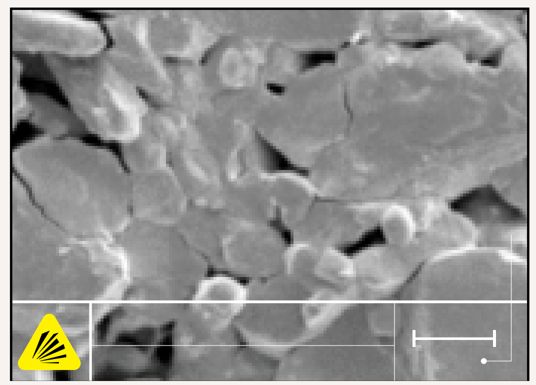


Photo: Kathryn Brown

■ Pictured: "Explosives are useful to us because—like rocks—they have microstructure," says physicist Carly Donahue. "And like rocks, high explosives have curious acoustic behavior."

The definitive way to test an aging detonator in the U.S. nuclear stockpile is to fire it. But this destroys the detonator, and it doesn't reveal much about what impact time has on the high explosives inside.

For decades, the weapons in our stockpile have been exposed to high and low humidity, and to intense cold and heat depending on where they're kept, which makes the aging process unique to each. "Getting information on the high explosive inside those detonators is either really difficult or not possible," says explosives chemist Peter Schulze. Even so, answering this question—will an aged detonator still work as intended?—is vital to the Lab's mission.

Here is where the partnership of two Lab disciplines is paying off. For 20 years, the Elasticity, Vibrations, and Acoustics team at Los Alamos has used ultrasound to study rock microstructure, which is full of cracks. It turns out that high explosives share a similar microstructure. "That's what gives explosives their explosive properties," says physicist Carly Donahue, who has studied the microstructure of everything from moon rocks to medicines. "Also like rocks, high explosives have curious acoustic behavior."

Last year, Schulze and Donahue applied for a Laboratory Directed Research and Development grant to study this curious acoustic behavior. By pulsing an ultrasonic wave through a pressed high-explosive pellet (the kind found in detonators), they hoped to learn what role time plays in the performance of these devices—and they wanted to do it without destroying the detonator. Here's how it worked:

When an ultrasonic wave meets a crack in the explosive's microstructure, the wave changes slightly. As you increase the wave's vibrational intensity—its amplitude—it will deform as it encounters microscopic cracks in the pellet. Eventually, the frequency shifts lower and becomes flat. The wave becomes nonlinear.

It's a concept similar to someone playing a musical note on a guitar, and as the note is plucked harder, it becomes more out of tune. Under normal circumstances, a note played at any volume should remain the same. But not with rocks and high explosives.

Schulze and Donahue theorized that as high explosives age, their microstructure alters to make them more prone to this frequency change. To test their theory, they used heat to artificially age pressed high explosives, exposing different batches of pellets to the heat for different lengths of time. They then tested each batch with ultrasound, slowly increasing the amplitude until the frequency changed. Then they fired the detonators to compare results.

What they discovered was that the high-explosive pellets that demonstrated the frequency change at lower amplitude were the same pellets that, later, when destroyed, had become more sensitive with age. They exploded too easily.

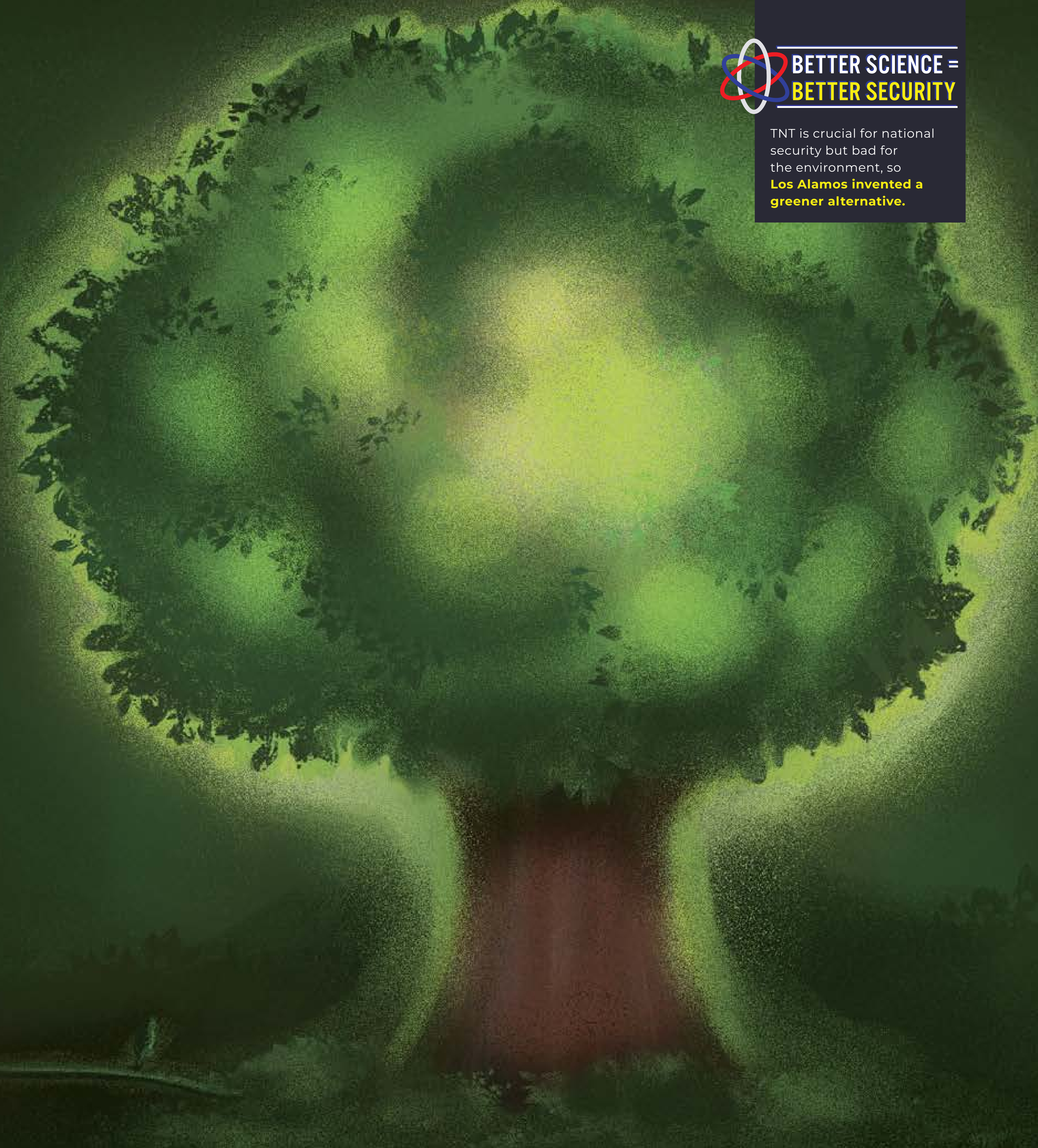
As the two set out to find, the test determines the quality of detonators without destroying them. It's inexpensive, easily repeatable and, eventually, Donahue says, "We hope it will tell us more about how high explosives age so we can understand what this means for our nuclear weapons." ★

Donahue and Shulze's work will be published in early 2020 in *Propellants, Explosives, Pyrotechnics*.

ECO BOOM

BY J. WESTON PHIPPEN

EXPLOSIVES SUCH AS TNT ARE HIGHLY TOXIC TO PRODUCE. THAT'S WHY THE LAB IS DESIGNING SAFER, GREENER REPLACEMENTS.



BETTER SCIENCE = BETTER SECURITY

TNT is crucial for national security but bad for the environment, so **Los Alamos invented a greener alternative.**

The West Virginia Ordnance Works factory produced TNT, which was vital to helping the Allied Forces win World War II. But the chemicals used to create the explosive have left a toxic burden.
Photo: U.S. Army Corps of Engineers

Construction on the West Virginia Ordnance Works factory began in March 1942. The factory spread across more than 8,000 acres on the east bank of the Ohio River, about six miles north of Point Pleasant, West Virginia, tucked between the pines and maples. Eight months later the factory was producing 720,000 pounds of trinitrotoluene (TNT) every day for use during World War II.

The process of making TNT uses toluene, a solvent most commonly found in paint thinners; as well as nitric acid, sulfuric acid, and oleum oil—all caustic chemicals. The combination is washed in warm water and soda ash, then cold water, leaving behind massive pools of what's called red or pink water—a 93 percent sulfuric acid liquid that's clear, oily, and toxic. By the time the government closed the factory, six days after dropping Fat Man over Nagasaki in August 1945, 39 of these acidic ponds remained. Remediation workers had to "flash" all the equipment with a quick burn to rid it of chemicals. Ten pipelines that carried TNT to and from various buildings were removed.

The factory was mostly forgotten . . . until 1981, when locals noticed toxic pink water seeping from a sulfur pond into a creek. The Environmental Protection Agency (EPA) listed the location as a Superfund site, and the government has worked ever since to rid the area of contamination.

Even after advances in production safety since World War II, making TNT still leaves behind hazardous chemicals. The United States produces millions of tons of the explosive every year, not just for military uses, but also for the construction, demolition, and mining industries. On military land alone, the Army estimates 1.2 million tons of U.S. soil are contaminated from the production and use of TNT, which the EPA considers a possible carcinogen. And because TNT leaves a 2 percent chemical trace anytime it explodes, contaminated sites aren't limited to active and shuttered processing plants. On any bombing range and anywhere artillery is fired, grenades are hurled, or a weapon using TNT is detonated, small amounts of toxic residue are left in the ground.

It's not likely the United States' demand for an inexpensive, dependable explosive will lessen anytime soon. So it's no surprise that developing a safer, greener alternative to TNT has become something of a Holy Grail quest—one that Los Alamos explosives chemist David Chavez was able to complete.

Three years ago, Chavez, answering a call from the Department of Defense, set out to develop a more eco-friendly replacement for TNT. What he created contains none of the dangerous chemicals found in TNT and leaves no toxic byproducts behind. And it's 50 percent more powerful.

DEVELOPING A SAFER, GREENER ALTERNATIVE TO TNT HAS BECOME SOMETHING OF A HOLY GRAIL QUEST.

EXPLOSIVES HISTORY

German chemist Julius Wilbrand accidentally invented TNT in 1863. He was trying to develop a powdery yellow clothing dye, and it took another 30 years before the world realized his invention's potential as an explosive. Then came World War I. The Germans were the first to widely use TNT, filling their armor-piercing bombs with the new material. By World War II, TNT was standard in nearly all military explosives.

The next development came around 1940, when the British created RDX, another high explosive, which packed one-and-a-half times the energy of TNT. America honed the RDX manufacturing process and was soon producing 500 tons a day to fill the weapons carried to Europe during World War II—bazookas, "dambuster" explosives, and other massive bombs dropped from planes. To this day, most military weapons around the world use an RDX and TNT combination, called Comp B. The problem is that RDX production also involves the synthesis of toxic chemicals the EPA has termed likely carcinogens.

THE HAMMER TEST

This is where Chavez's groundbreaking science comes into play. Chavez's office occupies a squat building in a quiet corner of Los Alamos National Laboratory. And it was here, in his lab of glass beakers and flasks, that he first thought of and created BOM—bis(1,2,4-oxadiazole) bis(methylene) dinitrate. BOM meets all the requirements of a TNT replacement: it's relatively inert, meaning it won't blow up easily. You can drop it on the ground and it won't detonate. And using heat, it can be converted into a liquid, then poured into any-shaped weapon, where it solidifies—a property known as being melt castable.

Most importantly, BOM has no sulfur waste-water problem. "There's hardly any heat in the process at all. And by eliminating the heat, you avoid the degradation products, which are toxic," Chavez says. "It actually takes very mild reaction conditions to make BOM."

Both BOM and TNT contain carbon, oxygen, hydrogen, and nitrogen atoms. But the difference lies in BOM's synthesis process—only four relatively easy steps. First, Chavez dissolves a chemical in a solvent, boiling the two together. He waits for the mixture to cool, filters the byproduct, and then mixes the leftovers with another solvent. This is repeated three times with different chemicals until the last step, which involves reducing the mixture's temperature until…voila! You have a fine, white explosive powder.

The molecular difference between TNT and BOM comes from replacing two carbon atoms with nitrogen atoms. This boosts the combustion rate and makes the explosive burn cleaner. "This material has a much better oxygen balance," Chavez says, "so its fuel is more likely to be burned completely. And anything that's unreacted would degrade relatively easily in the environment." The new synthesis also made the molecule denser, another factor in why it's 50 percent more powerful than TNT. It's melt castable, and doesn't require any mixing with RDX to create an explosive with the same output as Comp B. BOM alone is enough.

Besides being more environmentally friendly and more powerful, BOM is also safer to handle. As way of demonstrating, Chavez kneels on the ground and prepares to perform what is called the hammer test.

"I think I like this hammer better," says Chavez, as he trades a mallet for a ball-peen. "It's smaller." He leans forward and places less than a one-eighth of a teaspoon of BOM on a metal block.

"Cover your ears," Chavez says.

He smacks the hammer down and… nothing. So he packs the powder a bit more densely, then places one hammer directly atop the BOM and taps it with another. The tiny explosion echoes in the lab and down the hallway. A slight trace of smoke rises. What the simple test proves is that BOM needs deliberate action to detonate—it's very safe but still packs a lot of energy.

The hammer test is just one of many tests experimental explosives undergo at the Lab. This way, scientists have a good understanding of what they're working with. Some of the tests involve fancy, high-tech machines. Others, like the hammer test, are much more analog: dropping a weight from various heights on an explosive or holding a barbecue lighter to a small amount of the explosive.

■ BOM—bis(1,2,4 oxadiazole) bis(methylene) dinitrate—is twice as powerful as TNT and leaves no toxic trace. BOM is melt castable: it can be converted into a liquid, poured into any shape, and will solidify.

IT ACTUALLY TAKES VERY MILD REACTION CONDITIONS TO MAKE BOM.

—DAVID CHAVEZ

BOM can be made in four relatively easy steps. And it's not only better for the environment, it's also safer for the chemists (such as Chavez, pictured) working with the molecule.

An additional benefit of DAAF is that because it can be ground into smaller particle sizes, it can have increased shock sensitivity, which means it can be used in all parts of a nuclear weapon: in detonators, as a booster, and/or as the explosive, which compresses a plutonium pit.

Francois developed a plastic bonding process for DAAF so it could be shaped and pressed into pellets, which makes it safer for handling. Once Francois figured this out, PBX 9701 was born—the first new PBX developed in four decades.

Francois, Chavez, and their team are already synthesizing PBX 9701 in the tens-of-kilograms level. In a few years it could be produced at the hundreds-of-kilograms level at the Pantex Plant.

BOM could also follow this path, but its future is less certain.

In October 2019, BOM was a finalist for an R&D 100 Award—an "Oscar of Invention." This designation could help attract some much-needed publicity. If there's interest in developing BOM, Chavez says, "The typical lifetime of a new molecule from discovery to production tends to be 15 to 20 years because of all the testing and searching for funding to develop the molecule."

"If we had enough money, though," Francois points out,"we could probably do it in five years."

BEYOND BOM

BOM isn't the only green explosive being developed by Los Alamos. Laboratory scientists are also working on a more environmentally friendly high explosive for use in nuclear weapons.

But why worry about making a high explosive in a nuclear weapon environmentally friendly?

Even if a weapon is never detonated, the Lab's mission includes ensuring the safety of the nuclear stockpile, which involves testing new and old components and updating them as necessary. That requires the production of PBX (plastic-bonded explosive) 9501 and 9502—the high-explosive materials used inside the weapons. PBX is made in large quantities at the Pantex Plant in Amarillo, Texas. Like TNT, the current PBX explosives require mixing caustic chemicals, which creates a risk to the chemical engineers producing the explosive and leaves behind toxic waste.

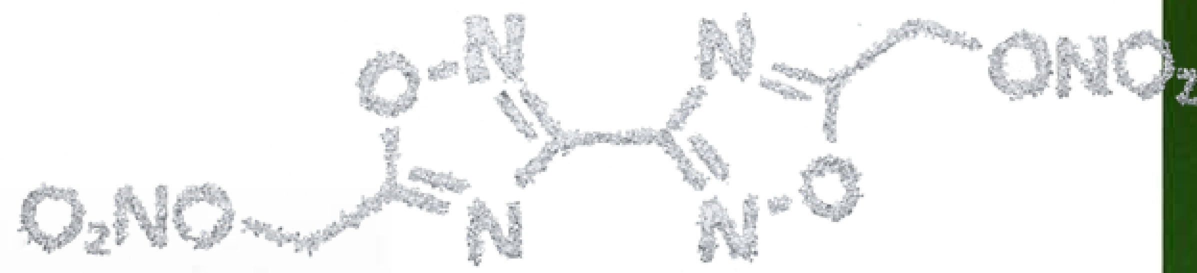
Los Alamos scientist Elizabeth Francois and Chavez collaborate on many projects (throughout the BOM process they were constantly bouncing ideas off one another). Chavez came to the Lab in 2003 from Harvard University, and Francois came five years later, from the University of California, Berkeley. In 2008, they both started toying with a new PBX formulation.

Most high explosives require nitration, the chemical process of introducing nitrogen into a molecule. This step almost always involves acidic chemicals. Even BOM has a nitration process; it's just a milder form than most. But the new process Francois and Chavez developed doesn't. It has only an oxidation process. This allowed them to consider much milder chemicals, the result being that they were able to create an explosive called diaminoazoxyfurazan (DAAF) using common ingredients, such as baking soda. It also meant the byproduct waste was nontoxic. "It's essentially salty water," Francois says.

IN OCTOBER 2019, BOM WAS A FINALIST FOR AN R&D 100 AWARD—AN "OSCAR OF INVENTION."

REMEDIATION AT THE ORDNANCE WORKS SITE ALONE HAS COST THE GOVERNMENT $96.3 MILLION SO FAR, WITH ABOUT $70 MILLION MORE BUDGETED FOR THE FUTURE.

In the 1980s, the Environmental Protection Agency declared the West Virginia Ordnance Works a Superfund site, and cleanup continues to this day.
Photo: U.S. Army Corps of Engineers



The BOM structure spelled out in powder.

A GREENER FUTURE

The U.S. Army Corps of Engineers surveys the environment at the West Virginia Ordnance Works site every five years. The last review, completed in 2016, found that after 71 years, TNT still contaminated the soil at the site. At the TNT manufacturing area, now only a cement foundation, surveyors found nitroaromatic contamination in the groundwater. The steel and clay sewer lines leaving the factory floor were also still contaminated, as well as the three reservoirs that once held 30 million gallons of red wastewater.

The latest round of remediation involved replacing warning signs around the site. Two-foot-thick soil covers contaminated dirt. Depressions were leveled where polluted water had pooled. And the Army Corps continues to pump groundwater through filters to stop contamination from seeping into the water table.

All of this is expensive. Remediation at the Ordnance Works site alone has cost the government $96.3 million so far, with about $70 million more budgeted for the future. Of course, there are many more sites contaminated by TNT all over the country, including Camp Minden in Louisiana, the Apache Powder Company site in Arizona, Joliet Army Ammunition Plant in Illinois, and Bangor Naval Submarine Base in Washington.

BOM can't change what's already been done. But it can ensure that processing sites don't become health risks to humans or ruin the environment. So in the future, places like the West Virginia Ordnance Works facility might not be thought of as burdens to clean, but remembered as the places that helped win the wars that kept the nation safe. ★

BETTER SCIENCE = BETTER SECURITY

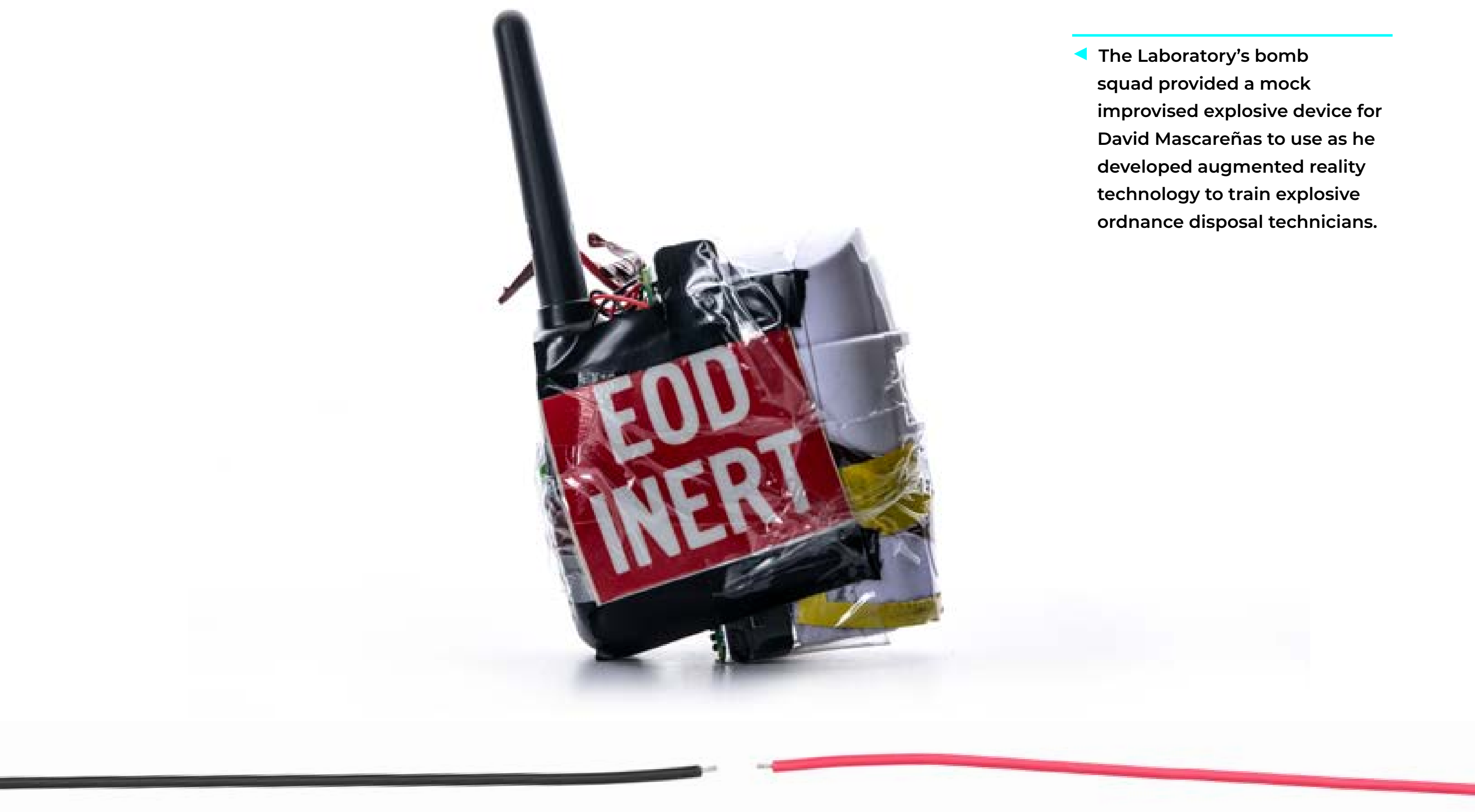
Los Alamos scientists use augmented reality to train first responders to locate, identify, and evaluate all types of IEDs.

ENTERING THE REALM OF AUGMENTED REALITY

BY OCTAVIO RAMOS

FIRST RESPONDERS TRAIN TO DISMANTLE IMPROVISED EXPLOSIVE DEVICES FROM THE SAFETY OF THE COMPUTER WORLD.

► Evan Wells, a Laboratory employee and former Marine, models the augmented reality headset that helps train the military s explosive ordnance disposal technicians.



◄ The Laboratory's bomb squad provided a mock improvised explosive device for David Mascareñas to use as he developed augmented reality technology to train explosive ordnance disposal technicians.

In an article published on August 1, 2019, the organization Action on Armed Violence reported that the previous day, a roadside improvised explosive device—commonly known as an IED—detonated under a bus in Afghanistan's Farah province. This IED killed at least 32 passengers, critically injuring an additional 15. Although no group has claimed responsibility for this attack, it is known that the Taliban and ISIS (Islamic State of Iraq and Syria) operate in this part of the world and frequently use IEDs.

Just what is an IED? According to the Department of Homeland Security, the term was coined in 2003 during the Iraq War. An IED is a "homemade" bomb or destructive device, one designed to destroy, incapacitate, harass, or distract an enemy.

The practice of placing explosive charges as a means of harming the enemy is not a new invention. Before IEDs there were various types of just-under-the-ground explosive devices, such as surface mines and underwater depth charges, designed to destroy military vehicles and personnel. The insidious nature of such weapons led to development of the 1997 Mine Ban Treaty, which specifically outlaws the production, use, stockpiling, and transfer of antipersonnel mines. More than 164 nations have signed this treaty to achieve a mine-free world.

Enter the IED, which is typically made by civilians using conventional materials and commercially available chemicals. Such improvised explosive devices can be used by criminals, vandals, terrorists, suicide bombers, and insurgent organizations. The goal of those who use IEDs is not only to cause damage and loss of life but also to call attention to their organization or to a radical cause. One of the particularly harrowing characteristics of the IED is its adaptability. Almost any organization can create and use IEDs to cause harm to targets of its choice, including civilians and first responders such as firefighters, medical personnel, and the police.

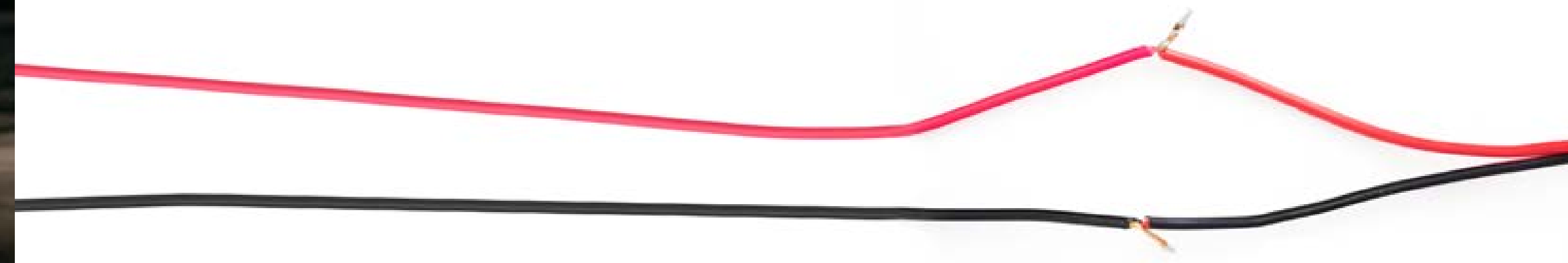
Every year, IED attacks injure or kill more people than any other type of weapon, save firearms. According to Action on Armed Violence, a review of selected international media reports from 2011 to 2015 revealed more than 6,300 IED explosions, which killed more than 105,000 individuals. According to a letter from the United Nations Security Council, about half of the world's countries have suffered from IED attacks.

TRAINING FOR THE CHAOS

One of the principal problems associated with IEDs is their improvised nature. An IED can be made with various combinations of materials and chemicals. To cause more damage than just the blast of an explosion, some IEDs include screws and nails, scrap metal, and

▲ U.S. Air Force Senior Airman Jim Hendel disarms a simulated IED during a training exercise. Soon, augmented reality software developed at Los Alamos may be used in similar training exercises.
Photo: U.S. Air Force/Scott Reed

▶ Explosive Ordnance Disposal (EOD) techs wear augmented reality headsets that project holograms—in this case, an IED inside a trash can—onto a real-world environment. Techs can also pull up information about specific IEDs.
Photo: Los Alamos/Dreamstime (background)



other materials that add fragments to the explosion. These fragments are launched when the IED goes off, damaging buildings, injuring personnel, and destroying vehicles. IEDs can be of any size, from small pipe bombs and vest bombs (used by suicide bombers) to more sophisticated devices planted in vehicles to be used in destroying part or all of a building.

Such IED variability makes training designed to locate, identify, and ultimately render safe such devices a great challenge. The core idea behind training responders such as police and bomb squads is to make the training as realistic as possible. As with all such hazard-laden training, however, safety must always be of utmost importance. At first, bringing the inherent dangers associated with reality-based training together with comprehensive safety may sound impossible, but scientists at Los Alamos National Laboratory feel that they have found an answer. That answer is to employ augmented reality in such training.

IT'S NOT VIRTUAL, IT'S AUGMENTED

A small Los Alamos team led by David Mascareñas of the National Security Education Center has developed a software suite that, in conjunction with the hardware associated with augmented reality, can be used to train first responders in locating, identifying, and rendering IEDs safe under a variety of scenarios.

Mascareñas explains that augmented reality is basically an offshoot of its more recognizable cousin, virtual reality. "Virtual reality is designed to completely replace an individual's real-world environment," he says, "whereas augmented reality alters the perception of a real-world environment."

Mascareñas points to the recent Pokémon Go fad as a classical example of augmented reality. Released in 2016, the Pokémon Go game enabled smartphone users to locate, battle, and train virtual creatures, known as Pokémon. These virtual creatures could be found in a user's real-world location using a smartphone. Pokémon Go has gone on to become a worldwide hit, with more than 1 billion downloads and earnings in excess of $3 billion.

The immersive nature of augmented reality makes it a huge draw when it comes to gaming, as players can find themselves in outrageous situations in an otherwise real environment. Mascareñas, among others, has discovered, however, that it is also possible to use augmented reality to train first responders in countering dangerous devices with no chance of exposing the trainees to actual physical danger.

After all, the danger is virtual—it exists only in the realm of the digital—thus enabling trainees to face real-world dangers in real-world environments without worrying about getting hurt. Imagine firefighting trainees learning how to battle fires before they train under more real-life scenarios. Picture bomb squads locating and disarming an IED using virtual tools and explosives before moving on to train under more reality-driven scenarios. Augmented reality can be used to enhance the extensive training regimes of our emergency response community without the need to add the time and expense of hands-on training.

"We have developed a prototype of this technology specifically designed to help first responders train in countering IEDs," Mascareñas says. "So, what we've done is take the various components that make up an IED and use augmented technology to overlay these components onto the real world."

A key component of augmented reality is a headset that typically comes with transparent lenses, headphones, and a microphone. This headset is linked to a computer that runs a software program. Think about the interface Neo used in the 1999 science-fiction film *The Matrix*, only in this instance the software enables the user to blend objects into the real world rather than a user entering a virtual computer world.

"I like to think of it as someone wearing a set of cool, oversized glasses," Mascareñas says. "The software then projects what amounts to overlaid holograms onto a real-

> **Virtual reality is designed to completely replace an individual's real-world environment, whereas augmented reality alters the perception of a real-world environment.**
>
> — DAVID MASCAREÑAS

▶ U.S. Marine Corps Sergeant Scott Schaller returns from x-raying a suitcase. EOD techs use x-rays to determine if they can safely inspect items. Photo: U.S. Marine Corps/ Armando Elizalde

world environment, to where it is possible for the user to manipulate these holograms. These glasses enable you to see everything in the real world, but you can also see and hear holograms and virtual objects in this environment. As such, I would say that augmented reality is much more useful than virtual reality when it comes to military and industrial applications."

Although Mascareñas imagines many uses for this technology, his current focus is on IED awareness and training.

"Our software enables users to bring up information about specific IEDs to identify exactly what they are dealing with," Mascareñas continues. "The software can also simulate various types of sensors, such as an infrared sensor that once tripped, can trigger an IED to explode. If a trainee gets too close to such a sensor, for example, it can set off the IED, thus ending the training exercise."

Although Mascareñas and his team had experience in augmented reality, they did not have great knowledge or experience when it came to IEDs and explosives in general.

"We reached out and collaborated with explosives experts here at the Lab," Mascareñas says. "Working with such experts, we were able to develop virtual mockups of IEDs. For the prototype, we then hid an IED in a trash can. Now, there are all kinds of scenarios when it comes to IED placement—the trash can simulation is the first of many. We then designed a virtual infrared sensor, which pretty much works like a garage door opener. We even designed a defusing device, a water-canon disruptor, which the trainees must place in the proper place for it to defuse the IED. Otherwise, the IED will go off."

Mascareñas says future work includes emulating the different types of sensors used to interrogate IEDs to determine what's in them, developing a greater suite of IED types (each of which comes with its own set of problems) and incorporating different virtual objects where an IED can be hidden to achieve maximum damage (a pipe bomb in a suitcase or an IED inside the camper of a large truck, for example).

"We've actually started work on virtual tools to counter IEDs," Mascareñas says. "For example, we're working on simulating a bomb-disposal robot with virtual controls. Thus, you can simulate not only an IED and the object it's hidden in but also the tools necessary to defuse the IED."

GETTING INTO AUGMENTED REALITY

Mascareñas and his team have been exploring the applications of augmented reality for about three years.

"Before getting into augmented reality, my team and I worked on a project that used virtual reality to address problems related to nuclear criticality safety," Mascareñas says. "The project focused on the safety of a

> **The danger is virtual—it exists only in the realm of the digital—thus enabling trainees to face real-world dangers in real-world environments without worrying about getting hurt.**

technician operating a glovebox. We then changed the approach, using augmented reality instead of virtual reality. We found that augmented reality worked much better when it came to training—we also found that trainees learned faster and retained more knowledge when we used augmented reality."

As Mascareñas and his team expanded their understanding of augmented reality, they started to find various applications for it. "We've done some work on global security, such as visualizing satellite data. We've also worked with the United States Department of State in ways related to treaty verification."

Augmented reality also played a minor role in developing a structural health monitoring tool known as ViDeoMAgic, which in 2018 earned the Laboratory an R&D 100 Award from *R&D Magazine*. Dubbed the "Oscars of Invention," the R&D 100 Awards honor pioneers and their revolutionary ideas in science and technology.

ViDeoMAgic was invented by a Los Alamos team that included Yongchao Yang and Mascareñas. ViDeoMAgic (with the capital letters standing for Video-based Dynamic Measurement & Analysis) takes a video of a vibrating structure and from it extracts high-spatial-resolution (pixel-level) structural vibration/dynamics information. ViDeoMAgic applications cover the gamut of the imagination, from assessing aircraft and vehicle safety to detecting damage in large-scale infrastructure (buildings, bridges, and dams), providing noncontact analysis of sensitive machines such as wind turbines, performing quality control for manufacturing, and one day even helping physicians diagnose diseases such as cancer.

THE FUTURE OF AUGMENTED REALITY

Enhanced safety is just one benefit of using augmented reality for training. "Another benefit is expense," Mascareñas says. "Real-world training exercises cost a lot to pull off, particularly when it comes to building custom environments and using props designed to enhance an actual scenario but also ensure safety. It doesn't cost much, on the other hand, to create a three-dimensional hologram. Even the most primitive of these holograms get the point across, particularly when the environment itself is a real one."

Another option is to use real-world props on which you could overlay holograms to make the scenario much more elaborate. For example, it would be possible to place a suitcase in the trunk of a car. The response team would have to find the most effective means of opening the trunk, removing the suitcase, and then opening it to find a virtual set of pipe bombs, all linked to a timer but also with infrared sensors for additional security. The vehicle and the suitcase are real, but the pipe bombs and the sensors are holograms.

Mascareñas notes that the original software prototype and the commercially available hardware are now ready, with the team actually capturing video of scenarios that show a real environment with simulated objects.

"This prototype software demonstrates that it is possible to use this technology for training," Mascareñas says, "and that we're pretty good at it."

Although impressive today, the future of augmented reality begins to skirt the realm of science fiction.

"Five or ten years down the road, the holograms and virtual objects created by augmented reality will make the objects today look primitive," Mascareñas says. "The technology is getting better every day, and we at Los Alamos are getting better with it every day, so the results 10 years from now will be mind-blowing." ★

BETTER SCIENCE = BETTER SECURITY

Los Alamos anticipates national security challenges—and solves them using innovative science and engineering.

▲ In 2014, the U.S. Department of Homeland Security got wind of a possible bomb threat: a terrorist planning to smuggle an explosives-packed toothpaste tube onto an airplane headed for the Winter Olympics in Sochi, Russia. Within 24 hours, Los Alamos scientists in the Lab s Explosive Science and Shock Physics Division determined that the threat was credible. And judging by the hole their improvised toothpaste tube bomb made in this blast plate (shown here actual size), it could have brought down an airliner.

AMERICA'S SECURITY DEPENDS ON ITS SCIENTIFIC SUPERIORITY

Deterrence works only if our adversaries recognize we have the scientific power to nullify and counter their attacks.

BY THOM MASON, LABORATORY DIRECTOR

Not every major strategic threat to our country will likely come on the tip of a nuclear warhead. How can we prepare for such unanticipated threats? By staying scientifically and technologically ahead of everyone else on as many fronts as possible.

Scientific and technological superiority has always been essential for success in a competitive, sometimes dangerous, world. That point was made in World War II by the impact of the Manhattan Project and the development of radar. It was also made by such historical efforts as the British Navy's accurate measurement of longitude and, even further back, by the military and economic advantages of Iron Age civilizations over their Bronze Age or Stone Age rivals. Today, overwhelming scientific and engineering superiority gives us the advantage of being able to detect, analyze, and counter direct challenges, particularly unforeseen challenges, from adversaries taking advantage of new or emergent technologies.

This critical advantage—what author Richard Rhodes has called the deterrence of knowledge—depends on our nation committing to a long-term investment in science. Without that commitment, we risk abdicating our nation's superior position to adversaries and exposing ourselves to new, unimagined attacks in the coming decades. Simply put, we need the deterrence of knowledge to prevent the next Pearl Harbor.

The notion of a deterrence of knowledge is built into nuclear stockpile stewardship, the program that ensures the safety, security, and effectiveness of the U.S. nuclear stockpile in the absence of nuclear explosive testing. Stockpile stewardship depends on advanced capabilities in nuclear science and technology, materials science (especially the study of materials in extreme conditions), and high-performance computing in the form of modeling, simulation, and data analysis.

These capabilities are found here in Los Alamos, as well as at the other NNSA laboratories, and those capabilities have sparked breakthroughs in areas as diverse as nuclear astrophysics, the behavior of fluids and materials, the inner workings of the human genome, and the mysterious mechanisms of high explosives.

Studies across such a panorama of scientific fields keep researchers sharp and ready for projects large or small, so we can respond with unique agility to new, unanticipated threats. For instance, when reports emerged about the possibility of a bomb in a toothpaste tube that could bring down an airliner, Los Alamos devised a prototype within a day, tested it, and came back with the answer: Yes, a toothpaste bomb was a legitimate threat. That information led to tighter airport security protocols limiting toothpaste tubes and other liquid containers to 3.4 ounces.

The NNSA laboratories have also developed sophisticated sensors for detecting nuclear detonations anywhere on the globe, devices for pinpointing any kind of bacterial infection, scanners for spotting nuclear material in closed shipping containers, and spectrometers for analyzing materials from a distance.

In the realm of computer security, Los Alamos has called on its expertise in physics and information science to create an unhackable communications device that exploits the strange properties of quantum mechanics. Our research in genomics has given us the tools to detect and potentially neutralize new biological threats, and our expertise in all things nuclear gives us the unique capability to trace any nuclear bomb and its materials back to their origin. That attribution capability could very well deter rogue states and even terrorists from detonating a weapon in the United States because the bad guys know we will find out who they are and come after them.

Our adversaries recognize that the United States has the scientific power to potentially nullify and counter their attacks. That's the deterrence of knowledge in a nutshell. Only science can overcome the profound challenge of predicting how an attack might come, what technological form it might take, and how we could thwart it.

In decades past, the United States was such a dominant force economically and scientifically that we naturally captured benefits flowing from research across almost all fields. Today, a much larger share of scientific and economic activity happens outside our borders. Last year, nearly 80 percent of the submissions to the premier journals of the American Physical Society originated in other countries. In response to that trend, we must engage with developments elsewhere, as partners when appropriate but always as leaders.

As long as we have access to the most advanced science and technology, our collective knowledge is both the deterrent and, if an adversary crosses the line, the recourse. But that deterrence will be ours only as long as we maintain our lead in science. We must guard, nurture, and extend that lead with unwavering commitment. Then, no matter what threatens us, we will be up to the challenge. ★

A version of this article was published in the online edition of the *Dallas Morning News.*

SAFEGUARDING THE LABORATORY

The first woman to direct the Defense Security Program prevents and neutralizes threats across the Lab campus.

BY DIANA DEL MAURO

Growing up with an older brother who played football for the University of New Mexico and quizzed her on sports trivia incessantly, Unica Viramontes (née Gonzales) developed a passion for sports. Even though she rarely saw women commentators on TV, she felt destined to become an ESPN sportscaster.

After graduating from Española Valley High School in Northern New Mexico, Viramontes headed to the University of California, Berkeley, to study mass communications. But when she graduated in 2003, market conditions in her field were grim.

Thankfully, Viramontes had maintained relationships from her previous part-time employment at the Lab. As a high school and college student, she had worked for Sharon Eklund, the only female manager in the Security Division at the time. That connection opened a door for Viramontes, allowing her to use her communication skills in the enigmatic security organization.

"After I graduated from college, I had a job offer in security," Viramontes remembers. "I saw the opportunity as a challenge: Let's see if I can move up in this male-dominated field. To do that, I knew I needed to learn all of security. I made conscious choices to switch jobs—even if they were lateral and I wasn't getting any more pay—just so I could learn all there was about security."

First, she used her communications degree to develop articles, websites, and training materials about security issues for Lab employees. Next, she waded into the deep waters of the field, first as a security officer and then, in succession, as a security assessment specialist, program specialist, and program manager.

PART OF AN ELITE TEAM

Now, 20 years later, Viramontes is the first female senior director of the Defense Security (DFS) Program. Her program, which includes the Security Division and the Safeguards Division, is responsible for preventing and neutralizing threats.

The job includes things like safeguarding special nuclear material, property, information, and personnel. The program also provides expertise, support, and guidance in all areas of security—from classification to personnel security, and especially nuclear material control and accountability.

"Our threats are constantly evolving," Viramontes says. "We have to anticipate what the next threat is going to be and how to stop it."

"My favorite part of the job is not knowing what's going to happen," she continues. "It's always something different. The moment you say, 'Wow, that could never happen,' it happens. I guess I thrive in chaos. I was never in the military, but to me, this is my service to the nation."

A GROWING MISSION

To help the Lab resume production of plutonium pits by 2026, Viramontes is helping the Lab strategize a security game plan. Comprehensive infrastructure improvements to the Lab's existing Plutonium Facility will enable the pit manufacturing initiative, and Viramontes aims to provide a higher level of security across the Lab to protect this work from adversaries.

"Our biggest challenge here is that we're an open campus," Viramontes explains. "If you go to any other national laboratory, there is a distinct perimeter. Unless you have a badge, you're not getting in. At Los Alamos, we have public highways passing through our property. Working with Lab leadership and Department of Energy headquarters, we need to close our campus while still allowing the public to traverse it."

BUILDING RELATIONSHIPS

In an organization dominated by men and ex-military personnel, Viramontes has earned a reputation for getting teams to flourish and accomplish difficult things.

"The success of her team members is her success. She continuously works to ensure the ideas and suggestions of her team are heard," says Bill Mairson, the chief operating officer for the Environment, Safety, Health, Quality, Safeguards, and Security Associate Directorate.

Viramontes says her management style is based on what she learned from extraordinary role models throughout her Laboratory career. "Always be humble and kind" is a mantra she holds onto from former Associate Director Mike Lansing, who showed what it looks like to value relationships and be a champion for your team.

Viramontes keeps her door open, even though some days it means she doesn't get as much done because people drop in. "If something goes wrong, they can come to me," she says. She has trained herself not to overreact to problem situations but rather focus on the remedy. She keeps score of what's going right on her team and hands out monetary awards, handwritten notes, and encouraging words. And in meetings, when employees file in with serious faces, she helps them find humor without losing sight of the gravity of a situation.

"Unica seems to have an endless supply of energy. She is always moving at 110 miles per hour," Mairson says. "But to her credit, she is also focused on continuously training and stretching her leadership team so that they grow and develop professionally." ★

▼ Entrances to the Laboratory's Plutonium Facility are protected by guards, guns, gates, and working dogs. Security personnel, many of whom are ex-military, train using both lethal and nonlethal tactics. The Lab uses drones for surveillance.

"Our threats are constantly evolving. We have to anticipate what the next threat is going to be and how to stop it."

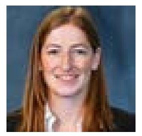
—UNICA VIRAMONTES

THE DISTINGUISHED ACHIEVEMENTS OF LOS ALAMOS EMPLOYEES

BETTER SCIENCE = BETTER SECURITY

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

Abigail Hunter, of the Computational Physics Division, and Shea Mosby, of the Physics Division, have received the Presidential Early Career Award for Scientists and Engineers. The award is the highest honor bestowed by the U.S. government on outstanding scientists and engineers in the early stages of their independent research careers. Hunter's research focuses on understanding and modeling nanoscale deformation mechanisms in metals. Mosby's research has focused on nuclear reactions relevant for applications using a variety of detector systems at the Los Alamos Neutron Science Center.



Patrick McClure and Bob Reid were honored with the 2019 Richard P. Feynman Innovation Prize for their work in developing designs for a small, cost-effective, and safe nuclear reactor to power future habitats in space, as well as remote terrestrial locations. To produce electricity, the reactor uses a nuclear fission system to generate heat for a small power converter. The technology was successfully tested in Nevada in partnership with NASA Glenn Research Center. The Laboratory is now collaborating with the power company Westinghouse to demonstrate the feasibility of using the reactors to bring power to remote, hard-to-reach locations.

A group of Laboratory scientists presented their work to businesses and the community as part of Los Alamos' annual DisrupTECH event. Kent Coombs won the Best Pitch award for his presentation about an innovative platform to grow living human heart cells on a chip. Derrick Kaseman won the award for Most Fundable Technology for his presentation about using the Earth's magnetic field to protect waterlines from chemical destruction.

As the new director of the G.T. Seaborg Institute for Transactinium Science at Los Alamos, Franz Freibert plans to focus on national nuclear security and on meeting the rising demand for well-trained, mission-focused actinide scientists and engineers. According to Freibert, an important new initiative for the Seaborg Institute will be addressing the educational needs of the workforce to conduct the Lab's charge of delivering plutonium pits by 2026.

David Teter is the Laboratory's new Weapons Infrastructure Program Director. In 2002, Teter became a Weapons project leader for metals issues for the W76-1 life extension program. In 2006, he served as a project leader in Enhanced Surveillance for Cases and Canned Subassemblies. For the past seven years, Teter was the Materials Science and Technology Division leader.

Daine Danielson, a student at the Laboratory who is working toward a Ph.D. in physics at the University of Chicago, was awarded a prize in the Innovations in Nuclear Technology R&D Awards, sponsored by the U.S. Department of Energy, Office of Nuclear Technology R&D. Danielson's winning paper was titled, "Directionally Accelerated Detection of a Second, Unknown Reactor with Antineutrinos for Mid-Field Nonproliferation Monitoring."

The American Association for the Advancement of Science selected bioscientist Harshini Mukundan as one of 125 IF/THEN Ambassadors. These ambassadors will be featured in a digital library that the media and educators can use to spread powerful portrayals of women in science, technology, engineering, and mathematics.

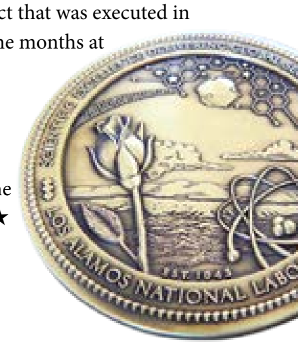
Daniel Trugman, Earth and Environmental Sciences Division's Richard P. Feynman Postdoctoral Research Fellow, garnered an HPC Innovation Excellence Award for his recent Quake Template Matching project. Trugman shares the award with his collaborators on the recent southern California earthquake big data analysis that resulted in the most comprehensive earthquake catalog to date, which may help researchers detect and locate quakes more precisely.

Benjamin Ryan and George Wong, of Computational Physics and Methods, are members of the Event Horizon Telescope collaboration, which won the 2020 Breakthrough Prize in Fundamental Physics for creating the first image of a black hole. Known as the "Oscars of Science," this prize annually recognizes achievements in the life sciences, fundamental physics, and mathematics.

The Regents of the University of California have appointed Michael Anastasio as the chair of the Triad Board of Directors, replacing the late Ellen Tauscher. Anastasio is a former director of both Los Alamos and Lawrence Livermore national laboratories. Triad National Security, LLC, operates Los Alamos National Laboratory.

Five Los Alamos researchers were inducted into the Innovation Honor Society for their outstanding contributions to scientific discovery, innovation, and the transfer of technology to the commercial sector. Inductees are Po-E (Paul) Li, Velimir (Monty) Vesselinov, Andrew Sutton, John Lewellen, and Alp Findikoglu.

Stephen Becker, Stephen Yarbro, and the team of Timothy Foley and Jonathan Zucker were awarded the Los Alamos Global Security Medal, which recognizes the exceptional achievements of active or recently retired employees who have made significant contributions to the Laboratory's global security mission. Becker is a retired Laboratory Fellow and design physicist. Yarbro is one of the world's leading experts in plutonium and actinide process technology. Foley and Zucker showed outstanding technical leadership over a high-profile, high-risk national security project that was executed in fewer than nine months at a cost of $1.2 million, and involved personnel from across the Laboratory. ★



50 YEARS AGO

On November 21, 1969, Los Alamos Scientific Laboratory conducted the Planer test at the Nevada Test Site. Planer was a weapons-related test with a yield of less than 20 kilotons that was conducted to gather data on a nuclear device. Planer was part of Operation Mandrel, a series of 52 tests conducted from 1969 to 1970. ★

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THEN + NOW

Above, New Mexico Congressman Manuel Lujan Jr. takes a spin on one of several bicycles used for quick transportation in the accelerator tunnel at the Los Alamos Meson Physics Facility (now the Los Alamos Neutron Science Center) in 1970.

On July 31, 2019, Laboratory Director Thom Mason wielded a giant pair of scissors and cut a ribbon to announce the opening of a new pedestrian and bicycle path through the Lab s main technical area. Mason (center) then hopped on his bike and tested the path s integrity with members of the Bicycle Safety Committee. Improving the walking, cycling, and driving experience and subsequent safety of Lab employees is part of what makes Los Alamos a quality place to work. ★