LOS ALAMOS NATIONAL LABORATORY ◇ SPRING 2022

NATIONAL ★ SECURITY SCIENCE

THE THREAT REDUCTION ISSUE

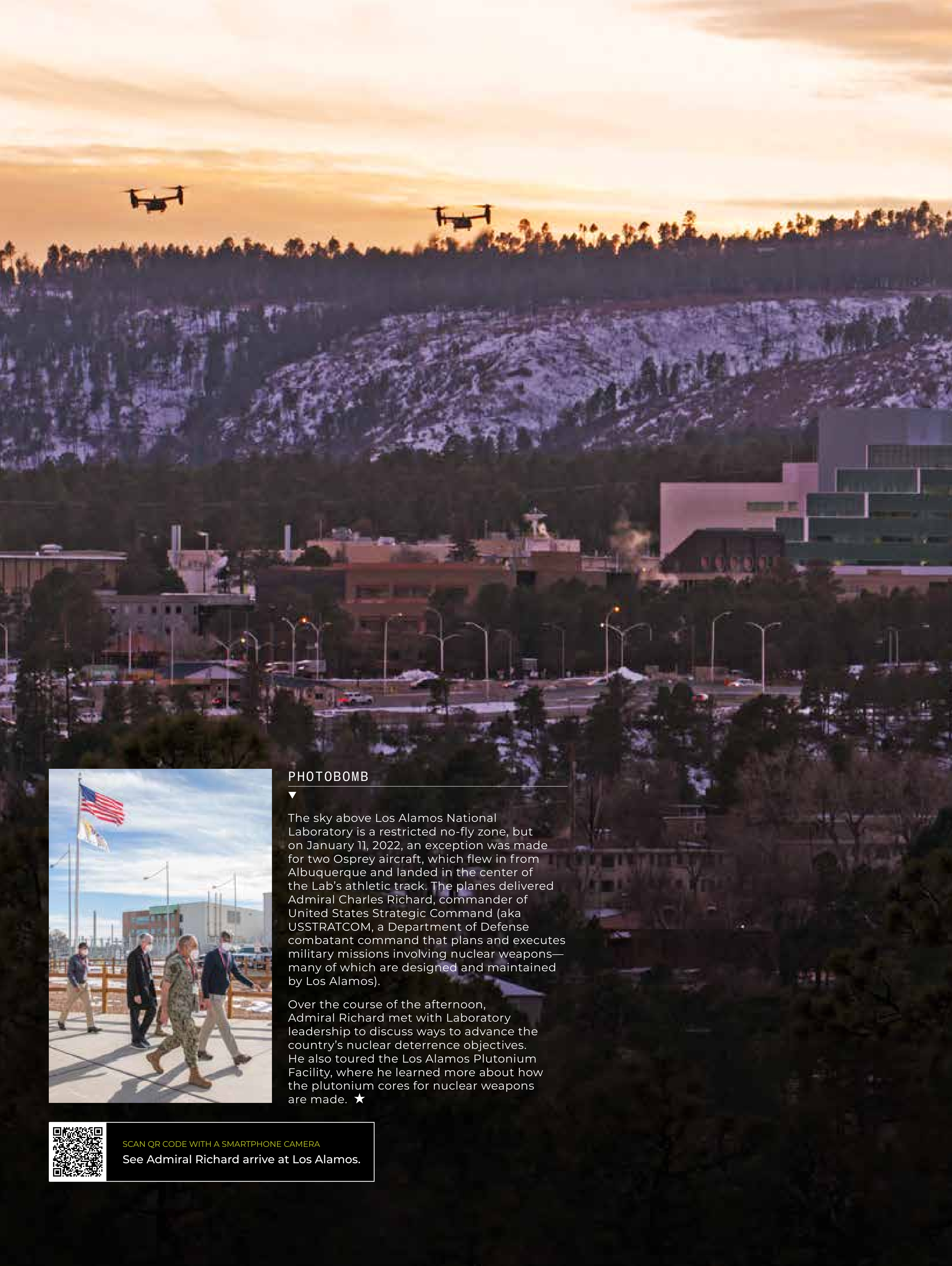
Waging nuclear peace:
Los Alamos National Laboratory helps safeguard nuclear materials.

Cosmic custodians:
Satellite instruments can detect nuclear detonations on Earth and in outer space.

Countering nuclear smuggling:
Los Alamos helps stop the spread of dangerous materials.

+PLUS:

A treaty to prevent the spread of nuclear weapons	The ground is shaking. Is the cause an earthquake or an explosion?	Turning plutonium metal into powder



PHOTOBOMB

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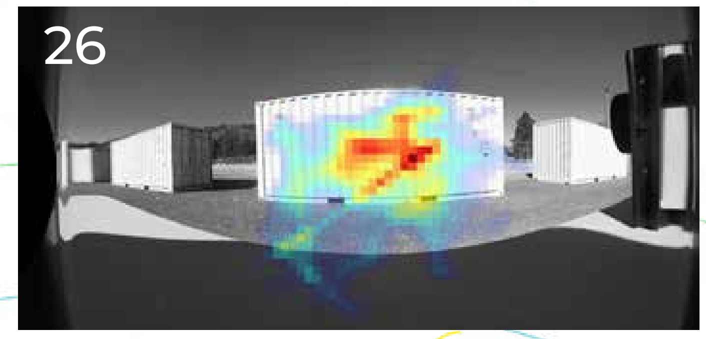
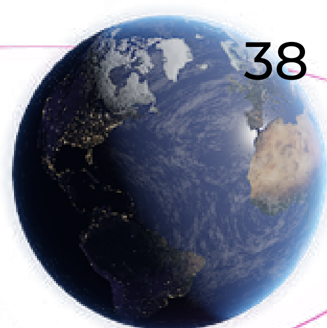
The sky above Los Alamos National Laboratory is a restricted no-fly zone, but on January 11, 2022, an exception was made for two Osprey aircraft, which flew in from Albuquerque and landed in the center of the Lab's athletic track. The planes delivered Admiral Charles Richard, commander of United States Strategic Command (aka USSTRATCOM, a Department of Defense combatant command that plans and executes military missions involving nuclear weapons—many of which are designed and maintained by Los Alamos).

Over the course of the afternoon, Admiral Richard met with Laboratory leadership to discuss ways to advance the country's nuclear deterrence objectives. He also toured the Los Alamos Plutonium Facility, where he learned more about how the plutonium cores for nuclear weapons are made. ★

SCAN QR CODE WITH A SMARTPHONE CAMERA

See Admiral Richard arrive at Los Alamos.





IN THIS ISSUE

FEATURES

About the cover: On December 7, 2021, this Atlas V rocket launched from Florida's Cape Canaveral Space Force Station. The rocket carried a satellite with two payloads on board that were designed and developed at Los Alamos National Laboratory. To learn more about these payloads—SABRS-3 and SENSER—and how they are able to detect nuclear detonations in outer space, turn to p. 38. ★

Photo: United Launch Alliance

THE THREAT REDUCTION ISSUE

Los Alamos plays a pivotal role in keeping the United States—and the world—safe from nuclear threats.

BY NANCY JO NICHOLAS
Associate Laboratory Director
for Global Security

This special issue of *National Security Science* magazine celebrates Los Alamos National Laboratory's contributions to global security and examines how we can best prepare to meet the growing nuclear proliferation challenges of the future. The issue is especially timely given that the Tenth Review Conference for the international Treaty on the Non-Proliferation of Nuclear Weapons (or NPT, see p. 6) is scheduled to take place in 2022, after being postponed nearly two years because of the COVID-19 pandemic.

At Los Alamos, we can look back with pride at our achievements in support of the NPT over the past 50 years. We also recognize that the NPT's three pillars—nuclear nonproliferation, nuclear disarmament, and the peaceful uses of nuclear energy—are more relevant today than ever.

Nuclear technologies and the issues that accompany them have grown immensely across the globe over the past five decades, and even greater changes loom on the horizon. A renaissance in the nuclear power industry in developed and developing nations, in part to address the threat of climate change, has spurred expansion of nuclear engineering and research programs, and as developments in Iran and North Korea demonstrate, the nonproliferation regime faces enormous pressures.

An entire branch of multidisciplinary science—the science of nuclear nonproliferation—is devoted to addressing these challenges. Timely, accurate, science-based tools are indispensable for evaluating proliferation threats to national and global security and giving policy makers the information they need to act.

Easy to describe, but complex to carry out, nonproliferation science tracks peaceful nuclear activity and develops tools and methods to counter the spread of nuclear weapons materials and technologies. Our Laboratory leads in many key areas of nonproliferation work, including, notably, international nuclear safeguards (see p. 16), which verify nuclear materials are secure and not diverted to weapons programs. Since 1957, Los Alamos has partnered with the International Atomic Energy Agency to develop technology for this purpose.

At Los Alamos, we also have an important role in arms control verification. As a weapons laboratory, we are uniquely suited to address challenging issues, such as how to verify treaty compliance while protecting sensitive information. Our scientists and engineers lead research and development efforts in nuclear proliferation detection, which involves monitoring for signs of weaponization by, for example, continuously scanning the atmosphere (see p. 38) and tracking earth-shaking events (see p. 50) to determine if a weapons test has occurred.

I hope you enjoy reading this issue of *NSS* and learning more about the past and future nonproliferation endeavors at Los Alamos National Laboratory. ★

As the associate Laboratory director for Global Security at Los Alamos National Laboratory, Nancy Jo Nicholas oversees nuclear nonproliferation, nuclear counterproliferation, counterterrorism, and related programs that rely on technical innovation to address complex threats to global security. She has worked at Los Alamos since 1990.

MASTHEAD

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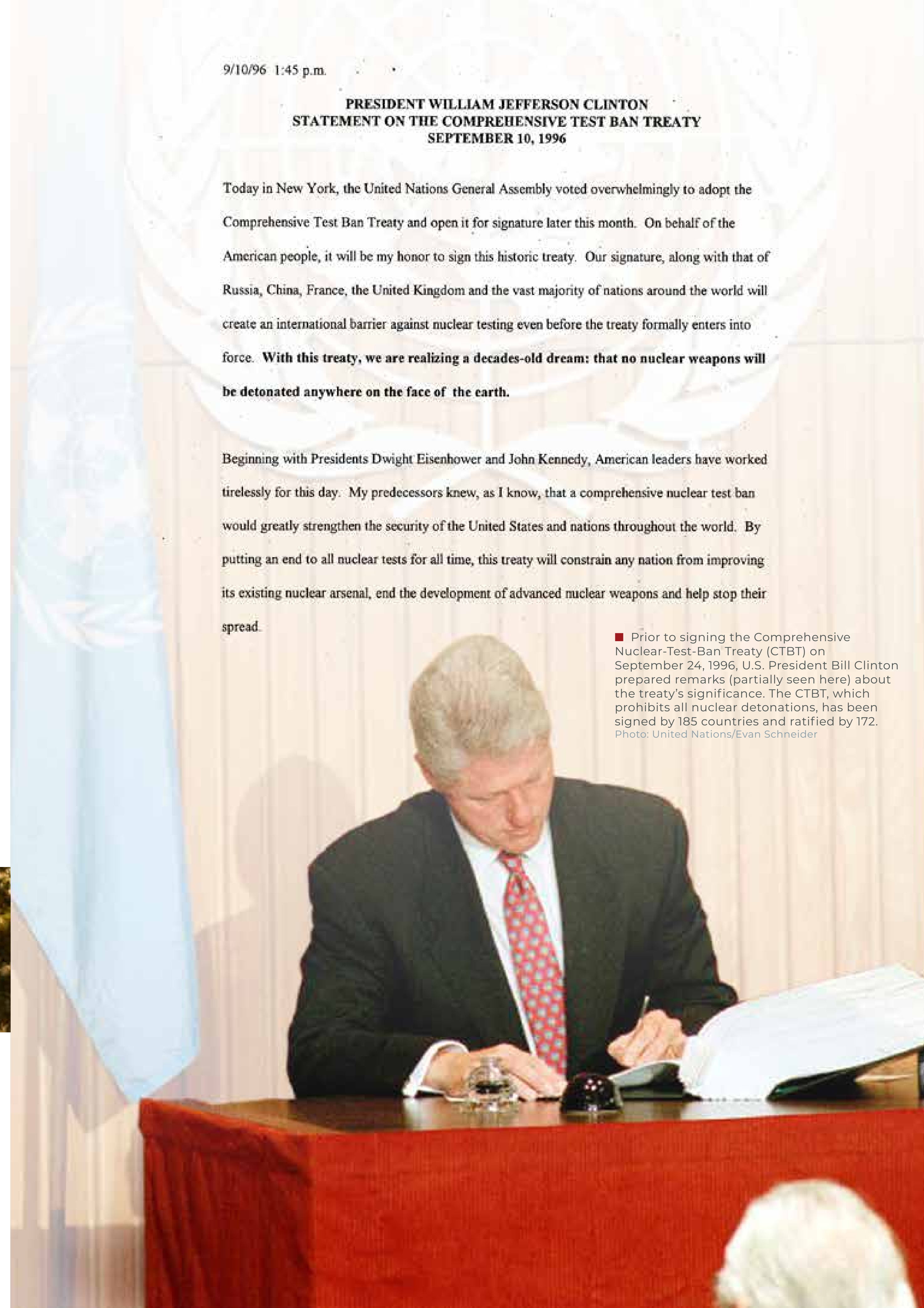
NSS STAFF SPOTLIGHT

Graduate student Jake Bartman, who is studying creative writing at the University of Florida, spent last summer working for *National Security Science*. Shortly after drafting "Waging nuclear peace" (p. 16), Bartman married his longtime partner, Los Alamos native Maura Taylor, in a small ceremony in Santa Fe, New Mexico. He'll return to Los Alamos this summer to continue writing for the magazine. ★



9/10/96 1:45 p.m.

PRESIDENT WILLIAM JEFFERSON CLINTON
STATEMENT ON THE COMPREHENSIVE TEST BAN TREATY
SEPTEMBER 10, 1996

Today in New York, the United Nations General Assembly voted overwhelmingly to adopt the Comprehensive Test Ban Treaty and open it for signature later this month. On behalf of the American people, it will be my honor to sign this historic treaty. Our signature, along with that of Russia, China, France, the United Kingdom and the vast majority of nations around the world will create an international barrier against nuclear testing even before the treaty formally enters into force. **With this treaty, we are realizing a decades-old dream: that no nuclear weapons will be detonated anywhere on the face of the earth.**

Beginning with Presidents Dwight Eisenhower and John Kennedy, American leaders have worked tirelessly for this day. My predecessors knew, as I know, that a comprehensive nuclear test ban would greatly strengthen the security of the United States and nations throughout the world. By putting an end to all nuclear tests for all time, this treaty will constrain any nation from improving its existing nuclear arsenal, end the development of advanced nuclear weapons and help stop their spread.

■ Prior to signing the Comprehensive Nuclear-Test-Ban Treaty (CTBT) on September 24, 1996, U.S. President Bill Clinton prepared remarks (partially seen here) about the treaty's significance. The CTBT, which prohibits all nuclear detonations, has been signed by 185 countries and ratified by 172.
Photo: United Nations/Evan Schneider

INFOGRAPHIC

THE INTERSECTION

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

NASA researchers estimate that the explosive force of the January 15 underwater volcanic eruption near the island nation of Tonga was the equivalent of 10 megatons of TNT—that's more than 500 times as powerful as the atomic bomb dropped on Hiroshima, Japan, in 1945. Photo: NASA

In the 1990s, Catherine Raven, author of the recent best-selling memoir *Fox and I*, spent five months working on the Human Genome Project at Los Alamos National Laboratory. She mentions the Lab on p. 179 of her book.

In December 2021, Bradbury Science Museum Director Linda Deck (left) and Los Alamos National Laboratory Director Thom Mason launched Challenge Tomorrow, two mobile exhibits that will travel to schools, fairs, and recruitment events throughout New Mexico.

J. Robert Oppenheimer (left) and General Leslie Groves are festive—and freezing—in downtown Los Alamos during a December 2021 snow storm. Photo: Los Alamos County

Oppenheimer, a movie about the legendary scientific director of the Manhattan Project, is in the works. Based on the Pulitzer Prize–winning book *American Prometheus* and featuring a star-studded cast (Cillian Murphy, Matt Damon, Robert Downey Jr., and Emily Blunt to name a few), the film is slated to hit screens in July 2023. Photo: Universal Pictures

CULTURE

SCIENCE

QUOTED

"I grew up partly in the mountain town of Los Alamos, which is dominated by the national laboratory complex founded as part of the Manhattan Project....My grandmother made precisely one trip to the high desert to visit us, when I was a baby. The altitude was bad for her blood pressure. There was nowhere to get good Chinese food. She was unimpressed."

—Journalist Jada Yuan, in her *Washington Post* essay, "Discovering Dr. Wu." Yuan's grandmother, Chien-Shiung Wu (pictured), was an influential physicist recently featured on a U.S. postage stamp. Yuan's father, Vincent Yuan, is a nuclear physicist at Los Alamos National Laboratory. ★

MOVIES

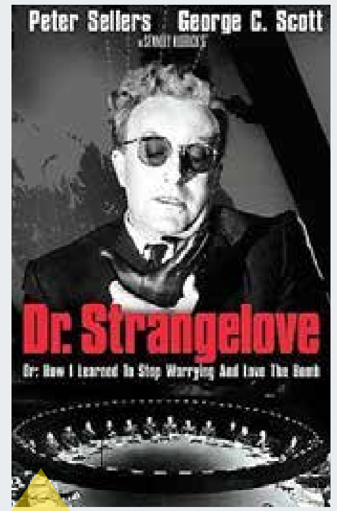
NOW STREAMING

Check out these films about Los Alamos and atomic history.

BY BRYE STEEVES

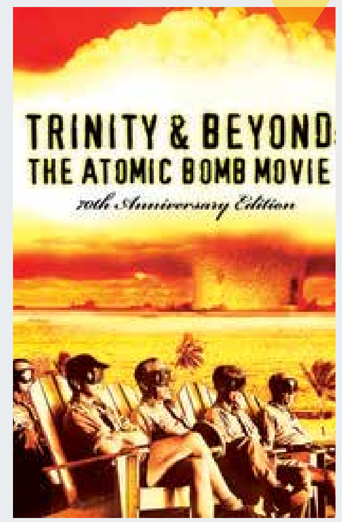
Social distancing and quarantining have many of us turning to streaming services to pass time. Sometimes it's hard to know what to watch, so let Riz Ali and Alan Carr (both of the National Security Research Center [NSRC] at Los Alamos National Laboratory) be your guides. Here they share their top picks about Los Alamos and related history. ★

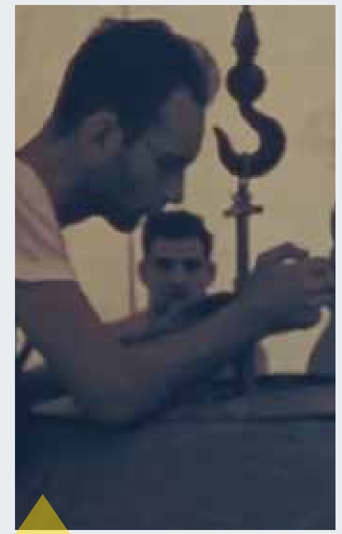
▲ NSRC Director Riz Ali (left) and Senior Historian Alan Carr. Learn more about the NSRC at nsrc.lanl.gov.



Dr. Strangelove Or: How I Learned to Stop Worrying and Love the Bomb
In this satirical, black-and-white movie released in 1964, a U.S. Air Force general orders his bombers to destroy the USSR.
Carr says: "Yes, it's fiction, though some senior government officials have said the premise was plausible and the movie prompted the development of some of the nuclear weapons use-control measures later implemented."

Trinity & Beyond: The Atomic Bomb Movie
Narrated by William Shatner, this documentary was released in 1995 and follows the development of nuclear weapons from their inception through the first Chinese atomic bomb test.
Carr says: "Peter Kuran, who made the film, won an Academy Award for developing film preservation techniques. He was also a lead animator for the original *Star Wars* films and is a consultant to the NSRC."





Trinity Films
This hour-long video features footage without sound of the Trinity test—the world's first detonation of an atomic bomb—on July 16, 1945. The Trinity footage was digitized by the NSRC and can be watched on Carr's YouTube channel.
Ali says: "It's incredible to have this footage surrounding the moment that the world entered into the nuclear age—what Trinity test director Kenneth Bainbridge described as 'a foul and awesome display.'"

Plutonium metal preparation and plutonium disk fabrication videos
These black-and-white, 10-minute videos show plutonium metal preparation and plutonium disk fabrication, respectively, at what was then Los Alamos Scientific Laboratory. Both were digitized by the NSRC and are available on Carr's YouTube channel.
Ali says: "I like watching videos like these because it reminds me just how important the preservation of historic materials is to the Lab and our mission. If it weren't for digitization efforts, footage like this would no longer exist."

The Flavius Factor* and *Trust, But Verify
These 30-minute documentaries were narrated in the '80s by Academy Award–winning actor and World War II veteran Charlton Heston. *Flavius* is a programmatic overview of the Lab, and *Trust* is about the collaboration between American and Soviet scientists. Both were digitized by the NSRC and can be watched on Carr's YouTube channel.
Carr says: "Interestingly, Heston received his security clearance to work on a series of classified films at Los Alamos. As a veteran, he was happy to come here for these projects and wouldn't accept payment for the work. The short documentaries have since been declassified and are publicly available."

The First 25 Years, A Documentary on Los Alamos Scientific Laboratory
In this film from 1970, Norris Bradbury, the Lab's second director, guides viewers through 25 years of Lab history. This 30-minute film was digitized by the NSRC and can be watched on Carr's YouTube channel (search for Historian Alan B. Carr).
Ali says: "This documentary offers a real step back in time—both at the Lab and the town of Los Alamos—and a great first-person account straight from Bradbury."

SCAN QR CODE WITH A SMARTPHONE CAMERA
See clips from each film here.

INTERNATIONAL RELATIONS

THE NUCLEAR NONPROLIFERATION TREATY

Since 1970, the Treaty on the Non-Proliferation of Nuclear Weapons has helped prevent the spread of nuclear weapons, and it has defined much of the work at Los Alamos National Laboratory.

On July 1, 1968, the world was in turmoil. American troops were embroiled in the sixth month of the Vietnam War Tet Offensive, and the American death toll for the conflict as a whole had reached the tens of thousands. Martin Luther King Jr. and Robert F. Kennedy had both recently been assassinated. Czechoslovakia was only weeks away from a bloody invasion by Soviet forces. And amidst all of this was the ever-present Cold War fear of nuclear war. But on this day, something positive—something peaceful—happened. On July 1, 1968, the United States and the Soviet Union, along with the United Kingdom, signed the Treaty on the Non-Proliferation of Nuclear Weapons, more commonly known as the Non-Proliferation Treaty or NPT.

The NPT, which went into effect on March 5, 1970, was born of the Cold War, with the goal of averting "the devastation that would be visited upon all mankind by a nuclear war." Although the Cold War between the United States and the Soviet Union continued until the early 1990s, the NPT helped prevent an arms race that had the potential to involve virtually every country in the world. The treaty also required nations in possession of nuclear weapons, including the United States and the Soviet Union, to reduce those arms.

The main components of the NPT are that

- Nuclear Weapon States—the five countries that possessed nuclear weapons at the time the NPT was signed (see map on p. 25)—will not give nuclear weapons or nuclear weapons information to Non-Nuclear Weapon States. Also, Non-Nuclear Weapon States must not accept nuclear weapons or nuclear weapons information.
- Non-Nuclear Weapon States commit to accept safeguards on transfers of nuclear technology for peaceful purposes. These safeguards are determined and enforced by the International Atomic Energy Agency (IAEA).
- all signatories work "toward the further development of the applications of nuclear energy for peaceful purposes."
- all signatories work toward an overall global reduction of nuclear weapons and the avoidance of another nuclear arms race.
- the treaty would be valid for 25 years (until 1995), at which point its future would be evaluated.

The NPT was difficult to negotiate because it allowed some states to keep nuclear weapons while requiring other states to give up the ability to pursue them. But, after many rounds of negotiation, the treaty was finalized.

For almost three decades, two nuclear states, China and France, did not sign. They both acceded to the treaty in 1992, first China in March and then France in August. Several nonnuclear states also refrained from signing, notably India, Israel, Pakistan, Saudi Arabia, and South Africa, nations that, in 1968, were on the verge of becoming nuclear states (two of which did—India in 1974 and Pakistan in 1983). South Africa signed in 1991, admitting two years later to a nuclear program and then dismantling all of its weapons by 1994. Current non-parties include India, Israel, Pakistan, South Sudan, and North Korea, the last of which originally signed but withdrew in 2003.

The NPT's first expiration date was also its last. On May 11, 1995, the treaty was extended without an end date, so the states party to the treaty still abide by its regulations and agreements. The treaty's extension continues to require Nuclear Weapon States to pursue disarmament and arms control agreements, which necessitates a great deal of work in treaty verification and monitoring, much of which is done at Los Alamos National Laboratory. "For more than 50 years, work at Los Alamos in nonproliferation and arms control has been grounded in the NPT," says Nancy Jo Nicholas, associate Laboratory director for Global Security. "I am proud of our world-renowned expertise in support of this important treaty, particularly in international safeguards, export control, and arms control verification."

"The Laboratory's support for the NPT spans most of its history and activities, from providing the technologies necessary for detection, monitoring, and verification, to support for the IAEA, to providing the means for deterrence, which has been one of the most effective U.S. nonproliferation policies," says Will Tobey, director of the Lab's Office of National Security and International Studies.

From the time it went into effect, the NPT has provided some stability in the often unstable landscape of nuclear weapons. It prevented, and continues to prevent, the spread of nuclear weapons, and it motivates its signatories to prioritize the development of nuclear energy for peaceful purposes, from nuclear power plants to power for outer space missions. This landmark treaty continues in perpetuity, keeping the world safer. ★

"For more than 50 years, work at Los Alamos in nonproliferation and arms control has been grounded in the NPT."

—NANCY JO NICHOLAS

President Johnson signed the NPT in the East Room of the White House. He called the event a "very reassuring and hopeful moment in the relations among nations."
Photo: LBJ Presidential Library

Q&A

NUCLEAR WATCHDOG

Nina Rosenberg, Nuclear Nonproliferation and Security Program director, discusses the Lab's global security mission and her role in it.

By the late 1980s, Nina Rosenberg had earned three geoscience degrees, but working at a national laboratory wasn't on her radar until her husband accepted a postdoctoral appointment at Los Alamos National Laboratory. "Thirty years later, I'm so grateful we moved to New Mexico," she says, reflecting on her career, which has spanned not one but two national laboratories. (From 1998 to 2011, she worked at Lawrence Livermore National Laboratory.)

At Los Alamos, Rosenberg started off working on a geological repository for nuclear waste, then, over the years, began to manage projects and gain interest in arms control and nuclear nonproliferation—the work of preventing the spread of nuclear weapons and materials. In 2012, she became the director of the Lab's Nuclear Nonproliferation and Security Program, where her primary responsibility is to make sure the program functions smoothly and effectively. "I see my most important job as hiring excellent program managers and support staff, then providing them with the support they need to do their jobs," she says.

■ Nina Rosenberg

What is the role of the Nuclear Nonproliferation and Security Program?

The Laboratory's work in support of its nuclear nonproliferation mission is led by our office. Our focus is on preventing countries without nuclear weapons and would-be terrorist groups from developing nuclear weapons or acquiring weapons-usable nuclear materials, equipment, technology, and expertise. Our work ranges from cooperative work with international partners to highly classified, unilateral approaches.

On the cooperative side, for example, we provide leadership and technical expertise to the International Atomic Energy Agency (IAEA) in its safeguards program, which helps ensure that nuclear materials for peaceful purposes are not diverted to nuclear weapon activities. The Lab has pioneered a wide range of IAEA measurement tools in use today and provides important training courses, including a class required for new IAEA inspectors.

Another example is the technical support we provide for the installation and maintenance of radiation detection systems at sites all across the world to help our many partner countries strengthen their capabilities to detect, disrupt, and investigate nuclear smuggling.

We also work with colleagues at other national laboratories to enhance U.S. capabilities to detect foreign nuclear material production and weapons development activities as early as possible, often using testbeds and facilities in New Mexico, Nevada, and across the nuclear security complex.

Another area we focus on is nuclear verification and monitoring. This takes many forms, from providing key science and technology to support the U.S. space-based nuclear detonation detection capability (see p. 38); to supporting national and international ground-based systems to detect underground nuclear tests (see p. 50); to developing the technology, systems, and approaches to respond to future arms control treaties or situations where the United States may need to account for a country's nuclear material and activities.

Our work is incredibly broad, and it is important to national and global security.

Why is Los Alamos a good place for this work?

Our nonproliferation work is based on activities we have been doing since day one. We are uniquely knowledgeable about what to look at when trying to decide, for example, whether a facility of interest is conducting conventional military or industrial activities, or whether that facility is involved with nuclear weapons work. We often use the expression "it takes a nuclear weapons lab to help find a nuclear weapons lab."

However, Los Alamos is much more than a nuclear weapons laboratory. The Lab's technical expertise, weapons knowledge, and operational capabilities make us impactful in providing solutions to important nuclear nonproliferation and nuclear security problems.

We are able to safely work with types and quantities of nuclear materials that very few others are. For example, when IAEA inspectors come to Los Alamos for their training, they can obtain hands-on experience making measurements from a more comprehensive group of uranium and plutonium samples than they have previously encountered. They are also able to receive instruction from experts who have extensive experience developing and using these instruments. ★

EDUCATION

SAFEGUARDING THE FUTURE

The Keepin Program helps train a new generation of safeguards experts.

BY JAKE BARTMAN

At the outset of the Manhattan Project, its director, J. Robert Oppenheimer, traveled across the United States, from the University of California, Berkeley, to the University of Chicago and beyond, to hire the scientists who would build the first atomic bombs at a top-secret laboratory in Los Alamos, New Mexico.

Today that laboratory is Los Alamos National Laboratory. No doubt its director, Thom Mason, has too many responsibilities to spend weeks roaming from school to school in search of talent. But the pipeline that leads scientists and students from universities to Los Alamos remains as vital as ever to the Laboratory's success.

One way that the Laboratory brings students to Los Alamos is the G. Robert Keepin Nonproliferation Science Program, which was founded in 2017. This summer program attracts some of the nation's brightest college students for an intensive eight-week introduction to the world of nonproliferation and nuclear security.

"When you're a kid, you want to be a firefighter or a police officer, or a lawyer or a doctor," says Nina Rosenberg, director of the Laboratory's Nuclear Nonproliferation and Security Program (see p. 8), which organizes the Keepin Program together with the Lab's Nuclear Engineering and Nonproliferation division. "Most people who are 10 years old don't say, 'I want to work in nonproliferation and security.'"

The Keepin Program helps address that problem. "It's a great opportunity for us to introduce really smart people to this field," Rosenberg says.

Many of the students who participate in the Keepin Program are fellows in the Nuclear Science and Security Consortium (NSSC). Each year the NSSC, which is sponsored by the National Nuclear Security Administration (NNSA) and led by the University of California, Berkeley, awards fellowships to undergraduates, graduate students, and postdocs from 11 partner institutions. Students attend the Keepin Program as a part of that fellowship.

In 2021, NSSC fellows composed half of the 12 students who attended the Keepin Program, representing nine academic institutions. Their majors ranged from international studies and diplomacy to nuclear engineering and radiochemistry.

Jack Morrison, a materials science doctoral student at the University of Florida, learned about the Keepin Program while on a yearlong fellowship at the Nevada Field Office (NFO). (The NFO comprises the Nevada National Security Site and related laboratories and facilities that support the NNSA.)

In addition to working with Los Alamos scientist Stacey Eaton on research related to radioisotope heater units, Morrison has appreciated the chance to tour facilities such as the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, and to interact with experts in the safeguards field.

Although program attendees typically would have the opportunity to travel to Sandia National Laboratories and other facilities, the COVID-19 pandemic has put that element of the program on hold. Morrison believes that the program has been worthwhile nonetheless. "It's been a good experience," he says, noting that he would consider a career at a national laboratory in the future.

Although the Laboratory hopes for that reaction from students, Rosenberg says that the Keepin Program's goals are broader.

"Maybe they'll want to work in another area, or be a professor. That's a win for us, too," Rosenberg says. "It helps to have people learn about this important mission, wherever they go." ★

■ Keepin Program participants visit the Detector for Advanced Neutron Capture Experiments at the Los Alamos Neutron Science Center (right) and the Device Assembly Facility at the Nevada National Security Site (above).

STOCKPILE STEWARDSHIP

CELEBRATING SUCCESS WITH AN EYE ON THE FUTURE

Leaders across the nuclear security enterprise applaud the first production unit of the B61-12 while recognizing there is still work to be done.

BY WHITNEY SPIVEY

The B61 gravity bomb, deployed to United States Air Force and North Atlantic Treaty Organization bases, has almost 50 years of service, making it the oldest and most versatile weapon in the enduring U.S. nuclear stockpile. Numerous modifications have been made to the B61 since it entered service in 1968, and four B61 variants remain in the stockpile: the B61-3, -4, -7, and -11.

For nearly a decade, the aging weapon system has been undergoing a life extension that consolidates and replaces three B61 weapon designs (the B61-3, -4, and -7) and combines them into one updated design: the B61-12. Los Alamos and Sandia National Laboratories are the design agencies for the B61-12 life extension program (LEP), with Los Alamos also being responsible for producing detonators and other classified components.

The B61-12 LEP refurbishes, reuses, or replaces all the bomb's nuclear and nonnuclear components, extending the bomb's service life by at least 20 years. The LEP addresses the bomb's age-related issues and enhances its reliability, ease of field maintenance, safety, and use control. When fielded, the B61-12 will balance greater accuracy, provided by the modern tail kit, with a substantial reduction in yield, but without any overall change in military requirements or capability.

On November 23, 2021, the first production unit (FPU) of the B61-12 was delivered. In the FPU phase of the nuclear weapons life cycle, all weapons components have been produced through qualified processes; all the necessary qualification testing, engineering analysis, and physics certification activities have been completed; and the FPU has been built at the Pantex plant, near Amarillo, Texas. In other words, all the processes required to produce the weapon are qualified and exercised, and the B61-12 is on track for full-scale production in May 2022.

"It has been, and continues to be, an honor to work with such a diverse and integrated team of talented technicians, designers, scientists, engineers, physicists, and other professional staff to achieve the B61-12 FPU and meet one of our country's most critical national security milestones," says engineer and program manager Jessica Trujillo. "This has been a long journey with the support and collaboration of our national security enterprise partners. I am proud to say we have delivered a quality product that meets the highest standards of Los Alamos National Laboratory weaponry."

On January 20, 2022, the B61-12 FPU was celebrated during a virtual event hosted by the Kansas City National Security Campus. More than 300 people attended from across the nuclear security enterprise and the United States Air Force, including Jill Hruby, head of the National Nuclear Security Administration (NNSA) and Los Alamos Director Thom Mason.

After thanking all those involved, Mason noted that work on the B61-12 is far from over. "FPU is a really important and tangible milestone, but we've now got to move on to rate production and completing the program," he said. "I am absolutely confident that the team that got us to this point is going to see us through in support of our national deterrence mission—which one only needs glance at the newspapers to understand is critically important in today's world."

The B61-12 LEP and other ongoing weapons modernization programs will ensure the safety, security, and military effectiveness of the U.S. nuclear stockpile in this increasingly complicated and uncertain global environment.

"The effectiveness and credibility of our nuclear stockpile depends on our scientific engineering, technological, and production capabilities," Hruby said. "[The B61-12 LEP] provides me, other leaders, our allies, and our adversaries confidence that we will be able to deliver on the future life extension and modernization programs ahead. This achievement clearly demonstrates that NNSA can innovate, collaborate, and deliver our mission on behalf of the American people." ★

■ The B61-12 LEP "is vital to sustaining the credibility of America's air-delivered nuclear deterrent capability and ensuring our continued ability to deter threats to our nation and, importantly, to our allies," NNSA Administrator Jill Hruby explained during a virtual celebration of the bomb's first production unit.
Photo: DOD F-35 Joint Program Office

QUOTED

"The measure of success is not the absence of challenges. The measure of success is the resilience to overcome challenges."

—Los Alamos Director Thom Mason during an event that recognized the B61 LEP ★

ABSTRACTS

Los Alamos National Laboratory, through its ARIES program, is the only place in the United States that can convert plutonium metal into powder.

TECHNOLOGY

METAL TO POWDER

The ARIES program alters plutonium so that it can't be used in nuclear weapons.

BY MAUREEN LUNN

In astrology, the Aries zodiac sign—a ram—is associated with strength, bravery, and ambition. A program of the same name at Los Alamos National Laboratory also embodies those characteristics—but in relation to national security.

The purpose of the ARIES (Advanced Recovery and Integrated Extraction System) program is to convert plutonium metal that could be used to make nuclear weapons into plutonium oxide powder, which cannot be used in nuclear weapons. The program supports the Laboratory's—and the nation's—nuclear nonproliferation commitments by helping to prevent the spread of weapons-grade nuclear material.

"Not only does weapons-usable plutonium pose a security threat due to proliferation of nuclear weapons, but there are potential environmental, safety, and health consequences if this surplus material is not properly safeguarded and managed," explains ARIES Program Director Leisa Davenhall.

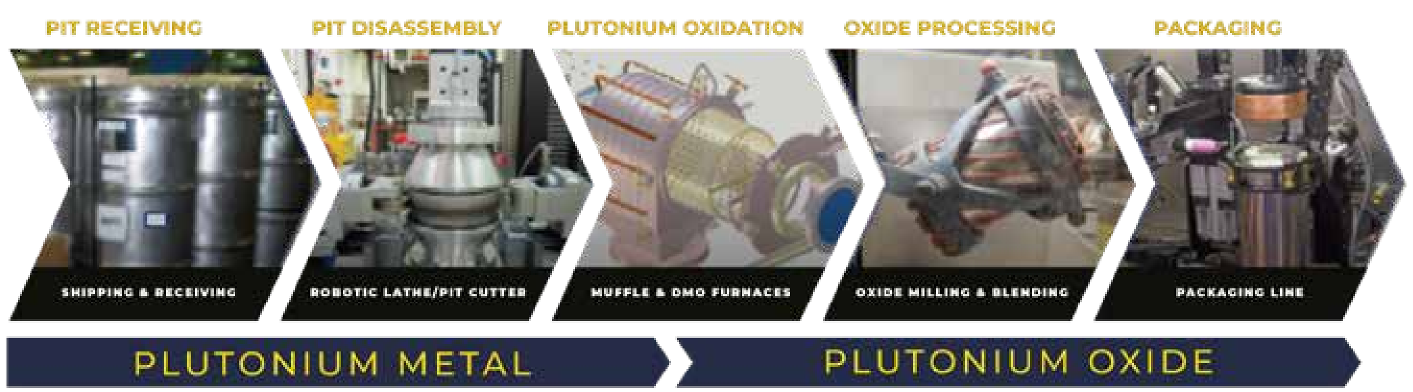
ARIES dates back to 1998, when the program was mandated by U.S. policy born out of an agreement between United States and Russia. In 2000, each country began working toward the conversion of 34 metric tons of weapons-grade plutonium sourced from Cold War weapons declared no longer necessary for national defense. Despite Russia purportedly suspending the agreement in 2016, the United States has continued its ARIES work in support of its nuclear nonproliferation goals.

Initially, the United States hoped to convert weapons-grade plutonium into fuel for commercial power reactors, but that plan was scrapped when cost estimates skyrocketed. Instead, in 2018, Congress approved a much less expensive "dilute and dispose" plan in which Los Alamos receives surplus nuclear weapon pits (cores) from the Pantex plant near Amarillo, Texas. The pits are disassembled, using a machine called a pit cutter, and the plutonium is placed into a furnace for up to 48 hours. The heat from the furnace turns the plutonium metal into plutonium oxide powder, which is then blended to ensure uniformity.

Next, the plutonium oxide powder is placed in special stainless-steel cans, which are welded shut for safe interim storage and transport to the Savannah River Site in Aiken, South Carolina. There, it is diluted with other materials and packaged for eventual transport to the Waste Isolation Pilot Plant in Carlsbad, New Mexico, where it will be stored safely and indefinitely in underground salt flats.

"When it comes to producing plutonium oxide, not a lot has changed in the process over the past two decades," explains Steve McKee, a technical project manager with the ARIES program. "That gives the program a sense of consistency as we continue to inch closer to our goal of 34 metric tons."

To date, more than a metric ton of weapons-grade plutonium has been safely processed through the ARIES program. In 2022, ARIES program managers hope to produce between 100 and 150 kilograms of oxide. "The process is slow" McKee says, "but we are making the world safer, one kilogram at a time. ★

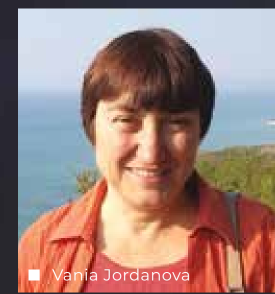


SPACE

FORECASTING SPACE WEATHER

Vania Jordanova has spent her career in the eye of the geomagnetic storm.

BY J. WESTON PHIPPEN



Vania Jordanova

The American Geophysical Union (AGU) is one of the most respected scientific organizations in the world. Its 130,000 members study Earth, space, and everything between. Last year, Vania Jordanova, of Los Alamos National Laboratory's Space Science and Applications group, became an AGU fellow—a title bestowed on just 0.1 percent of members.

"I have been a member and supporter of AGU's mission for many years, and it was such a great honor to be recognized," Jordanova says. "I'm very proud of the work I've done at the Lab, and I look forward to contributing more to our ability to advancing our knowledge in this field."

While completing her PhD at the University of Michigan in the mid-1990s, Jordanova devised one of the first models to simulate geomagnetic storms, which occur when charged surges of solar wind—bursts of energy on the sun's surface—travel millions of miles and crash against the Earth's magnetic field, bombarding near-Earth space with charged particles.

These events are so powerful they can disable satellites and severely damage infrastructure on Earth. In 1989, a geomagnetic storm shut down an entire power grid in Canada. In 2003, a storm ruined power transformers in South Africa and at a nuclear plant in Sweden. In 2010, a storm damaged the Galaxy 15, a $250-million U.S. telecommunication satellite, which cost $3.5 million to repair.

Jordanova's Ring Current-Atmosphere Interactions Model emphasized the role of plasma waves in geomagnetic storms. These waves, she found, could be generated in near-Earth space and, thus, precipitate ions into the atmosphere or increase the energetic power of electrons inside the magnetosphere by a factor of 10.

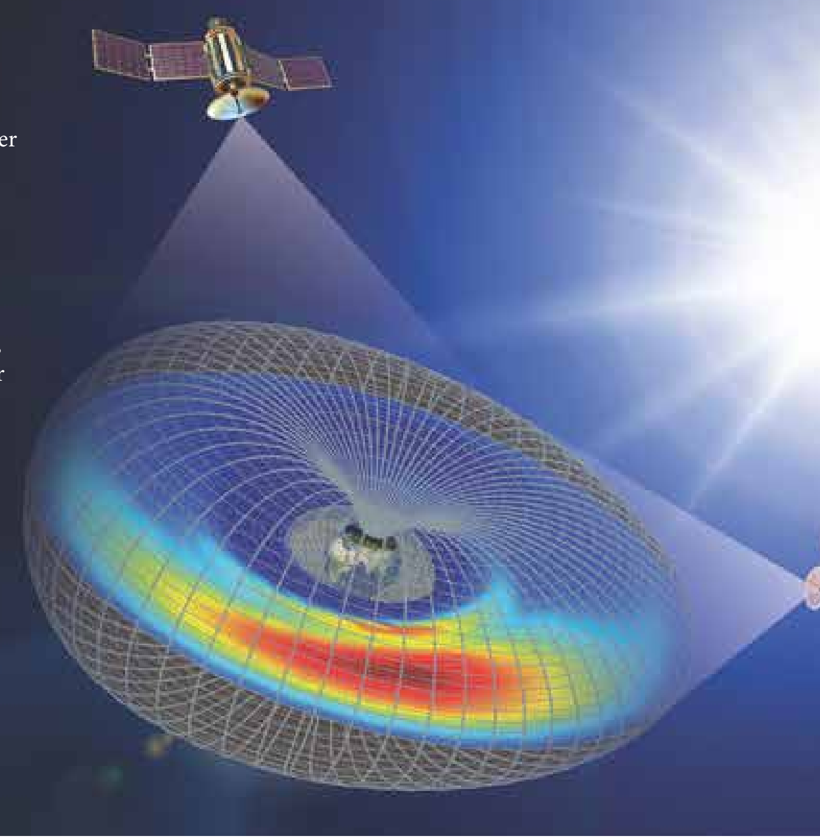
Until that time, plasma waves hadn't been given much credence. "This process of wave-particle interactions was recognized in theory, but people were skeptical it was important in space," Jordanova says. "Twenty years later, we find that plasma waves are a very important element of understanding the physics of charged particles in the magnetosphere."

Jordanova also played a key role in the Dynamic Radiation Environment Assimilation Model (DREAM), the project that brought her to the Lab in 2006. This project focused on radiation belts, which are areas of energetic charged particles surrounding Earth. These belts can be damaging to satellites, but DREAM helps scientists and engineers mitigate hazards for satellites in orbit. Using the model, they can predict the safest times for satellites to operate in space and when to take adequate actions.

In 2014, Jordanova became a principal investigator on the Space Hazards Induced near Earth by Large, Dynamic Storms (SHIELDS) project. Drawing from her breakthroughs in understanding plasma waves and charged particles, Jordanova helped create a multi-scale model of the magnetosphere that can forecast space weather. In 2017, the model won an R&D 100 Award—an "Oscar of innovation"—for being the world's most advanced tool for predicting geomagnetic storms.

Today, such models provide advance notice of geomagnetic storms to people who operate satellites, power grids, flight communications, and anything else that relies on information beamed from orbit to the Earth—which these days is just about everything. ★

An image from a model that Jordanova worked on shows how Earth's magnetic field interacts with plasma during geomagnetic storms.



TECHNOLOGY

ATOMIC ANALYSIS

Nuclear Technology **highlights new research about the Trinity test.**

BY WHITNEY SPIVEY

In the summer 2021 issue of this magazine, "Trinity revisited" discussed new research about the world's first atomic blast, which took place on July 16, 1945. Much of that research—23 unclassified papers—was recently published in a special, open-access issue of the American Nuclear Society's *Nuclear Technology* journal. Eighty-three people contributed to the 460 pages of articles, which were compiled by Mark Chadwick, chief operating officer and chief scientist for the Weapons Physics directorate at Los Alamos National Laboratory.

The papers (and 46 additional, related papers published in May 2021 in the Laboratory's *Weapons Review Letters* journal) likely represent the most in-depth analysis of the test ever completed, at least since the years immediately following World War II, when Manhattan Project luminaries documented their findings. The papers include never-before-seen information and data that further ratify the event as one of the most important scientific experiments of all time. The papers also solidify Los Alamos' place in history.

"In the process of researching and writing these papers, we confirmed that Los Alamos invented the field of nuclear science," Chadwick says. "That was somewhat known, but this catalog of research shows the outside world exactly how much was invented here. The basic weapons science, physics, and engineering we use at the Lab today comes from that first breakthrough 75 years ago."

"I can speak for all the authors when I say that we had fun writing these papers and that we learned many new things in the process," Chadwick continues. "I trust that this collection is indeed a contribution to both the history of science and to the advancement of science." ★

Ground zero of the Trinity test is viewed from the top of Compaña Hill in 2021 and 1945.

Luke Stover

Susan O'Rourke

James Bevins

Air Force Fellow Lieutenant Colonel Luke Stover (left) and Major Boone Gilbreath raise the American flag at the Lab's Detonator Production building.

MILITARY

PROMISING PARTNERSHIPS

Nuclear experts from the Air Force spend a year with Los Alamos' nuclear experts.

BY J. WESTON PHIPPEN

Each July, the U.S. Air Force normally sends two service members to Los Alamos National Laboratory for a yearlong fellowship to learn from the scientists and engineers who maintain America's nuclear weapons. But little, if anything, was normal about 2021, including the number of fellows at the Lab, which was three and included—for only the second time in fellow history—a civilian.

But as a civilian, Susan O'Rourke was no stranger to Los Alamos. O'Rourke came to the Lab from an assignment in Ramstein, Germany, and before that, she worked at U.S. Strategic Command as a senior weapons systems analyst. She was responsible for tracking and reporting all aspects of the U.S. nuclear stockpile. This included weapon reliability, sustainability, and circular error probability—basically, the accuracy of weapon systems—a role that required she talk often with the Lab and make numerous visits to Los Alamos.

O'Rourke says being a fellow at Los Alamos has furthered her knowledge about weapons systems of the future and the scientists developing them. "Every time I visit the Lab, I'm impressed with how open and available everyone is to share their knowledge," she says. "My time here will definitely make my job going forward a lot easier."

Lieutenant Colonel Luke Stover is one of the two active-duty fellows who came to the Lab in 2021. He came to Los Alamos from Italy, where he served as the commander of the 704th Munitions Support Squadron at Ghedi Air Base. The 704th Munitions Support Squadron supports the wartime strike mission of the 6th Stormo Wing of the Italian Air Force, which operates the PA-200 Tornado fighter and bomber aircraft. The squadron also maintains custody and control of U.S. munitions supporting the North Atlantic Treaty Organization.

At Los Alamos, Stover has enjoyed learning about the variety of work that goes into maintaining America's nuclear stockpile. With this knowledge, Stover is developing a paper on assurance theory: conveying to allies that America's nuclear capabilities remain as robust as ever. "My focus this year was to go a mile wide and an inch deep, learning about as many aspects of the Lab's involvement in stockpile stewardship as possible," Stover says. "My exposure here has really increased my appetite and appreciation for everything the Lab does in that field."

The third fellow, Major James Bevins, arrived at Los Alamos from the Air Force Institute of Technology, in Ohio, where he taught all things nuclear, including radiation transport modeling, radiation detection, signature detection and analysis for nuclear security applications, nuclear forensics, and nuclear weapon effects.

Bevins, who has a PhD from the University of California, Berkeley, splits his time at the Lab between two projects. The first dives into improving nuclear hardness (the ability for warheads to survive a nuclear environment). The second examines how the U.S. Air Force can attract and retain more talent in the fields of science, technology, engineering, and math.

"Our adversaries are increasing their militaries' focus in these areas to gain a competitive advantage in future wars and grey-zone conflicts, so it's important that we as an Air Force internalize this challenge, that we walk the walk and ensure our leaders have the background necessary to lead highly technical efforts to ensure our national security interests," Bevins says. "At the Lab, we have experts who have studied these adversaries and technologies for decades, so being able to tap into their knowledge has been invaluable."

O'Rourke, Stover, and Bevins will be at Los Alamos until June 2022. ★

WAGING NUCLEAR PEACE

For more than half a century, technologies developed at Los Alamos National Laboratory have helped account for and control the spread of nuclear materials.

By Jake Bartman

The United Nations Security Council is responsible for reviewing compliance with the Nonproliferation Treaty, which helps ensure that nuclear materials are only used for peaceful purposes. Photo: IAEA

▲ President Eisenhower delivers his “Atoms for Peace” speech to the United Nations General Assembly on December 8, 1953. Photo: IAEA

Not long after the end of World War II, Manhattan Project Director and U.S. General Leslie Groves speculated that the Soviet Union wouldn’t have the know-how to develop an atomic weapon until the late 1960s. Instead, the Soviet Union detonated its first atomic device in August 1949, just four years after Manhattan Project scientists successfully tested their atomic “Gadget” at the Trinity site in southern New Mexico. By August 1953, the United States had tested dozens of nuclear (including two thermonuclear) devices, and the Soviet Union was not far behind.

Faced with a burgeoning arms race and the knowledge that—as Great Britain had demonstrated in 1952—it was only a matter of time before other countries also developed nuclear weapons, U.S. President Dwight Eisenhower chose to discourage states from pursuing nuclear weapons while also promoting peaceful uses of nuclear technology.

In December 1953, Eisenhower delivered a speech titled “Atoms for Peace” to the United Nations General Assembly. In closing, he said, “The United States pledges before you, and therefore before the world, its determination to help solve the fearful atomic dilemma—to devote its entire heart and mind to finding the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life.”

The ideas expressed in Eisenhower’s speech led, four years later, to the creation of the International Atomic Energy Agency (IAEA). According to its statute, which was signed by 81 nations in 1956, the IAEA seeks to “accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world.”

Safeguards come to Los Alamos

Since its inception, the IAEA enacted safeguards—measures to verify that nuclear material around the world is not diverted from peaceful purposes. These safeguards ensure that countries can develop nuclear technology for peaceful purposes, while the IAEA provides credible assurance to the world that nuclear weapons are not being developed and proliferated in those countries.

The safeguards of the late 1950s and early 1960s were hard to verify. Inspectors had no concrete way of knowing if a facility’s operating log was accurate or if containers of material were labeled correctly.

◄ Metallic seals secured to safeguards equipment help IAEA inspectors determine if nuclear material has been improperly used. Photo: IAEA

▲ Flags fly outside IAEA headquarters in Vienna, Austria. Photo: IAEA

> “The United States pledges before you, and therefore before the world, its determination to help solve the fearful atomic dilemma.”
> —PRESIDENT DWIGHT EISENHOWER

To address these shortcomings, IAEA inspectors would send chemical samples to laboratories for destructive analysis, meaning that the samples would be destroyed during the process of finding out what they were.

Not only did the process destroy valuable material, but it also was time consuming and often disrupted facility operations. In addition, some materials weren’t easily accessible. And, perhaps most importantly, once a sample had been destroyed, it couldn’t be analyzed again, which was problematic if a facility’s operator disputed an inspector’s findings.

George Robert (Bob) Keepin Jr., a nuclear physicist at Los Alamos National Laboratory, knew there had to be a better way—or at least another way that would supplement destructive analysis. In 1966, Keepin had just returned to Los Alamos after a two-year stint at the IAEA headquarters in Vienna, Austria. He thought it possible to develop tools that would allow inspectors to assay, or measure, a nuclear facility’s materials quickly, accurately, and safely, without destroying anything. And he thought that Los Alamos was the right place for this work.

Laboratory Director Norris Bradbury was quick to agree. “Los Alamos’ interest in safeguards should not really surprise you,” Bradbury said in 1969. “Our pioneering work in nuclear weapons has left us with the profound concern that these devices never get used in anger, never get used surreptitiously, never get made by surprise, by theft, or by diversion.”

Howard Menlove, who joined Keepin's team in 1967 and still works at Los Alamos today, recalls that "when Keepin sold the program, one of his sales points was that Los Alamos had technical staff who were among the best in the nation. We've got the staff, we've got nuclear material, and we've got instrumentation and technology to keep track of nuclear material. That's why the program's birth belonged at Los Alamos."

In December 1966, with support from the Atomic Energy Commission and others, the Los Alamos Safeguards R&D (research and development) program officially launched.

Nondestructive assay

The Safeguards R&D program's origins were humble; some 15 scientists worked in offices frequented by chipmunks and rattlesnakes. But what the program lacked in accommodations, it made up for with a sense of mission. "The challenge was to develop new nondestructive assay [NDA] technology to quantify nuclear material in all of its different forms," Menlove says.

And although the challenge was real, it seemed hardly insurmountable. In fact, the Lab's first safeguards scientists were so confident in their abilities that, according to Menlove, "We thought we'd have exhausted the field within five years."

▲ Los Alamos physicist Bob Keepin (left) pioneered the development of NDA technology for accurate measurement of nuclear materials. Here, Keepin is pictured with Sigvard Eklund, who led the IAEA from 1961 to 1981.

The group's optimism lay in the fact that the principles of nondestructive assay are fairly straightforward. The nuclear materials used in power plants, along with the "daughter" and fission byproducts produced by using those materials in reactors, are radioactive. This radiation varies in type and intensity depending on the material. By measuring the radiation emitted from a sample, scientists can determine the type and quantity of nuclear material present at a given point in the fuel cycle.

For example, "most nuclear material emits gamma radiation," explains Alexis Trahan, a nuclear engineer with Los Alamos' Safeguards Science and Technology group. "When you're measuring gamma rays, you're essentially counting how many you get at specific energies, and that's what you use to determine what the material is."

However, gamma ray readings may become difficult if a material emits too many gamma rays, if a material is so large that only gamma rays from its surface are detectable, or if a material is heavily shielded (by lead or stainless steel, perhaps) inside equipment or storage containers.

In such cases, an inspector might turn to neutron counting for confirming the presence or mass of nuclear material. Neutrons are more penetrating than gamma rays, so they can be measured even through shielding materials. Neutron counting is especially well-suited to plutonium assay because certain plutonium isotopes spontaneously fission at a high rate, causing them to emit more neutrons.

Some materials call for a more active assay approach. To get the best mass measurements for uranium-235, plutonium-239, and plutonium-241—all isotopes of uranium or plutonium that don't spontaneously fission at a high rate—scientists fire neutrons at them to induce fission and allow for assay.

Calorimetry is another NDA technique that measures heat energy and can be used for the accurate assay of plutonium or tritium. Since 1996, calorimetry technologies developed at the Laboratory have helped the United States keep track of plutonium in its domestic facilities, including the Plutonium Facility at Los Alamos.

Safeguards under the NPT

In 1970, the international Treaty on the Non-Proliferation of Nuclear Weapons (NPT, see p. 6) entered into force. The treaty's tripartite aim—to prevent the spread of nuclear weapons, promote the peaceful use of nuclear energy, and achieve widespread disarmament—remains central to nuclear nonproliferation.

As the IAEA saw its role in the global safeguards regime codified by the NPT, its inspectors' workload increased. Between 1970 and the end of 1980, the number of power reactors under IAEA safeguards rose from 10 to 126. Enrichment, reprocessing, and fuel fabrication plants likewise grew in number over the course of the decade.

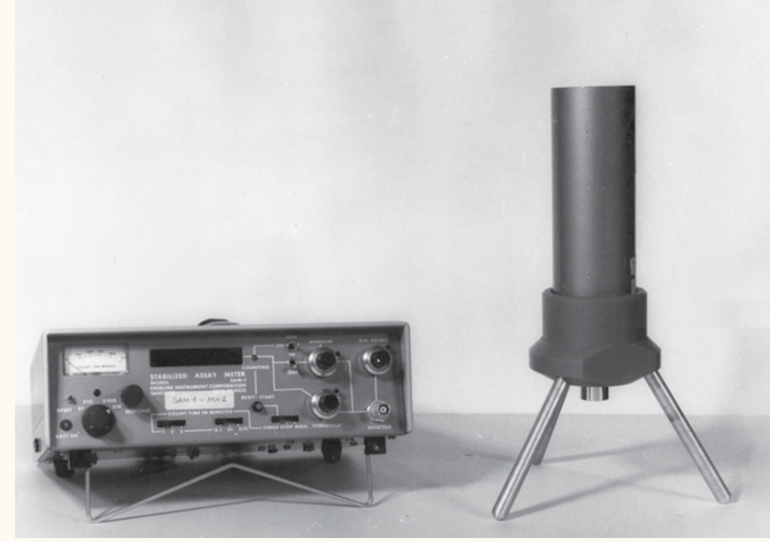
The quick assessments afforded by NDA technologies accordingly became more important than ever. Tools developed and deployed internally at Los Alamos in the 1970s became critical for IAEA safeguards inspections globally.

In 1971, Los Alamos presented the first portable NDA tool to the IAEA. The stabilized assay meter (SAM-II) was a battery-powered gamma ray–detection instrument. Although especially useful for detecting uranium enrichment and assessing uranium fuel rods, the tool could be supplemented with a neutron counter to assay plutonium, making it a versatile device. One IAEA bulletin called it "as important to the safeguards inspector as his briefcase." The device was about the same size as a briefcase, too, and resembled a stereo amplifier with a thermos-sized cylinder attached via a cable.

Another tool, the hex counter—so named for its hexagonal shape—quickly became a standby for plutonium assay. Likewise, the active well coincidence counter, which uses neutron counting to assess bulk uranium, soon attained widespread use.

NDA technologies developed at Los Alamos also began to be incorporated into the design of reactors and nuclear facilities. By the mid-'90s, using special cameras and other tools, inspectors could monitor a facility without setting foot inside.

> "Our pioneering work in nuclear weapons has left us with the profound concern that these devices never get used in anger, never get used surreptitiously, never get made by surprise, by theft, or by diversion."
>
> —NORRIS BRADBURY



▲ Developed in the early 1970s, the SAM-II quickly became a critical tool for nondestructive assay. Photo: IAEA

▲ Until 1979, the IAEA was headquartered in the former Grand Hotel in Vienna, Austria. Today the IAEA operates out of the Vienna International Centre. Photo: IAEA

▲ New IAEA safeguards inspectors display their respective flags at IAEA headquarters in July 2021. Photo: IAEA

Today, the IAEA employs more than 100 NDA systems, the majority of which were developed at Los Alamos.

The spent-fuel challenge

In 2008, the U.S. Department of Energy's National Nuclear Security Administration launched the Next-Generation Safeguards Initiative. Then-Secretary of Energy Samuel Bodman described the initiative as an effort to "plan and stay ahead" as climate change and other developments made nuclear power more attractive to nations around the world.

The Spent-Fuel Nondestructive Assay project was inaugurated at Los Alamos in response to this initiative. The multi-year project developed ways to more quickly and accurately assay the highly radioactive fuel that has been irradiated for months or years inside reactors. Or, as Trahan says, "the most complicated nuclear material on the planet."

Initially, the project considered 14 possible spent-fuel NDA methods, before settling on five that it developed, fabricated, and tested at facilities around the world.

Two such methods, which were developed at Los Alamos and tested in Sweden as a proof-of-concept technology, are called differential die-away self-interrogation (DDSI) and differential die-away (DDA). Because these techniques assay large and heavy spent-fuel assemblies, the instruments are the size of a commercial refrigerator. They contain tubes of helium that ionize in response to the neutrons emitted by spent-fuel, allowing for assay of the material.

The DDSI device was the first to use "list mode" data acquisition in measuring the neutrons emitted by a power reactor spent-fuel assembly passively. List mode allowed DDSI a far greater degree of accuracy than that afforded by traditional technologies, often yielding terabytes of data in a single assay. The DDA device then used a neutron generator to perform active interrogation and list mode analysis to obtain results even more effectively. "The results of this project significantly improved our ability to both measure and model burnup, cooling time, and fissile content of an assembly, far exceeding what was state-of-the-art even a few short years ago," says Los Alamos' Holly Trellue, who led the multi-laboratory Spent-Fuel Nondestructive Assay project. Although not currently used in safeguards evaluations, both instruments offer potential future uses.

Los Alamos and international nonproliferation

Over the years, the initial 15-person Safeguards R&D program at Los Alamos has grown to four groups in the Lab's Nuclear Engineering and Nonproliferation division. These 300-or-so employees work with others across the Lab, across the government, and beyond to support the IAEA's work.

Los Alamos has been providing safeguards technical support to the IAEA for the past half-century. "The fact that Los Alamos has such unique and extensive technical expertise in safeguards, verification, and security technologies greatly contributes to our engagement with the international community," says Olga Martin, program manager of Los Alamos' Global Engagement and Material Security programs.

Beyond developing the tools that allow IAEA inspectors to conduct safeguards inspections, the Laboratory plays a key role in instructing inspectors on the use of these tools. IAEA inspectors have visited Los Alamos for training in nondestructive assay since 1980.

"A lot of the NDA equipment, especially neutron-based equipment, was developed at Los Alamos," says Bill Geist, who conducts the Laboratory's safeguards training programs. "So we're certainly qualified to train inspectors on the use of that equipment."

Today, new IAEA inspectors undergo a four- to six-month training program at the Agency's headquarters in Vienna. After that, they travel to the Laboratory for an intensive two-week training course.

Scientists from the United States also work at IAEA's headquarters in support of the Agency's safeguards mission. Many of these experts come from Los Alamos. "Our experts spend several years in Vienna on leaves of absence from the Laboratory, and then when they come back, they understand much better what the needs are and how they can support the inspectors in their measurements," Martin says.

Geist notes that the IAEA trainings and work exchanges also foster relationships within the global safeguards community. "People come to our training, and when a problem arises later, they know that Los Alamos is a resource that can help resolve the issue," he says.

Menlove agrees that relationships are key. "Most of my innovations, the things that I developed over the years—20 or 30 systems that are being used worldwide—originated by visiting a facility and recognizing what the problem was, and having a good working relationship with the people, and then solving the problem with hardware," he says.

New horizons

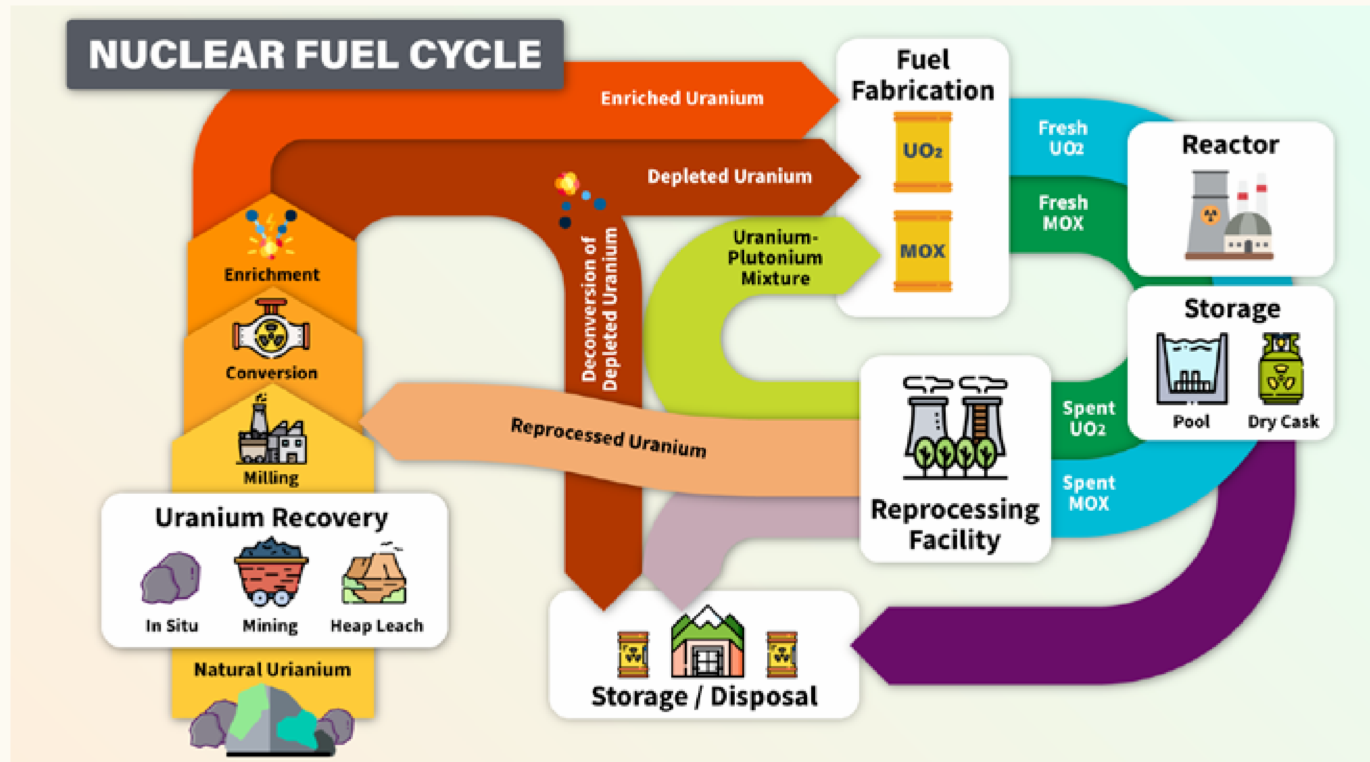
Just as new nuclear technologies and political realities have called for new NDA tools in the past, novel challenges ensure that future NDA systems will need to be developed.

Today, new nuclear power reactors continue to come online, especially as nations shift from fossil fuels to cleaner sources of energy, as demand for energy grows worldwide, and as countries recognize the importance of energy security.

"As the civilian nuclear energy sector grows, there is more and more demand for these technologies to ensure that nuclear material is protected—and not diverted from peaceful uses," Martin says.

Geist agrees. "More facilities are coming online, so there's a lot more to inspect," he says. "The focus will be on developing tools that allow inspectors to be more efficient, and to conduct inspections unattended."

Although tools such as DDSI collect abundant and accurate data, the sheer volume of data produced by such technologies poses another challenge. "That's really where the machine learning, data analytics piece comes in," Trahan says. "It's always great to take more data, but that means you're going to need to have more humans sitting



▲ The nuclear fuel cycle is the progression of nuclear energy from creation to disposal. In the United States, uranium is processed in different chemical and physical forms to create nuclear energy. Mixed oxide (MOX) is another type of nuclear energy. At each stage of the fuel cycle, nuclear materials can be measured. Photo: Nuclear Regulatory Commission there, interpreting the data. Machine learning can make this process significantly more streamlined and effective."

Computing, therefore, will be an important part of future safeguards design. At Los Alamos, scientists are working to develop machine learning algorithms that enable safeguards inspectors to process such data. They are also developing algorithms to determine if remotely collected data has been manipulated or fabricated. These algorithms may be especially useful as "deep fake" technologies increasingly threaten to undermine confidence in the data collected by NDA tools.

Reactor design continues to evolve, too. Miniature and micro reactors, for example, can be more efficient than traditional reactors. But to attain that efficiency, they rely on uranium that has been enriched to a much higher degree—and is, therefore, more suitable for use in nuclear weapons. In keeping with such developments, future NDA design will continue to seek new ways to incorporate verification technologies into facility design.

"What we don't want to do is to wait until there are advanced reactor facilities all over the world before we develop the technology to safeguard them," Trahan explains. "We want to be thinking ahead and saying, 'Here's how we can design these facilities to incorporate nondestructive assay into the flow of the facility itself—or maybe even into the reactor itself.'"

Los Alamos' long involvement with the international community and its long track record in safeguards mean that it is poised to remain central to efforts to meet these new challenges. ★

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

The NDA tools developed by Los Alamos help support nuclear safeguards and prevent the diversion of peaceful nuclear material for military use.

WHAT IS THE IAEA?

Founded in 1957, the International Atomic Energy Agency (IAEA) promotes safe, secure, and peaceful uses of nuclear energy.

* The United States, Great Britain, France, Russia, and China are not required to have IAEA safeguards agreements under the NPT. All five, however, have signed voluntary offer safeguards agreements that permit the IAEA to apply safeguards to material in select eligible facilities.

WHAT ARE SAFEGUARDS?

Safeguards are technical measures applied to nuclear facilities and material by the IAEA. Safeguards help the IAEA independently verify a state's legal obligation that nuclear facilities are not misused and nuclear material is not diverted from peaceful uses. The treaty on the Non-Proliferation of Nuclear Weapons (NPT) is a landmark international treaty that entered into force in 1970. Article III of the NPT requires all nonnuclear-weapon states to accept IAEA safeguards.

Los Alamos has developed the majority of nondestructive assay (NDA) instrumentation used by IAEA inspectors today. NDA provides rapid, nonintrusive characterization of nuclear material.

2020 IAEA statistics

CONDUCTED 2,856 in-field verifications

REMOTELY MONITORED 142 facilities

VERIFIED 23,600 seals applied to nuclear material, facility critical equipment or IAEA's safeguards equipment at nuclear facilities

COLLECTED 460 environmental samples

COLLECTED 489 nuclear material samples

MAINTAINED 1,530 surveillance cameras at nuclear facilities

ACQUIRED 1,264 commercial satellite images

UTILIZED 1,038 NDA systems for the measurement of nuclear material

Safeguards training

Los Alamos started its IAEA safeguards training program in 1973 and has trained every new inspector since 1980.

TRAINED 5,600 WORLDWIDE

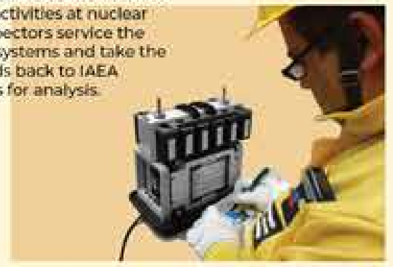
320 COURSES CONDUCTED

IAEA inspectors survey a uranium enrichment plant.

Types of NDA instrumentation

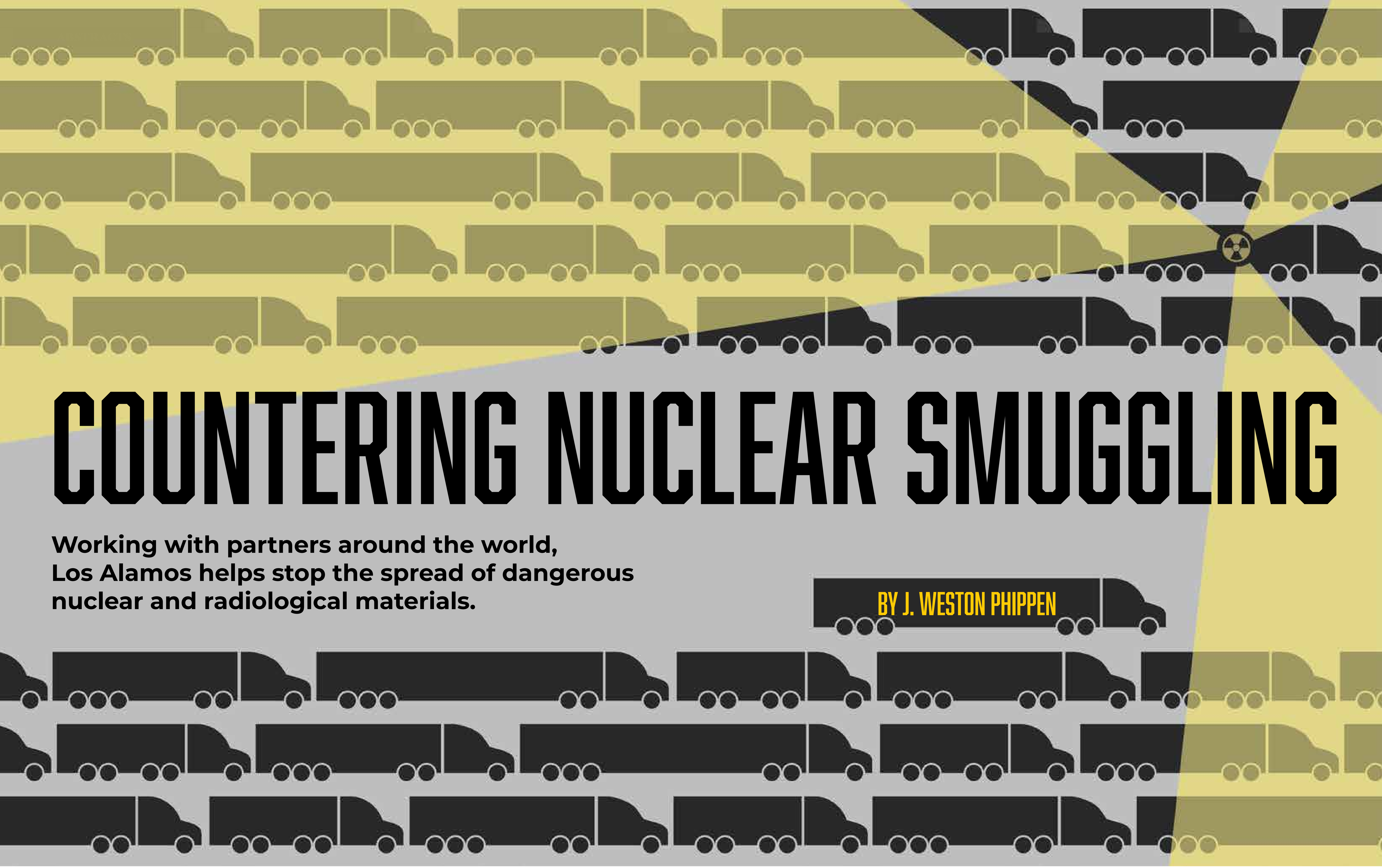
Hand-held NDA
Gamma and neutron detectors are the fundamental instruments upon which Los Alamos safeguards technology development has grown over the past decades. IAEA inspectors use hand-held gamma spectrometers to measure the gamma rays from fresh fuel assemblies. The measurements tell them the enrichment level of the uranium in the fuel.

Unattended monitoring
Surveillance cameras monitor the operational activities at nuclear facilities. Inspectors service the surveillance systems and take the memory cards back to IAEA headquarters for analysis.



UCVS
The Unattended Cylinder Verification Station (UCVS) could be used for safeguards verification to prevent nuclear materials from being diverted into clandestine programs.

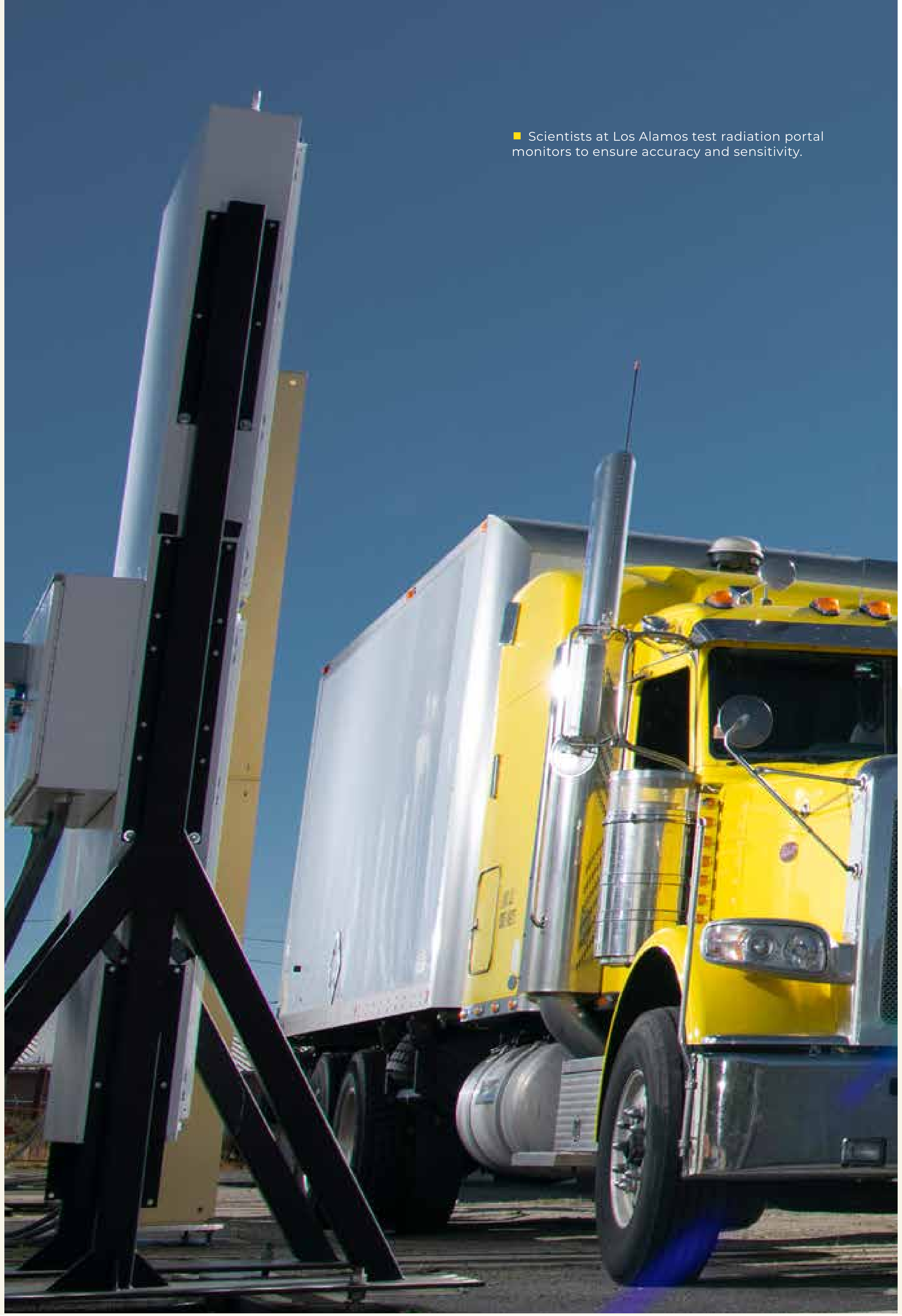
LIBS monitoring
Laser-induced breakdown spectroscopy (LIBS) technology was developed by Los Alamos to address environmental sampling and analysis for international safeguards. LIBS can determine the elemental composition of the target from more than 20 feet away.



COUNTERING NUCLEAR SMUGGLING

Working with partners around the world, Los Alamos helps stop the spread of dangerous nuclear and radiological materials.

BY J. WESTON PHIPPEN



Scientists at Los Alamos test radiation portal monitors to ensure accuracy and sensitivity.

On a brisk February afternoon, buckets of specially prepared Ice Melt and soil—each of which contains naturally occurring radioactive material (NORM)—are loaded into shipping containers in a remote area of Los Alamos National Laboratory. The shipping containers and their contents are used to test the performance of radiation portal monitors, which are large devices placed on either side of a traffic lane. Each monitor contains gamma and neutron detectors, and if these detectors register radioactive material inside a container, or any other type of vehicle, an alarm is triggered.

The Laboratory employees working here—loading shipping containers, adjusting monitor settings, analyzing data—support the National Nuclear Security Administration's Office of Nuclear Smuggling Detection and Deterrence (NSDD). The office, which comprises teams across seven national laboratories and collaborates with more than 100 agencies around the world, aims to detect, disrupt, and investigate the smuggling of nuclear and other radioactive materials—such as plutonium and highly enriched uranium—that could be used in acts of terrorism or be harmful to people's health.

"We think holistically about nuclear smuggling—we create tailored, layered defenses that incorporate technology, training, and enduring relationships," explains office director Andrew Vogt. "The further we push out these capabilities, the closer we are to the sources of the threats. And as a result, we enhance not only the national security of the United States but also global nuclear security."

The NSDD office oversees a vast portfolio of work, but on this particular day, the NSDD team at Los Alamos is concerned with a very specific slice of the office's mission: testing, characterizing, and optimizing the performance of radiation portal monitors—which are commercially manufactured and then shipped to the Lab—so that the monitors are able to detect minimum quantities of material deemed to be a potential threat. This work is complicated because many naturally occurring substances can be radioactive.

"There are a lot of naturally occurring substances that give off radiation," explains engineer Marc Paff, of the Lab's International Threat Reduction group. "Kitty litter, a lot of construction materials, ceramics, even a bag of fertilizer, can be mildly radioactive. Obviously, one bag of fertilizer won't set off an alarm. But an entire shipping container might."

With many NORM loads crossing borders every day, interdicting dangerous radiological material is a little like finding a needle in a haystack. But the Los Alamos cadre of the NSDD program is uniquely equipped to help solve this problem because it has access to nuclear materials as a result of the Lab's nuclear weapons work. To simulate a real-life smuggling scenario, team members fill shipping containers with naturally occurring radiological material and sometimes with nuclear material hidden at different locations inside.

"We think holistically about NUCLEAR SMUGGLING—we create tailored, layered defenses that incorporate technology, training, and enduring relationships."
—ANDREW VOGT

As a container passes through a monitor, the monitor measures the level of radiation emitted from the conveyance. If a certain alarm threshold is exceeded, an alarm sounds. When deployed at borders, airports, or other locations of concern, radiation portal monitors can identify conveyances containing radiological material in real time. If the monitor alarms, authorities use handheld radiation detection devices to precisely locate and identify radioactive material in the conveyance.

NSDD then and now

When the Soviet Union collapsed in 1991, the United States became increasingly concerned about protecting the world from smuggled nuclear materials. Not wanting any of the Soviet's estimated 30,000 nuclear weapons and more than 600 metric tons of weapons-grade nuclear material to end up in the wrong hands, the United States and its allies instituted a two-pronged approach. First, they encouraged partner countries—including Russia—to secure known nuclear sites through a program called Material Protection Control and Accounting, which implemented procedures to keep the material safe.

In 1998, the Second Line of Defense program (which became the NSDD program in 2015) was established and focused on the movement of that material across international borders. A vast network of radiation portal monitors was strategically placed at busy airports, large sea ports, and at border crossings so that, if smugglers got ahold of nuclear material, they would be caught when trying to exit former Soviet countries.

"At the time of its inception, the program was focused primarily on former Soviet Union countries," explains Los Alamos NSDD program manager Nathan Limback, who notes that the program's emphasis has grown over time to encompass additional routes for smuggling and a wider range of source material. "This program has been instrumental in assisting our partners in preventing the smuggling of nuclear material around the world," he says.

Today, in addition to working closely with domestic partners such as the Federal Bureau of Investigation and the U.S. Department of State, Department of Homeland Security, and Department of Defense, NSDD has established partnerships with more than 100 agencies in some 80 countries on six continents. Many partners regularly share information with NSDD, demonstrating a global commitment to smuggling prevention.

"If a question about building capacity to counter nuclear smuggling ever arises, NSDD is the natural first choice to address it," Vogt says. "We are fortunate to have so many partners abroad who are willing to work with us on these important efforts, and we strive to develop and sustain these partnerships for the long-term."

NSDD offers an array of tools, including equipment, training, and other support, to provide flexibility and scalability to address the unique needs of law enforcement and security operations in each partner country. The community of participating agencies shares a steady flow of new ideas and operational needs, which in some cases have developed into internationally recognized standards and strategies for effective counter-smuggling efforts.

Much of this work is made possible by the seven national laboratories (Argonne, Brookhaven, Lawrence Livermore, Los Alamos, Oak Ridge, Pacific Northwest, and Sandia) that support NSDD. These labs provide critical subject matter expertise, including data analysis, training, and evaluating, testing, deploying, maintaining, and troubleshooting systems.

"Los Alamos experts have been key since the beginning of the program—testing systems, calibrating systems, offering that weapons lab expertise that you just can't substitute," Vogt explains. "In addition to being incredible technically, they know our partners and know how to engage international audiences."

On the ground

As part of the NSDD office, Jason Brock, of the Lab's International Threat Reduction group, has spent the past 12 years traveling around the world to install, maintain, and train security forces on how to use radiation detection systems, which include radiation portal monitors.

"Some of the more interesting places I've traveled are Lebanon, Jordan, and Ukraine," says Brock, who has visited 35 countries for his work in the NSDD program. "There was a time when I was traveling most of the year."

Brock works with partner agencies in other countries to decide what types of detection equipment are needed, as well as how and where the equipment should be deployed, and whether portable, mobile, or fixed systems offer the best return on risk reduction. Making these decisions for fixed systems involves analyzing information to determine optimal deployment points—locations

> "Kitty litter, a lot of **CONSTRUCTION MATERIALS,** ceramics, even a bag of fertilizer, can be mildly radioactive."
> —MARC PAFF

Because smugglers might try to hide dangerous nuclear material along with goods that are naturally radiological, the team at Los Alamos uses models that can differentiate between legal and illegal items.

With many NORM loads crossing borders every day, interdicting **DANGEROUS RADIOLOGICAL MATERIAL** is a little like finding a needle in a **HAYSTACK.**

where geography and infrastructure naturally funnel people and vehicles through facilities or across borders. For portable and mobile applications, it involves finding the right organizations and officers to train and equip for the mission.

For fixed locations, radiation surveys are conducted to characterize background radiation levels at each location. "In some regions, the soil is naturally radioactive," Brock says. "And because roadways, sidewalks, and various construction materials are made from the soil, they can be radioactive as well."

In addition to providing radiation detection systems, NSDD trains partner agencies on how to operate and maintain the systems, placing emphasis on practical exercises and real-world scenarios. "We could have a person hide a radiological source in a backpack or car or truck," Brock explains. "Then, we'd have them walk or drive through the radiation detection system. The security officers need to be able to notice the alarm and properly carry out procedures for locating and identifying the material. If the material is determined to be material out of regulatory control (MORC), it would be investigated further."

Although every country has its own laws and judicial system, the International Atomic Energy Agency recommends common operating procedures to help countries deal with smuggled nuclear material. "Some countries have a strong legislative and regulatory framework in place with regard to the smuggling of nuclear material and MORC," Brock says. "We work with partner countries to strengthen this framework when necessary."

Brock manages NSDD projects in Vietnam and Cambodia. In addition to maintaining good relationships with government and other partner agency representatives in these countries, Brock conducts regular evaluations of operations, training, and maintenance for their radiation detection systems. When these evaluations show areas in need of improvement, Brock works with partner agencies to jointly develop and implement corrective action. "It's important work," he says. "I'm fortunate to be a part of this program."

Orphaned sources

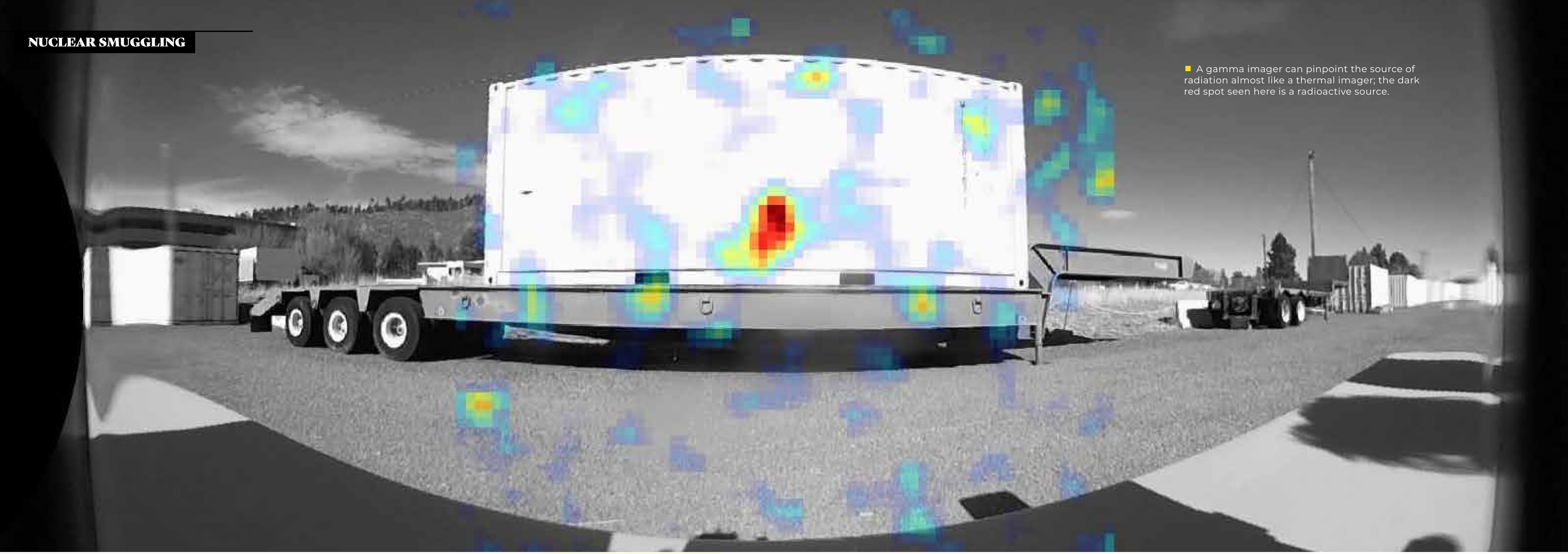
All radiation detection systems deployed by NSDD are commercially available systems purchased by the program directly or through its implementing contractors and national laboratories. After testing, systems are delivered to partner nations. Radiation detection systems deployed around the world help disrupt smuggling networks and deter would-be smugglers. Both factors are important given ongoing concerns about orphaned sources, which are radioactive materials that are no longer under proper regulatory control.

Legally purchased radioactive materials are often used in the healthcare, oil, and construction industries. For example, to sterilize blood, treat cancer, or study blood circulation, doctors use technetium-99, cesium-137, and isotopes of other radioactive elements. To check the strength of welds, construction companies sometimes use devices that contain iridium-192 or cobalt-60.

However, "through theft or improper disposal, sometimes this radioactive material finds its way out of regulatory control" and becomes a public health concern, explains Greg Orlicz of the Lab's International Threat Reduction group. "Radioactive material likely from orphaned sources has been found in metal beams used to build structures and even in metal trays used to serve food." If people have close contact with these sources over time, they can become sick or increase their risk of developing cancer.

Preventing orphaned sources from moving across borders and detecting those sources as early as possible in their movement have become priorities for NSDD. "Detecting nuclear and radioactive material is our primary mission," Paff says. "Knowing that these portal monitors can prevent nuclear materials

Radiation portal monitor software varies, but their main components are the same: gamma and neutron detectors.



A gamma imager can pinpoint the source of radiation almost like a thermal imager; the dark red spot seen here is a radioactive source.

and orphaned sources from movement through a partner country is a big benefit. Radiation detection systems, including portal monitors, have really become a great tool in so many areas."

The future of NSDD

Addressing the illicit smuggling of nuclear and radioactive material requires NSDD partners to balance security concerns with the need to facilitate legitimate commerce with minimal delays and additional costs. Because of these pressures, nuisance and false alarms from radiation detection systems are a major concern for officials at ports of entry. Given the need to balance ease of transport with security, NSDD places a strong emphasis on increasing the efficiency of radiation detection processes while maintaining the sensitivity of the systems to materials of concern.

"We have a dedicated science and engineering team that is always looking at ways to improve the execution of our mission and to support new mission areas," Vogt explains. "If we can reduce the burden on front line operators and make the process more efficient, it is more likely that they will continue using those systems effectively in the long run."

> NSDD systems have proven to be effective in **DETECTING, DISRUPTING, AND INVESTIGATING** the smuggling of radiological and nuclear materials.
>
> —NATE LIMBACK

Limback agrees, stating "There are certainly a lot of challenges to overcome with this work. However, NSDD systems have proven to be effective in detecting, disrupting, and investigating the smuggling of radiological and nuclear materials. We have some amazing and enduring partners that are committed to this mission."

This commitment involves improving and sustaining existing radiation detection systems and continually testing new technologies. Recently, all of the national laboratories that support NSDD have been working on the next generation of hand-held radiation detection equipment and evaluating them for programmatic use.

NSDD has also been testing spectroscopic portal monitor technology. Rather than only sounding an alarm if radioactive material is detected, these systems identify the specific radionuclide detected and, in some applications, provide a visual depiction of where material of interest is likely to be located.

In the coming years, NSDD seeks not only to sustain the existing partnerships and systems it has already built but also to field new systems and develop novel approaches based on today's test campaigns. With a constant eye on reducing impact to commerce and minimizing operator burden, NSDD aims to disrupt and deter dangerous and illegal movements of radioactive material—without delaying commercial goods that could end up in stores near you. ★

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

The technology and expertise developed at Los Alamos as part of the NSDD program helps detect and disrupt the smuggling of nuclear materials.

WHAT HAPPENS WHEN A NUCLEAR DEVICE IS INTERCEPTED?

Los Alamos scientists apply their expertise to aid nuclear forensic efforts wherever and whenever they're needed.

BY LISA KISNER

When most people hear the word *forensics*, they conjure images of crime tape, scruffy detectives, and flashing police lights. But what happens when *nuclear* precedes *forensics*? That image might be more difficult to evoke, but the concept—the collecting and analyzing of evidence—is the same.

According to the International Atomic Energy Agency, nuclear forensics is "the examination of nuclear and other radioactive materials using analytical techniques to determine the origin and history of this material."

The United States began to prioritize nuclear forensics capabilities in the 1990s, after the Soviet Union crumbled, and fears of nuclear material trafficking surfaced. After the September 11 attacks, concerns were amplified. "The world saw that terrorists have no limits," explains Warren Oldham, of the Nuclear and Radiochemistry group at Los Alamos National Laboratory. "An improvised nuclear device went from a low-probability concern to suddenly a very real, immediate threat."

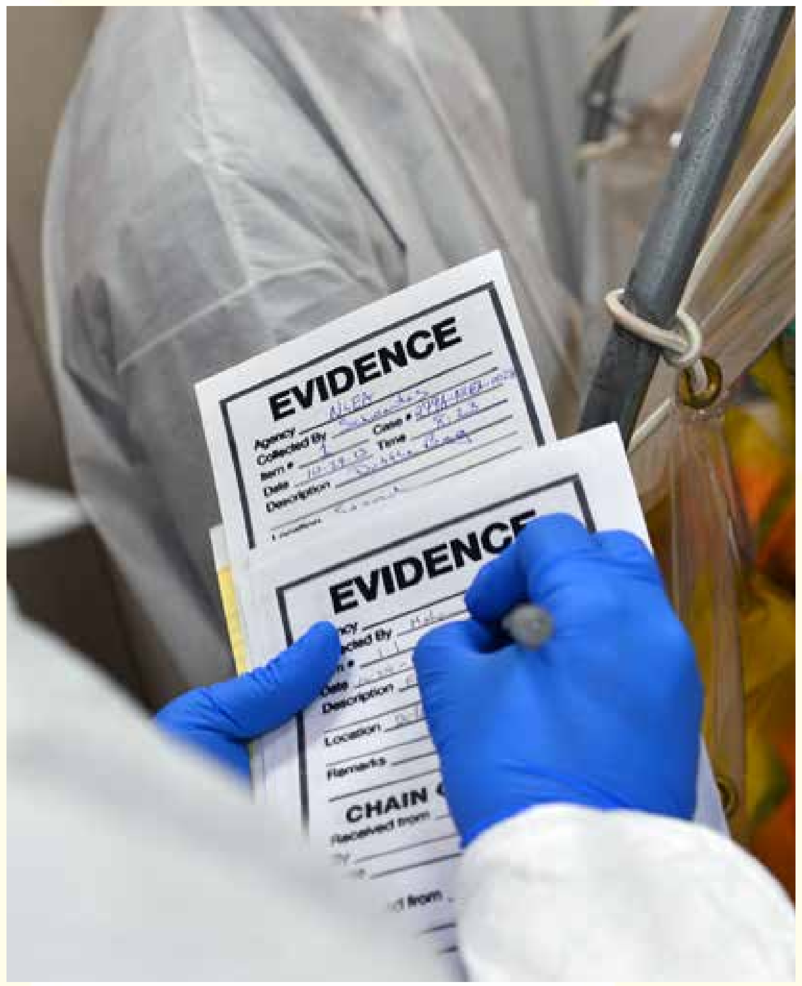
Since then, interest, tactics, and funding for nuclear forensics have waxed and waned. Los Alamos remains committed to supporting this important U.S. government mission. With the Lab's directive to ensure the safety, security, and effectiveness of the nation's nuclear stockpile, it simply makes sense. "We have expertise in handling materials, providing chemical and isotopic analysis, and assessing the data," Oldham says. "Our weapons designers can take their known data and apply it to unknown—potentially dangerous—situations."

The broad capabilities at Los Alamos are unique in the complex. George Brooks, the lead program manager for nuclear forensics, says "We are the only laboratory that can participate 'end to end,' contributing technical expertise to all phases of a nuclear forensics investigation."

If a threat device is intercepted, for example, at a border crossing, it's taken to a remote site and disassembled. The dissembled parts are sent to Los Alamos and other partner organizations for the next level of evaluation and investigations. Even under these controlled conditions, "it is not a nice, neat experiment, so what we need to do at Los Alamos varies," says Oldham. "We're trying to anticipate what we don't know."

Los Alamos nuclear forensic scientists prepare for such real-life scenarios by continually demonstrating their capabilities (including practicing sample receipt, conducting analysis, reporting findings, and providing assessments), often in conjunction with other agencies, and sometimes with real nuclear material.

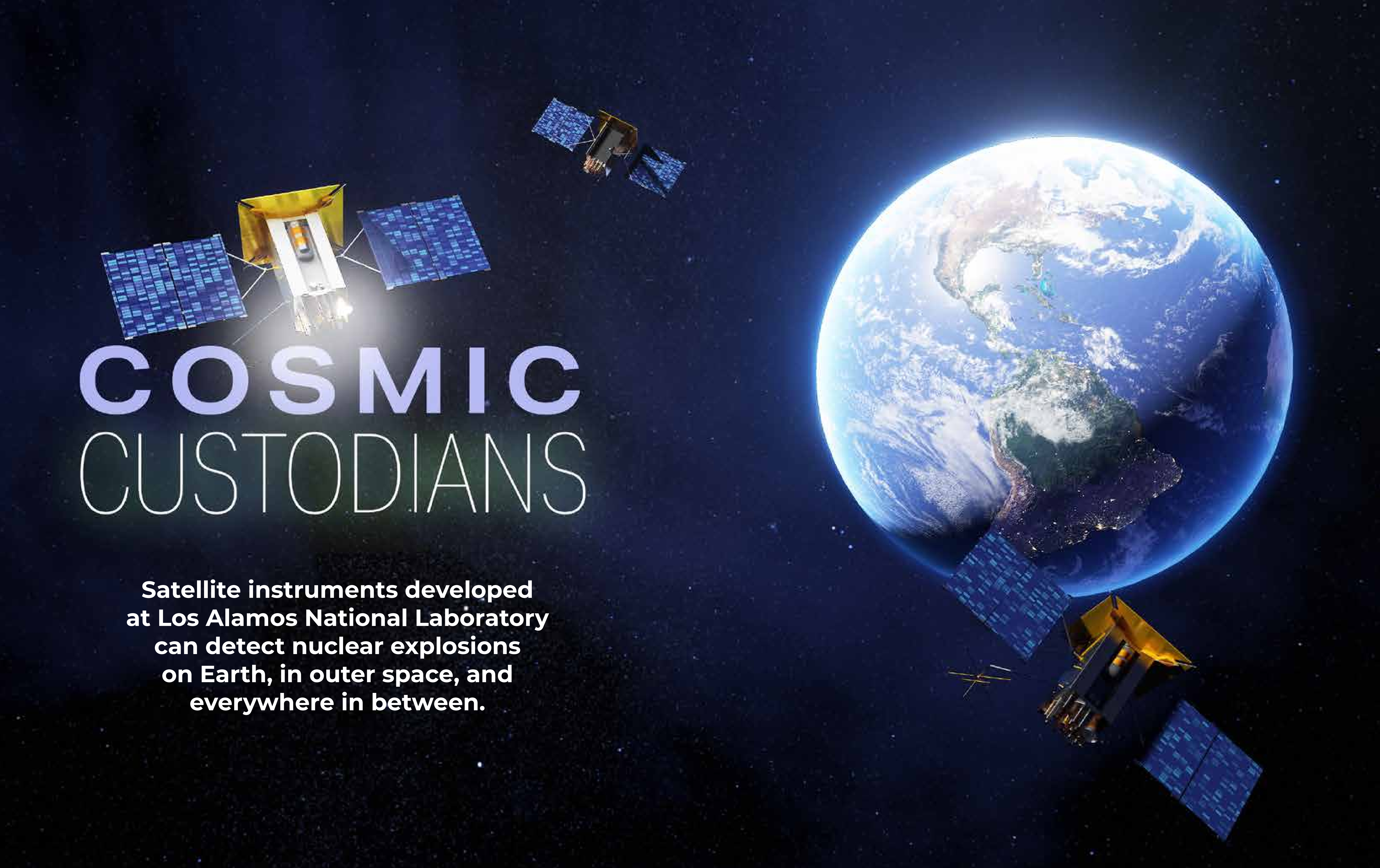
Wherever suspicious materials are found, the analysis done at Los Alamos is essential for intelligence and law enforcement officials to fully understand a threat and then act. "We must be prepared for a low-probability, high-impact event," Oldham says. "We're always weighing immediate threats versus long-term risks, hoping to maintain global security." ★



▲ Los Alamos National Laboratory participates in realistic exercises with partners around the world, including the International Atomic Energy Agency, to improve analyses and help personnel gain necessary problem-solving experience.
Photos: IAEA

COSMIC CUSTODIANS

Satellite instruments developed at Los Alamos National Laboratory can detect nuclear explosions on Earth, in outer space, and everywhere in between.



It is a practical thing to avert atomic war.

—J. ROBERT OPPENHEIMER

Immediately after the Trinity test—the detonation of the world's first atomic bomb on July 16, 1945—scientists realized the immense destructive power of nuclear weapons.

In fact, exactly 15 months after the Trinity test, physicist J. Robert Oppenheimer addressed the American Philosophical Society:

> "It is a practical thing to avert atomic war. It is a practical thing to recognize the fraternity of the peoples of the world. It is a practical thing to recognize as a common responsibility, wholly incapable of unilateral solution, the completely common peril that atomic weapons constitutes for the world. To recognize that only by community of responsibility is there any hope of meeting that peril."

Over the years, largely motivated by the expansive Soviet and U.S. nuclear testing programs, the global "community of responsibility" has enacted several treaties to limit the sizes and locations of nuclear detonations. In 1963, the Limited Test Ban Treaty prohibited nuclear detonations in the Earth's atmosphere, underwater, and in outer space. In 1976, the Threshold Test-Ban Treaty (see p. 61) limited the size of underground nuclear detonations to 150 kilotons. Most recently, the Comprehensive Nuclear-Test-Ban Treaty (CTBT, see p. 3) prohibits all nuclear detonations, period.

President Bill Clinton signed the CTBT in 1996, and although the United States has not ratified the treaty, it has maintained a unilateral moratorium on nuclear testing since 1992. But what about other countries? How do we know if they're playing by the rules?

"A treaty by itself without the means to verify it is just a piece of paper," says Marc Kippen, a scientist and program manager in the Global Security associate directorate at Los Alamos National Laboratory. "So, when we go into a treaty, we're big on making sure we have the methods and means to verify that no one is breaking it."

In other words, the United States has the tools—many of them developed at Los Alamos in conjunction with Sandia National Laboratories and other organizations—to detect nuclear explosions anywhere in, on, or above the world, at any time.

"The deterrent is not so much that we use these tools" to monitor nuclear events, Kippen says, "but that the tools are there, and other countries know they are there." Other countries realize they'll be caught if they detonate a nuclear weapon.

About 300 Laboratory employees (most of whom are in the Lab's Intelligence and Space Research division) focus specifically on developing satellite instruments to detect and measure aboveground nuclear explosions in the atmosphere and outer space. This type of work has a long history at Los Alamos and Sandia, whose nuclear-detonation-detecting sensors were first launched on Vela satellites in the 1960s as a way to verify the Limited Test Ban Treaty.

The Velas (there were 12 of them) and their modern-day descendants operate in more or less the same way: specialized sensing instruments on satellites detect and measure the products of a nuclear explosion. At high altitudes and in outer space, the most easily detected products are x-rays, gamma rays, and neutrons. At lower altitudes, these products interact with the atmosphere and produce detectable optical and radio signatures. If certain levels of products are detected in the right proportions, the ground systems analyzing the sensor data can definitively identify a nuclear blast, estimate where and when it occurred, and gauge how big it was.

"Vela was the kitchen sink satellite that included neutron, gamma, particle, optical, and radio sensors," explains scientist Brian Dougherty, of the Lab's Space Science and Applications group. "A lot of the instruments we fly now are more or less the same design, conceptually, because it works."

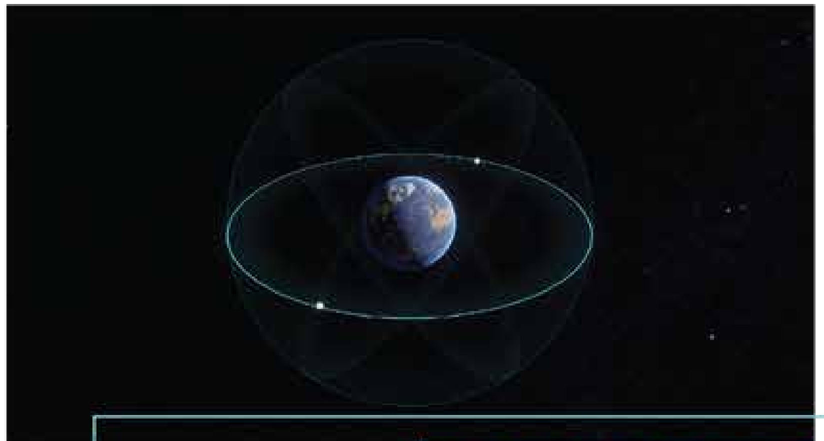
VALIDATION

But how do we know it works? This is where Los Alamos being a weapons lab—a place that specializes in the design, maintenance, and effects of nuclear weapons—comes

> A treaty by itself without the means to verify it is just a piece of paper."
>
> —MARC KIPPEN

GEOSTATIONARY EARTH ORBIT

A satellite circles with the Earth above the same location at all times.



MEDIUM EARTH ORBIT

A satellite circles the Earth twice a day.

GEOSYNCHRONOUS TRANSFER ORBIT

A satellite travels in an ellipse; its distance from Earth varies.

in handy. Using data from recent nonnuclear experiments and legacy nuclear testing data, Los Alamos weapons experts use complex supercomputer models to simulate how nuclear weapons detonate—including the products they release. What happens next is what the space-based detection researchers care about. "The weapon has done something, has created signals, and so that's where we pick it up," explains Charlie Light, an engineer and program manager in the Lab's Intelligence and Space Research division. "We leverage the weapons models."

And they also leverage weapons scientists. "At Los Alamos, subject matter experts on outer space and nuclear explosion byproducts collaborate," says Ben Norman, a scientist in the Lab's Space Science and Applications group. "Having access to weapons experts is really important because there is variability in weapons output."

Armed with information from the Lab's weapons programs, space scientists use computer models, such as Distributed Infrastructure Offering Real-time Access for Modeling and Analysis (DIORAMA) to simulate outer space, complete with orbiting satellites and various types of natural and human-caused (that is, nuclear) products. Such models allow scientists to virtually test their sensors in various scenarios to ensure they meet the mission needs.

COMPREHENSIVE COVERAGE

As computer modeling and simulation has improved, so has sensing instrumentation and satellite technology.

A satellite can soar through space in several ways. A satellite in geostationary earth orbit (GEO) circles with the Earth, above the same location at all times. Starting

■ Jacob Valdez, lead mechanical technician for the Space Instrument Realization group, connects a cable to a sensor that detects radio waves from nuclear detonations. This unit will be used to verify the design of electromagnetic pulse sensing payloads that will be hosted on GPS satellites starting in 2026.

in the 1970s, updated sensing payloads—successors of those on the Velas—from Los Alamos and Sandia started to be flown in GEO aboard the U.S. Air Force's Defense Support Program (DSP) satellites. The DSP satellites formed the first incarnation of the U.S. Nuclear Detonation Detection System (USNDS)—a combination of sensing payloads, satellites, communications, and ground computer systems that constantly monitor and report nuclear detonations. The USNDS umbrella continues to this day, although the components have changed over time.

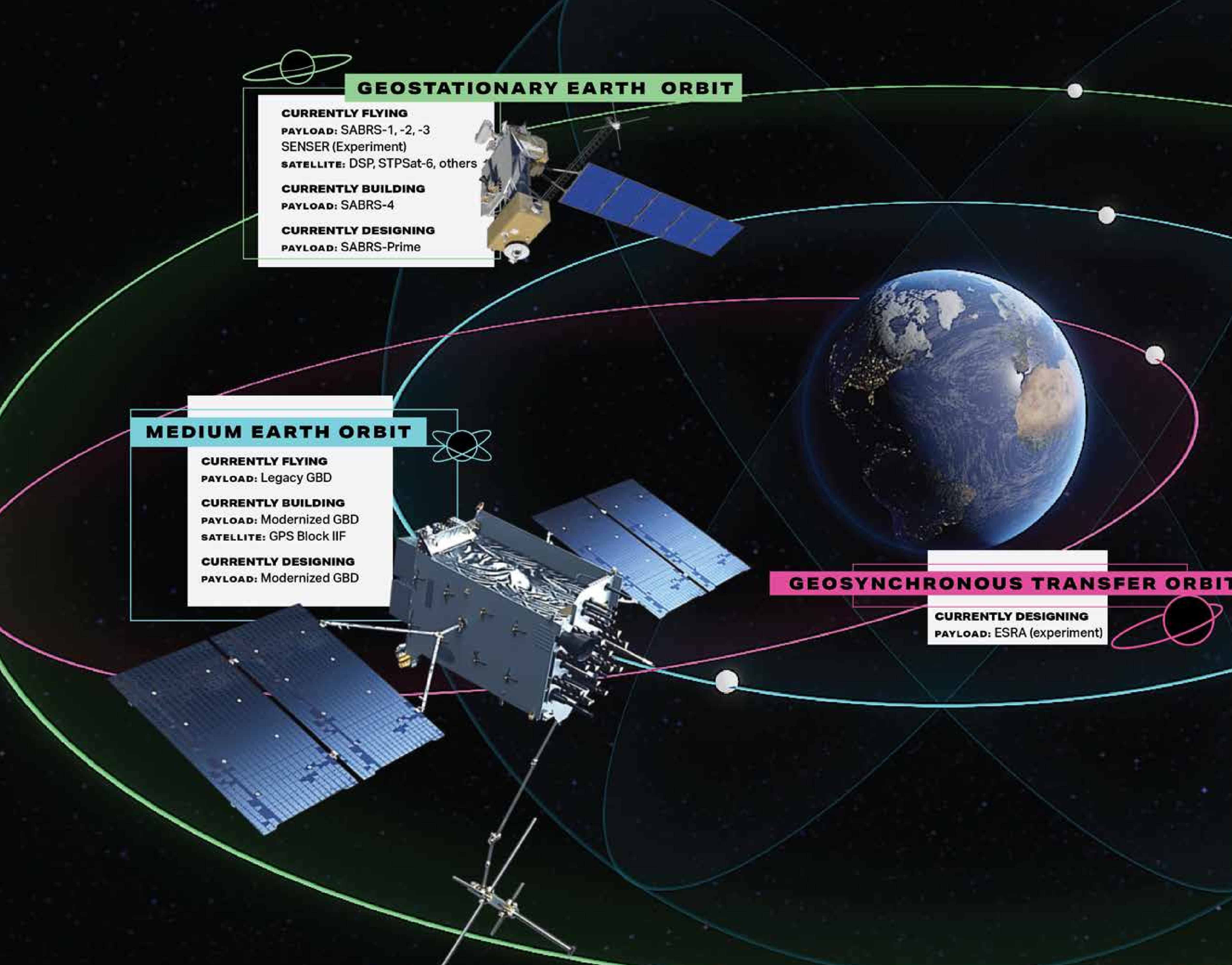
In the late 1970s, researchers at the U.S. Naval Research Laboratory were developing the Global Positioning System (GPS). The system, which is operated today by the U.S. Space Force, uses a constellation of about 30 satellites to transmit position, navigation, and timing data to users on the ground. These satellites fly in medium Earth orbit and circle the Earth twice a day. Nuclear detonation detection sensors from the national laboratories were first flown on GPS satellites in April 1980, and they've been on board ever since. Each GPS satellite hosts a collection of sensors called a global burst detector (GBD) payload.

A variety of sensors, on a variety of satellites, in a variety of orbits provide comprehensive coverage of the Earth and space at all times. "Having sensors in different orbits, persistently over time, gives us the ability to monitor all the time, everywhere, without fail," Kippen says.

SWORDS DRAWN

Like all technology, nuclear detonation detection sensors don't last forever. Aging due to the wear and tear from orbital temperature cycling and harsh space weather radiation mean that sensors must be replaced every so often.

In 2005, for example, some Los Alamos–designed sensors on geostationary satellites had neared the end of their useful lives, and the opportunity to replace them with upgraded sensors resulted in the Space and Atmospheric Burst Reporting



> "Having sensors in several orbits, persistently over time, gives us the ability to monitor all the time, everywhere, without fail."
>
> —MARC KIPPEN

System (SABRS)—a newer sensing payload developed at Los Alamos. SABRS-1, -2, and -3 are currently in orbit on host GEO satellites; SABRS-4 is under construction; and SABRS-Prime (the updated follow-on to the original SABRS series) is in early design phases.

Each iteration of SABRS is more advanced than its predecessor, but they all specialize in detecting high-altitude and space nuclear detonations. SABRS instruments are able to detect two types of gamma rays: prompt gamma rays, which are the initial burst of gamma rays in a nuclear explosion, and delayed gamma rays, which are found in radioactive decay after the initial burst. SABRS instruments can also detect high- and low-energy charged particles, as well as neutrons.

All SABRS payload development and fabrication work takes place at Los Alamos, and each SABRS payload takes about four and a half years to build, test, and deliver for integration with its host satellite.

The SABRS-4 unit is in the midst of this process and should be ready for integration with a satellite in the next couple years.

Even though SABRS-4 is still being constructed, its technology and parts are already considered dated. “For the longer-term future, it is no longer possible to build more SABRS payloads because many of the specialized electronic components are obsolete and no longer available,” Kippen says. “Hence, the Los Alamos team has started to design a new payload—SABRS-Prime—based on modern components.”

SABRS-Prime is also an opportunity to consider new payload configurations. Unlike previous SABRS models, which are essentially one large and three small boxes of instruments placed onto a satellite, SABRS-Prime instruments can be split up and distributed on the satellite wherever it makes the most sense to house them. “We’re designing something a little less aggregated,” Dougherty says. “This might ease our accommodation onto host satellites because the satellite developers can choose to put the different sensors and processors in different places to balance their thermal loads, mass loads, and such.”

“SENSER is an experimental payload that allows us to… truly dive into the performance of the technologies.”

—ALEXEI KLIMENKO

FUTURE SENSORS

SABRS-Prime is just one of several new sensing payloads in development. Because sensing payloads are crucial to national—and global—security, scientists and engineers are always planning far in advance, innovating new sensing techniques and technology that will one day go into space. But the design and development process for this technology—which must be able to survive in space for decades—is onerous and lengthy. For example, the modernized GBD payloads slated to begin space deployment on new GPS satellites later this decade started their development process at Los Alamos and Sandia more than 10 years ago. That process included development of two new Los Alamos GBD components: the x-ray, gamma-ray, and particle sensing hard radiation (HRS) sensor and the radio-frequency sensing electromagnetic pulse (EMP) sensor. Each component includes a full suite of modern technologies that were proven based on decades of prior research and development (R&D).

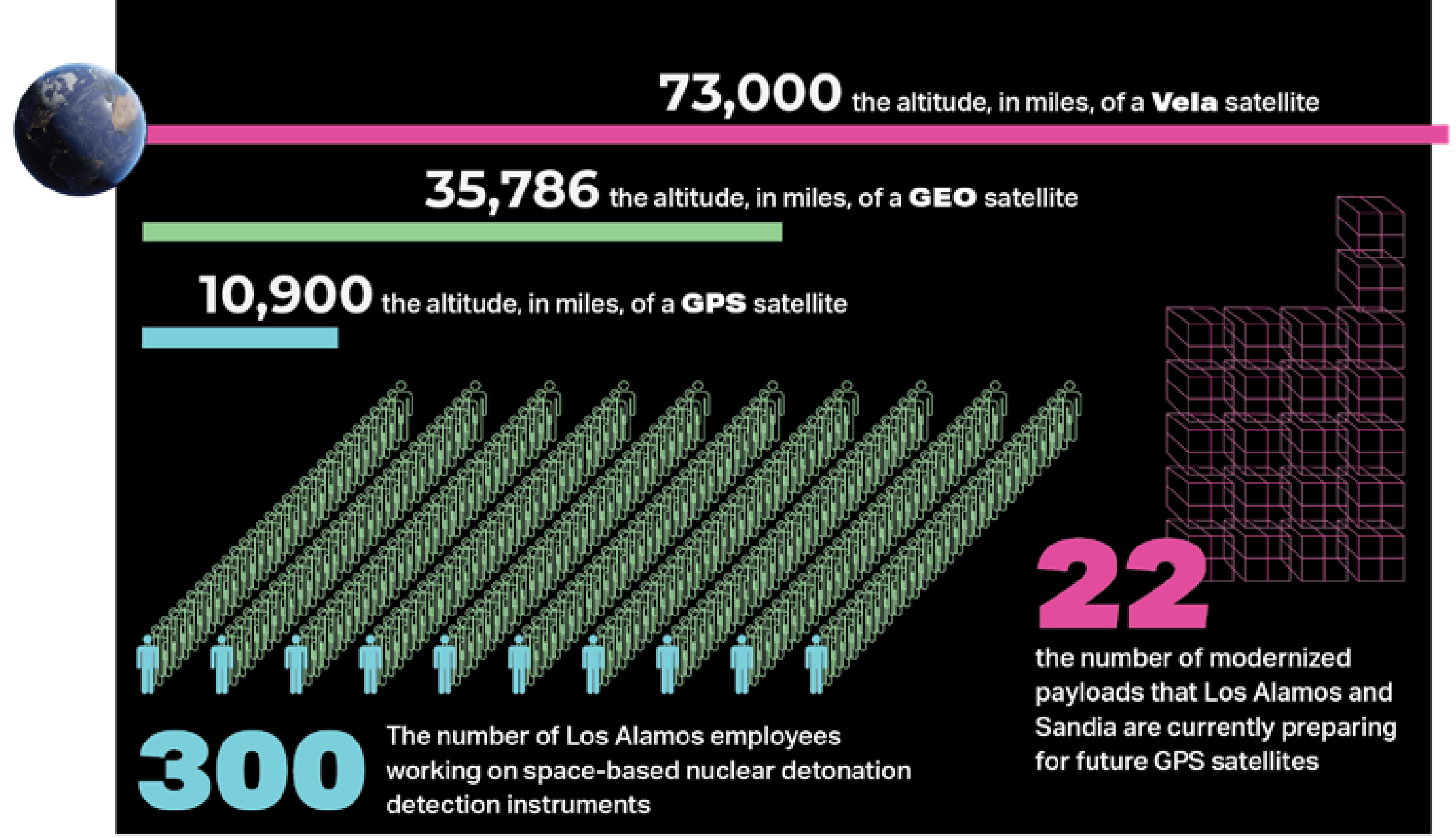
An essential part of this ongoing R&D process is fielding space experiments to demonstrate and validate new technology in the space environment before it is used for USNDS payloads. For example, the Space and Endo-Atmospheric NuDet (Nuclear Detonation) Surveillance Experimentation and Risk-Reduction, or SENSER, project (again, a collaboration between Los Alamos and

Sandia) is flying a suite of newer technologies that may one day contribute to future USNDS payloads. SENSER instruments employ newer technologies to collect information across the electromagnetic spectrum, including radio frequency, optical, x-ray, and high-energy gamma-ray data. “SENSER is an experimental payload that allows us to do a lot of commanding and reconfiguration to truly dive into the performance of the technologies and perform a broad range of studies and unique data collections,” explains Alexei Klimenko, of the Lab’s Space and Stockpile Management group. “The technologies that SENSER is helping to advance will be considered for application to future space-based treaty monitoring payloads and other space missions.”

Another experimental technology demonstration and validation project at Los Alamos is the Experiment for Space Radiation Analysis (ESRA). ESRA researchers are developing a new generation of plasma and energetic particle sensors. The data collected by these sensors will allow researchers to

■ Ryan Hemphill, Space Instrument Realization group dynamics test lead, attaches a model of a high-voltage power supply to a vibration table to test its ability to survive a rocket launch. Researchers recently launched a similar version of this instrument as part of the SABRS-3 payload.

■ Vernon Vigil, Space Instrument Realization group thermal/vacuum test lead, applies temperature monitors to a HRS test unit. The HRS will be used on 22 future GPS satellites scheduled to launch starting in 2026.



better understand how instruments are affected by space weather and evaluate if the sensing technology is suitable for future USNDS use. (For more on space weather, see p. 13.)

Unlike SENSER, which flies on a GEO satellite, ESRA will orbit on an elliptical path known as geosynchronous transfer orbit (GTO). Instead of maintaining a constant distance from the Earth, GTO satellites are sometimes closer and sometimes farther away. This variation in environment provides a range of conditions for sensors to collect data. "Designing and operating satellite systems in GTO provides the perfect scenario to demonstrate and validate space systems across many space environments," says Carlos Maldonado, the ESRA project leader of the Lab's Space Science and Applications group.

ESRA is scheduled to launch in 2024. It will ride on its own dedicated small satellite, known as a CubeSat. ESRA will also be the first Los Alamos space experiment to fly on a commercially produced satellite (as opposed to a satellite produced by a defense contractor or by Los Alamos) and the first to use commercial ground stations to communicate with the satellite. Developers hope that by partnering with these companies, ESRA and other emerging technologies can be launched more often and at a lower cost than historically was possible.

DATA INTERPRETATION

Currently, data collected by USNDS satellite-borne sensing equipment is transmitted down to Earth, where it is collected and processed in ground-based computing systems operated by the U.S. Air Force. These systems, assisted by human operators, examine data from all the USNDS sensors, all the time, searching for the telltale signs of a nuclear explosion. If data points to a nuclear explosion, the operators report it to national command authorities, including the White House.

Although the Laboratory is not involved in initial analysis of whether a nuclear event has occurred, scientists and engineers at Los Alamos do support that analysis as necessary.

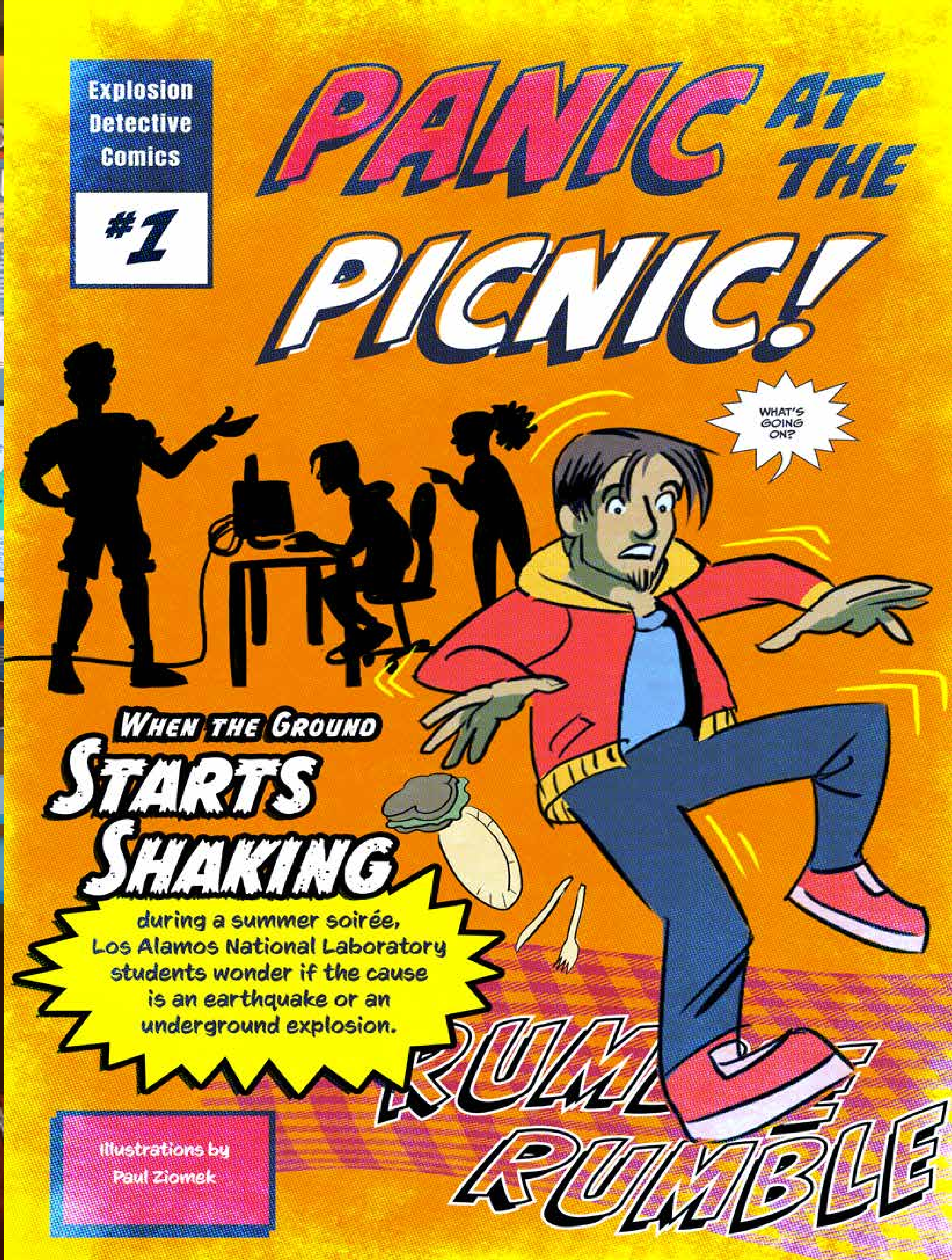
Los Alamos researchers also use the data for other purposes, including tracking the performance of the sensors over time, developing long-term maintenance plans, and advancing technologies for future satellites. Each generation of sensors provides data that helps with the creation of the next generation. "We've been doing this for nearly 65 years," Kippen says. "It makes sense to have the Lab involved in this very unique mission." ★

TAKEAWAY

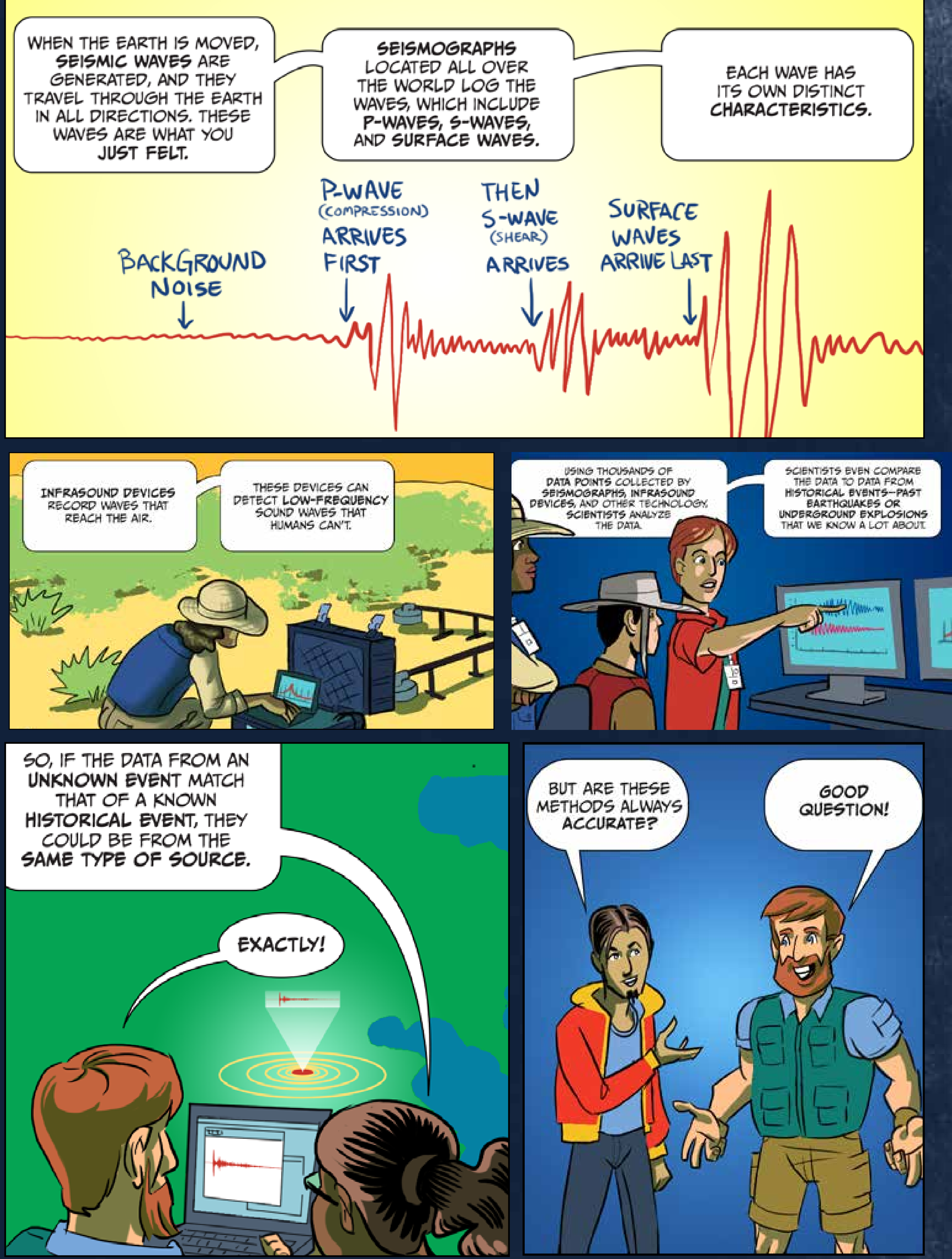
BETTER SCIENCE = BETTER SECURITY

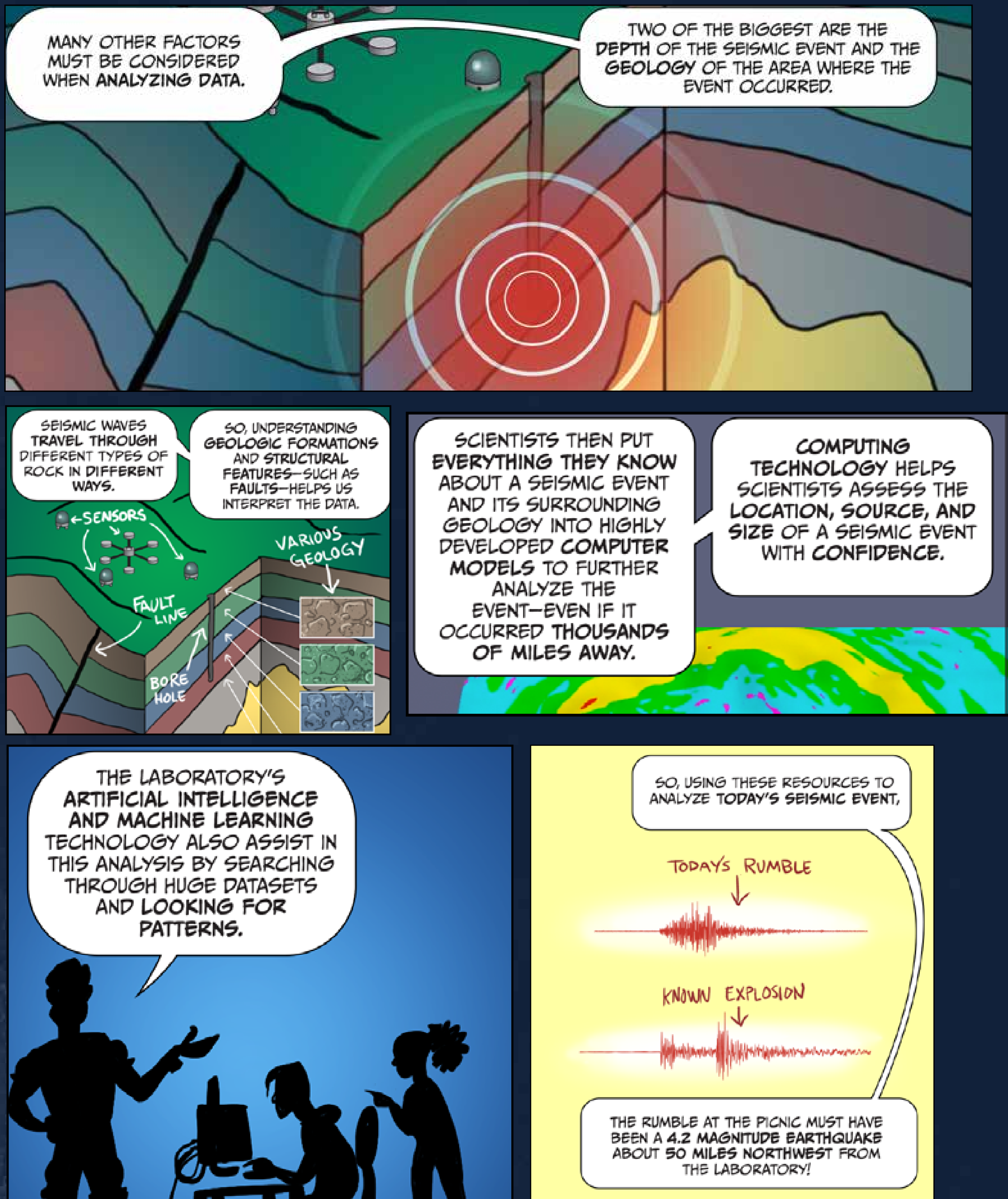
Our ability to detect nuclear detonations in space—using sensing technology developed at Los Alamos—helps ensure that countries are adhering to various nuclear nonproliferation treaties.

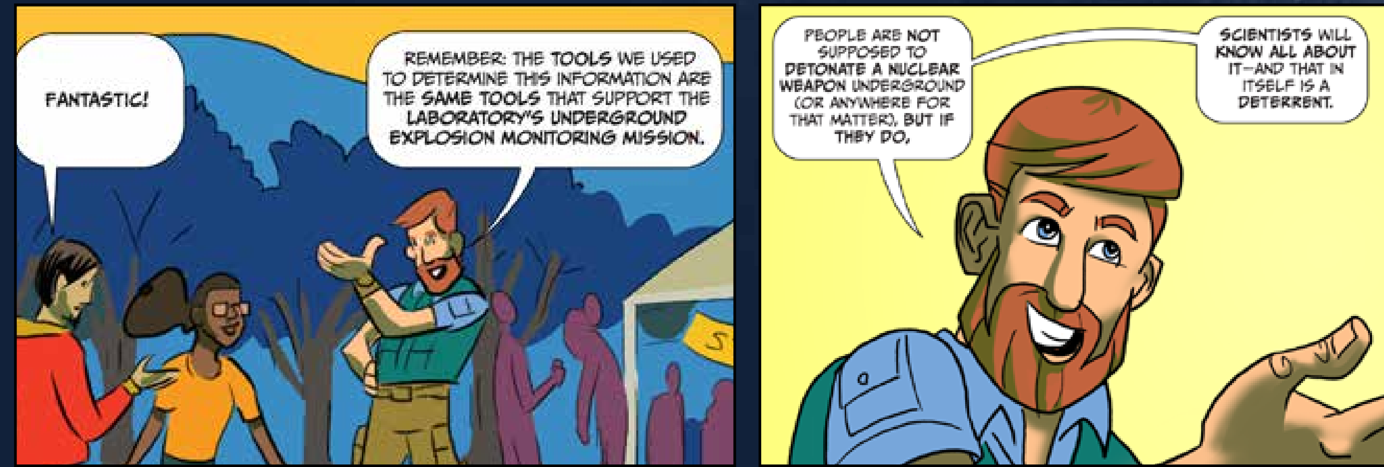
The comic featured on the following pages was originally created for an exhibit at the Bradbury Science Museum. The Bradbury, which is part of Los Alamos National Laboratory, is located in downtown Los Alamos, New Mexico. The museum is free and open to the public.




JULY 12, 2021
9:33 A.M.
IT'S A BRIGHT, SUNNY DAY IN LOS ALAMOS DURING THE STUDENT PICNIC...
STUDEN
WHAT'S GOING ON?
RUMBLE RUMBLE
I'M GLAD YOU ASKED!
THAT COULD'VE BEEN ANY NUMBER OF THINGS—SUCH AS AN EARTHQUAKE OR AN UNDERGROUND EXPLOSION.
HOW CAN YOU TELL WHAT IT WAS?


WHEN THE EARTH IS MOVED, SEISMIC WAVES ARE GENERATED, AND THEY TRAVEL THROUGH THE EARTH IN ALL DIRECTIONS. THESE WAVES ARE WHAT YOU JUST FELT.
SEISMOGRAPHS LOCATED ALL OVER THE WORLD LOG THE WAVES, WHICH INCLUDE P-WAVES, S-WAVES, AND SURFACE WAVES.
EACH WAVE HAS ITS OWN DISTINCT CHARACTERISTICS.
BACKGROUND NOISE
P-WAVE (COMPRESSION) ARRIVES FIRST
THEN S-WAVE (SHEAR) ARRIVES
SURFACE WAVES ARRIVE LAST
INFRASOUND DEVICES RECORD WAVES THAT REACH THE AIR.
THESE DEVICES CAN DETECT LOW-FREQUENCY SOUND WAVES THAT HUMANS CAN'T.
USING THOUSANDS OF DATA POINTS COLLECTED BY SEISMOGRAPHS, INFRASOUND DEVICES, AND OTHER TECHNOLOGY, SCIENTISTS ANALYZE THE DATA.
SCIENTISTS EVEN COMPARE THE DATA TO DATA FROM HISTORICAL EVENTS—PAST EARTHQUAKES OR UNDERGROUND EXPLOSIONS THAT WE KNOW A LOT ABOUT.
SO, IF THE DATA FROM AN UNKNOWN EVENT MATCH THAT OF A KNOWN HISTORICAL EVENT, THEY COULD BE FROM THE SAME TYPE OF SOURCE.
EXACTLY!
BUT ARE THESE METHODS ALWAYS ACCURATE?
GOOD QUESTION!





The earthquake described here did in fact occur in July 2021. The Laboratory reported no damage or disruption to normal operations—including to this fictional student picnic. ★

TAKEAWAY

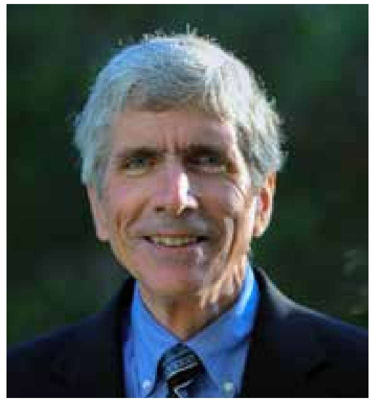
BETTER SCIENCE = BETTER SECURITY

Tools developed at Los Alamos help scientists determine the location, source, and size of a seismic event—such as an underground explosion.

LEADING TRANSPARENTLY

Charles Verdon reflects on his 42 months as head of Defense Programs at the National Nuclear Security Administration.

BY WHITNEY SPIVEY



On October 9, 2018, Charles Verdon was sworn in as the deputy administrator for Defense Programs at the National Nuclear Security Administration (NNSA). In this role—and during the six months he served as acting NNSA administrator in 2021—he directed the nation's Stockpile Stewardship Program, which uses cutting-edge science and technology to maintain the safety, security, and effectiveness of America's nuclear weapons stockpile without nuclear testing.

Verdon, who holds a PhD in nuclear engineering, was a member of the senior leadership team at Lawrence Livermore National Laboratory before joining NNSA. "I continued to learn a lot after I left Livermore to take the Defense Programs position, and my admiration for the nuclear weapons complex just continues to grow," he says. "It has been my honor to serve."

After working across two presidential administrations, Verdon stepped down in April. Before saying goodbye, he sat down for a brief conversation with *NSS*.

How does NNSA attract and retain top scientists and engineers to work at the national laboratories?

Because of the world's geopolitical environment, national security is of growing importance right now. NNSA is sending a strong message, especially to people fresh out of school, that national security is something the country values. We're coming up with all sorts of initiatives to attract people, and our hiring has been pretty successful. We're also doing a good job of knowledge transfer—we're delivering the mission with a relatively new workforce.

Retention is an emerging issue that we're still trying to wrap our heads around. The nuclear weapons complex has traditionally had a history of very high retention—people believed in the mission and they stayed for decades because the work is exciting. But now, because of COVID-19, we're certainly seeing a change. For example, highly classified work might require a person to come in to work five days a week, but now that person might rather come in only three days a week. How do you accommodate that and still do the mission? I don't think we have the answer yet, although certainly NNSA is working on it.

How do the national laboratories—specifically Los Alamos and Lawrence Livermore—best work together in support of the stockpile stewardship mission?

Managed competition has always existed between Livermore and Los Alamos. Prior to the Stockpile Stewardship Program, this competition benefited the country because it brought forward the best warheads to answer the needs of the DOD [Department of Defense]. Then, with the cessation of underground nuclear explosive testing and the advent of the stewardship program, because the science of weapons performance is not completely understood, having competition between the two labs is even more important.

Los Alamos, being J. Robert Oppenheimer's lab, and Livermore, being Edward Teller's lab, approach the same problem very differently. If they come up with the same answer, we have improved confidence. If they come up with differences, we'd better listen.

As the deputy administrator for Defense Programs, what is your relationship with Los Alamos?

I've always had great admiration and respect for the abilities of Los Alamos. I've tried to make sure that Los Alamos retains a balance of activities while also focusing on producing 30 plutonium pits per year by 2026. Pit production is a new and different challenge; Los Alamos has the scientific and technical wherewithal to do it, now it has to learn the operational wherewithal. It's been a long time since the nuclear enterprise has done sustained pit production, so relearning how to do it, especially with COVID-19, is quite a challenge. I think everyone is working hard to achieve it. Everyone believes in the mission. What more could you ask for?

How should Los Alamos strike a balance between research institution and production facility?

I think by making sure and all the scientific work continues to move forward and is not lost in the noise of pit production. For example, the W93 warhead program could have *not* gone to Los Alamos, but that would have been, in my mind, the wrong decision. Los Alamos is doing a good job balancing its priorities, although there's no question that pit production will continue to take a lot of the oxygen out of the room for a significant period.

What are some challenges faced by Defense Programs these past three and a half years?

The biggest has been making sure we understood what was required to support the nation's nuclear deterrent. We

▲ Laboratory Director Thom Mason (right) shows Admiral Charles Richard (head of United States Strategic Command, left) and Charles Verdon (head of Defense Programs at NNSA, center) around Los Alamos.

transparently identified all those issues and made sure that we came up with a prioritized way of addressing them. And then we were as transparent as possible with our DOD partners and our colleagues on Capitol Hill so that they understood what it takes to meet DOD's current and future requirements. It's a big effort that was both challenging and rewarding.

So many important activities are in progress; that's why I was asked, and agreed, to stay on through the administration change. Being able to continue that momentum and ensure a smooth transition between one administration and the next was important. I've been transparent about what we've done and what still needs to be done, but of course it is up to the NNSA administrator and new head of Defense Programs how they want to continue, change, or finish it.

I've rarely had the joy of actually seeing projects that I helped launched get completed. So, I've taken the approach that I just have to be pleased with the fact that we identified important things to be accomplished and the timeline they should be accomplished on. And then, after getting support from DOD, from the Hill, from the administration, we got to work with our M&O [management and operating] partners—including Los Alamos and other national labs, plants, and sites. So that's kind of the victory I have to take—knowing that maybe I'll get to see projects completed, but it will be from a rocking chair on the porch. ★

During the summer of 2020, Lunn took the bike he made to Angel Fire Resort, one of the premiere mountain biking locations in northern New Mexico.
Photo: Maureen Lunn

Lunn's custom bike design fits his body's unique proportions.
Photo: Toby Lunn

AN EYE FOR DETAIL

Toby Lunn's engineering background complements his global security work and his mountain biking habit.

BY OCTAVIO RAMOS

As far back as he can remember, Toby Lunn, of the Intelligence & Systems Analysis group at Los Alamos National Laboratory, has loved bicycles.

"I've been doing something related to mountain biking since I got my first bicycle, which was when I was 6 or 7 years old," explains Lunn, who grew up in Kansas. "I lived right at the edge of town, so I rode my bike through dirt and ditches. Mountain biking became popular when I was a teen, and I fell in love with the sport right away. It's become a big part of my life, and it was definitely a factor in coming to Los Alamos and starting a career at the Laboratory."

SUPPORTING INTELLIGENCE WORK

Although he has experience working as an intelligence analyst, Lunn says that he works in a niche position, one where he applies engineering analysis and visualization techniques to support analysis teams' assessments, which then inform decisions associated with national and global security.

"The bulk of my teammates are analysts who bring together different pieces of information to craft a more complete picture," Lunn says. "In my position, I support analytical teams with my engineering experience to get at some of the technical details associated with intelligence information."

To amplify what he does, Lunn provides an example: "Maybe there's a system under analysis by a team in my group. I can use my skills in mechanical engineering and manufacturing to help us understand small details. I may not deal with the big picture behind the overall intelligence need, but I help with specific pieces that require clarification.

"When I came to the Laboratory in June 2017, I learned from the best intelligence analysts in the world, eventually becoming an analyst myself," Lunn continues. "In my current role in intelligence analysis support, I get to work with a number of analysis teams, each working on a completely different problem that I can assist with. What satisfies me most is contributing in a small way to various projects that in the end make our world a much safer place."

Lunn's engineering experience before coming to the Laboratory involved a few years working in the commercial sector, followed by an eight-year stint at the Kansas City National Security Campus, where he first started working on issues associated with national security.

MAKING CUSTOM RIDES

When Lunn joined the Laboratory, he immediately started riding his bike around northern New Mexico. He was drawn to the challenging terrain—and the idea of building a custom bike for this specific landscape.

"Even before college, I was fascinated with metal work and welding—which is actually what led me to explore mechanical engineering and is key to being able to build bikes," Lunn says. "A bike's core is its frame, and so I design custom bikes from the frame up. About 10 years ago, I decided to try making them myself to find a bike that works better with the terrain and my own height. I really enjoy the science and engineering that goes into planning and building a bike frame."

Lunn has put all that brain power into designing and building four different bikes, all of which he has tested on various mountain trails. Some bikes specialize in downhill trails while others are best for rocky paths. He's working on his fifth.

"For me, building these custom bikes comes down to the fact that everyone's body is different," Lunn explains. "I'm on the tall side, with a very long inseam, so there are few bicycles that comfortably fit my frame. My bikes are built to fit me. The process is a lot of fun, and the bikes feel a lot better to ride."

One of the key skills in building custom bikes is precision. Associated with precision is attention to detail.

"These two things are key," Lunn says. "The science is what's behind the design, but the end result is a smoother and more enjoyable experience riding the trails." ★

ACCOLADES

THE DISTINGUISHED ACHIEVEMENTS OF LOS ALAMOS EMPLOYEES

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

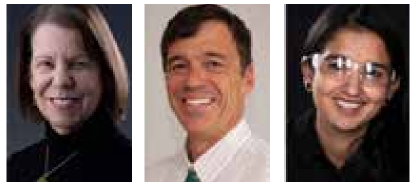
Hardworking people—the Laboratory's most important asset—enable Los Alamos to perform its national security mission.

Former Los Alamos Weapon Programs Executive Officer John Benner is now the Laboratory's associate director for Weapons Production (ALDWP). In this role, Benner leads the 1,400 employees responsible for a portfolio that includes the production and evaluation of plutonium pits, nuclear weapon detonators, and other nonnuclear components. ALDWP also oversees plutonium processing and disposition, manufacturing of power supplies for NASA deep space missions, surveillance, materials management, and waste operations.

Project engineer Robert Penn Jr., of the Lab's Engineering Project Delivery group, was awarded the American Nuclear Society (ANS) Milton Levenson Distinguished Service Award for his "untiring and continued support for the mission of nuclear energy for over 45 years with ANS as a leader, an advisor, a hard worker, a friend, and a visionary."

The National Postdoctoral Association announced the launch of the Postdoc Council Pilot Program. Los Alamos postdoc Leonardo de Melo, of the Quantum Technologies team, was selected to serve on the inaugural committee.

Joshem Gibson, of the Lab's Dynamic Structure Design and Engineering group, is a new member of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Committee. In this role, Gibson can help the Lab stay informed about ASME's potential changes to guidance and recommendations that affect the design and use of confinement vessels, and Gibson can inform ASME of the Lab's unique application and design plans.



Three Los Alamos scientists have been named fellows of the American Association for the Advancement of Science. Babetta Marrone, of the Lab's Bioenergy and Biome Sciences group, was recognized for her contributions of multidisciplinary experimental and computational approaches that provide life science solutions to energy and national security applications. Thomas McCleskey, of the Chemistry division office, was honored for the development of polymer-assisted deposition of thin-film coatings, for the elucidation of a new paradigm in beryllium binding, and for enlightened chemistry leadership at a national laboratory. Harshini Mukundan, of the Physical Chemistry and Applied Spectroscopy group, was selected for pioneering the understanding of the biochemistry of interactions between pathogen amphiphiles and host lipoproteins, and development of novel spectroscopic assay modalities for their detection.

More than 60 Los Alamos staff members on four different teams were recognized with Honor Awards from the U.S. Secretary of Energy—the highest honor a Department of Energy employee or contractor can receive. The W76-2 Modification Team was recognized for its dedication to engineering the submarine-launched W76 warhead to have a low-yield capability. The Burning Plasma on the National Ignition Facility Team was recognized for advancing lasers, diagnostics, targets, and physics understanding of capsule coupling and compression that, when combined, enabled a three-fold increase in fusion performance in the period of a few months. The Nuclear Incident Response Stabilization Team was recognized for equipping and training bomb technicians to identify, communicate, diagnose, isolate, and defeat weapons of mass destruction. Lastly, the Lovelace Biomedical Research Institute Material Removal Team was recognized for collaborating at the federal, state, and local levels to safely remove radioactive materials from the Lovelace Biomedical Research Institute under an intense and time-constrained schedule during the COVID-19 pandemic.

The Lewis Wolpert Prize for Best Paper in 2022 was awarded to authors Ruian Ke, Ethan Romero-Severson, Steven Sanche, and Nick Hengartner, all of the Laboratory's Theoretical Division at the time of the publication. The paper, "Estimating the reproductive number R0 of SARS-CoV-2 in the United States and eight European countries and implications for vaccination," was published in the *Journal of Theoretical Biology* in May 2021.

Los Alamos received the 2022 Family Friendly Business Award for the third consecutive year from Family Friendly New Mexico, a nonprofit that recognizes and supports businesses that have implemented family-friendly policies in support of employees' work-life balance.

Sara Dumit, of the Lab's Radiation Protection Services group, was recognized with the 2022 John D. Boice Jr. Young Investigator Award of the National Council on Radiation Protection and Measurements. The award celebrates an early career professional engaged in some aspect of science pertaining to radiation protection and measurements. ★

LOOKING BACK

34 YEARS AGO

On August 17, 1988, the first test of the Joint Verification Experiment (JVE) was conducted in the United States at the Nevada Test Site (now the Nevada National Security Site). The second and final test was conducted about a month later, on September 14, at the Soviet Union's Semipalatinsk test site, located in what is now Kazakhstan. The JVE tests were part of an agreement that allowed scientists and engineers from the United States and the Soviet Union to witness and analyze underground nuclear tests in each country as part of the Threshold Test-Ban Treaty of 1976, which limited the yields of nuclear tests to no more than 150 kilotons.

The JVE marked a period of cooperation between the United States and the Soviet Union that aided in stabilizing the nuclear world after the fall of the Soviet Union in 1991. Says Siegfried Hecker, director of the Laboratory at the time of the JVE, "If you want to avoid a world of nuclear war, nuclear proliferation, and nuclear accidents, you need cooperation."

Pictured here are the American (white hats) and Soviet (red hats) crew members present at the second test. ★

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THEN & NOW

Starting in 1955, Los Alamos Scientific Laboratory's Project Rover attempted to harness nuclear power for space travel. Pictured here in 1968, the Phoebus-2A reactor produced more than 4,000 megawatts of thermal power, making it the most powerful nuclear propulsion reactor of its time. Although Phoebus-2A was never meant to go into space, researchers hoped the prototype reactor could be modified for travel to Mars. That dream, however, ended in 1973 when Project Rover was terminated.

Forty-five years later, in 2018, Los Alamos National Laboratory—in conjunction with several other organizations—successfully demonstrated another prototype, Kilopower. This nuclear reactor power system can provide up to 10 kilowatts of electrical power—enough to enable long-duration crewed missions to the Moon, Mars, and beyond. Four Kilopower units (illustrated here) would be enough to establish an outpost in outer space. In 2020, Los Alamos licensed the Kilopower technology to the Space Nuclear Power Corporation, which has been busy writing proposals to advance the technology. ★

SCAN QR CODE WITH A SMARTPHONE CAMERA
Watch a video about Phoebus-2A.