

NATIONAL ★ SECURITY SCIENCE

THE INFORMATION ISSUE

▲ **Envisioning the W93:**
What will the Navy's
nuclear deterrent look like
in the 2030s?

💡 **Trinity revisited:** Analysis
of the first atomic blast
sheds light on the origins of
nuclear science

🎮 **Wargames:** Simulating
wartime decisions helps
prepare for the real thing

🔍 **The archives of the future:**
Artificial intelligence is the
solution to digitizing,
cataloging, and searching
collections

+ PLUS:

The future of trucking
is hydrogen

The fourth atomic spy

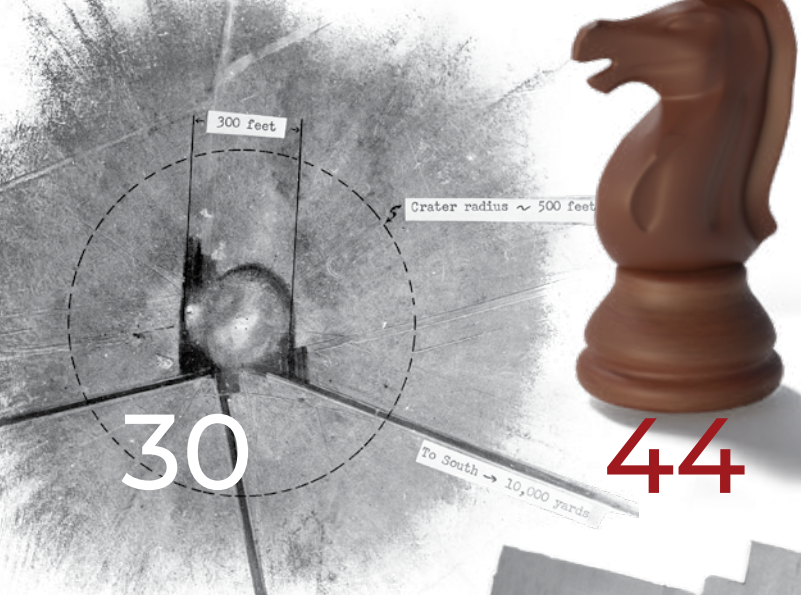
DNA: the ultimate
storage solution

PHOTOBOMB

Air Force Global Strike Command bombers—a B-1B Lancer, a B-2 Spirit, and a B-52H Stratofortress—fly over Raymond James Stadium in Tampa, Florida, before Super Bowl LV. The B-2 is capable of carrying the Los Alamos National Laboratory–designed and maintained B61 gravity bomb—but that’s not the only connection the Laboratory has to the Super Bowl.

Members of the Lab’s nuclear emergency support team (NEST) worked with the Florida Highway Patrol, the Florida Bureau of Radiation Control, and the U.S. Department of Homeland Security’s Countering Weapons of Mass Destruction Office to help keep the event safe from radiological and nuclear incidents and accidents. NEST provided command and control of deployed personnel and operations, alarm adjudication services, scientific and technical support, interagency coordination, and associated map products. ★

Photo: U.S. Air Force/Jacob Wrightsman



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About the cover: During the Manhattan Project, Los Alamos scientists contemplated conducting the Trinity test—the detonation of world's first atomic device—inside Jumbo, a 214-ton steel cylinder that would contain the plutonium if detonation failed. Jumbo was built and transported to southern New Mexico but never used as originally intended. After World War II, eight 500-pound bombs were exploded inside Jumbo, but much of the cylinder stayed intact and remains today at the Trinity site. For more on recent analysis of the Trinity test, turn to p. 30. ★

THE INFORMATION ISSUE

Don't let the theme fool you—this issue is *not* boring.



JOHN SCOTT
DIRECTOR, OFFICE OF NATIONAL SECURITY AND INTERNATIONAL STUDIES

Information—in the form of facts, data, and knowledge—is the foundation of everything we do here at Los Alamos National Laboratory. Our business is solving the world's most pressing national security challenges, and we do that by continually acquiring new information to advance our understanding of those challenges and their potential solutions.

This issue of *National Security Science* magazine highlights just a few ways the Laboratory generates, interprets, conveys, and stores information.

“Trinity revisited,” for example, on p. 30, tells the story of scientists who used new-to-them historical documents and modern data analysis to better understand the Trinity test—the first-ever detonation of a nuclear device, which occurred more than 75 years ago. Their findings have been published in a special issue of the Laboratory's internal classified journal *Weapons Review Letters*. The articles—all 46 of them—expand the Trinity literature and constitute what is likely the most comprehensive technical history of this world-changing event. The American Nuclear Society will publish 23 of the articles in a special issue of its open-access *Nuclear Technology* publication that is expected later this year.

Speaking of historical documents, on p. 52, Rizwan Ali, director of the Lab's National Security Research Center, discusses how artificial intelligence and machine learning technology (AI/ML) can organize archival materials, specifically documents that will help weapons designers do their work. “We see artificial intelligence as a tool to help us go through the monumental tasks we have in digitizing, cataloging, and searching our classified collections,” Ali says. “We're confident AI/ML will save the Lab a lot of time and even more money when it comes to our weapons research efforts.”

Often, the Lab must use information to evaluate technology that hasn't been invented yet. “Envisioning the W93,” on p. 20, details the development of a *potential* new warhead that might one day be developed at Los Alamos. The Laboratory is involved in a Phase 1, or concept, study to assess what an effective warhead would look like in the 2030s and beyond.

Future scenarios are also considered on p. 44 in “Wargames.” Full-scale wargames and smaller-scale tabletop exercises allow participants to simulate wartime decisions. “Wargaming is strategic analysis,” says Rich Castro, the retired director of the Lab's Strategic Analysis and Assessment Office. “The Lab's participation is important because wargaming is an analytical tool that brings together many different thoughts, combining the expertise of the Department of Defense, Department of Energy, and the national laboratories.”

As you can see, our interpretation of “information” is broad, but that's the point. Just about anything is information, and the possibilities for that information are endless. That's why working at Los Alamos is never boring—and neither is this issue. I invite you to dive in, learn something new, and share the...you guessed it... information. ★

MASTHEAD

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NSS STAFF SPOTLIGHT



Lieutenant Colonel Geoffrey Steeves, who wrote about flying the B-2 stealth bomber in the summer 2020 issue of this magazine, became Colonel Geoffrey Steeves in January 2021. Steeves and his kids are pictured here at his promotion ceremony at the Lincoln Memorial in Washington, D.C. Steeves, a former Air Force Fellow at the Laboratory, currently works in the Air Force Futures Directorate at the Pentagon. He was interviewed for “Is technology replacing pilots?” on p. 12. ★



Chien-Shiung Wu (second from right) sits with physicists J. Robert Oppenheimer (third from right) and Emilio Segrè (fourth from right), likely in the late 1930s when Wu was a graduate student at the University of California–Berkeley. Oppenheimer would later move to Los Alamos to become the scientific director of the Manhattan Project. Photo: Vincent Yuan

LETTERS

A STAMP OF APPROVAL

Nuclear physicist Chien-Shiung Wu is recalled fondly by her son, a Los Alamos physicist.



On February 11, the International Day of Women and Girls in Science, the U.S. Postal Service issued the Chien-Shiung Wu Commemorative Forever Stamp in tribute to the influential experimental physicist and longtime Columbia University professor.

Wu's demonstration of a fundamental law of physics—the effect called parity violation—was her most notable work, but she wasn't included in the Nobel Prize her male collaborators received.

“Chien-Shiung Wu is widely considered one of the most influential scientists in history, but her achievements were not widely acknowledged due to her gender and race,” according to the American Association of University Women (AAUW), which advocates for gender equity and economic security for women. In 1959, the AAUW presented Wu with its biennial achievement award. Her acceptance letter is at right.

Regarding the postage stamp, Wu's family is honored that she was selected. “Like anybody, you're proud of your mother,” says her son, Vincent Yuan, a scientist in the Applied and Fundamental Physics group at Los Alamos National Laboratory. “But it wasn't just her accomplishments. It was the embodiment of all the qualities she believed in: hard work and not sweeping problems under the rug and seeing the bigger picture of things. She applied that to her work and to her students.” ★



INFOGRAPHIC

THE INTERSECTION

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

JUST EAST OF THE VALLES CALDERA, THIS NEW MEXICO CITY & NATIONAL LAB SITE HELPED CREATE A DIFFERENT TYPE OF EXPLOSION IN WWII

"What is Los Alamos?" was the correct answer to this Jeopardy clue, which was read on the June 11 show.

A life-sized, 3D-printed likeness of Lab scientist Harshini Mukundan is part of an exhibit honoring 120 women STEM professionals at NorthPark Center in Dallas, Texas. The exhibit, which features the most women statues ever assembled in one place at one time, is open through August.

The logo for Boese Brothers Brewery's Dr. Strangehop IPA features Major Kong (actor Slim Pickens) atop the Los Alamos–designed Fat Man bomb. Coincidentally, Boese Brothers does have a Los Alamos location.

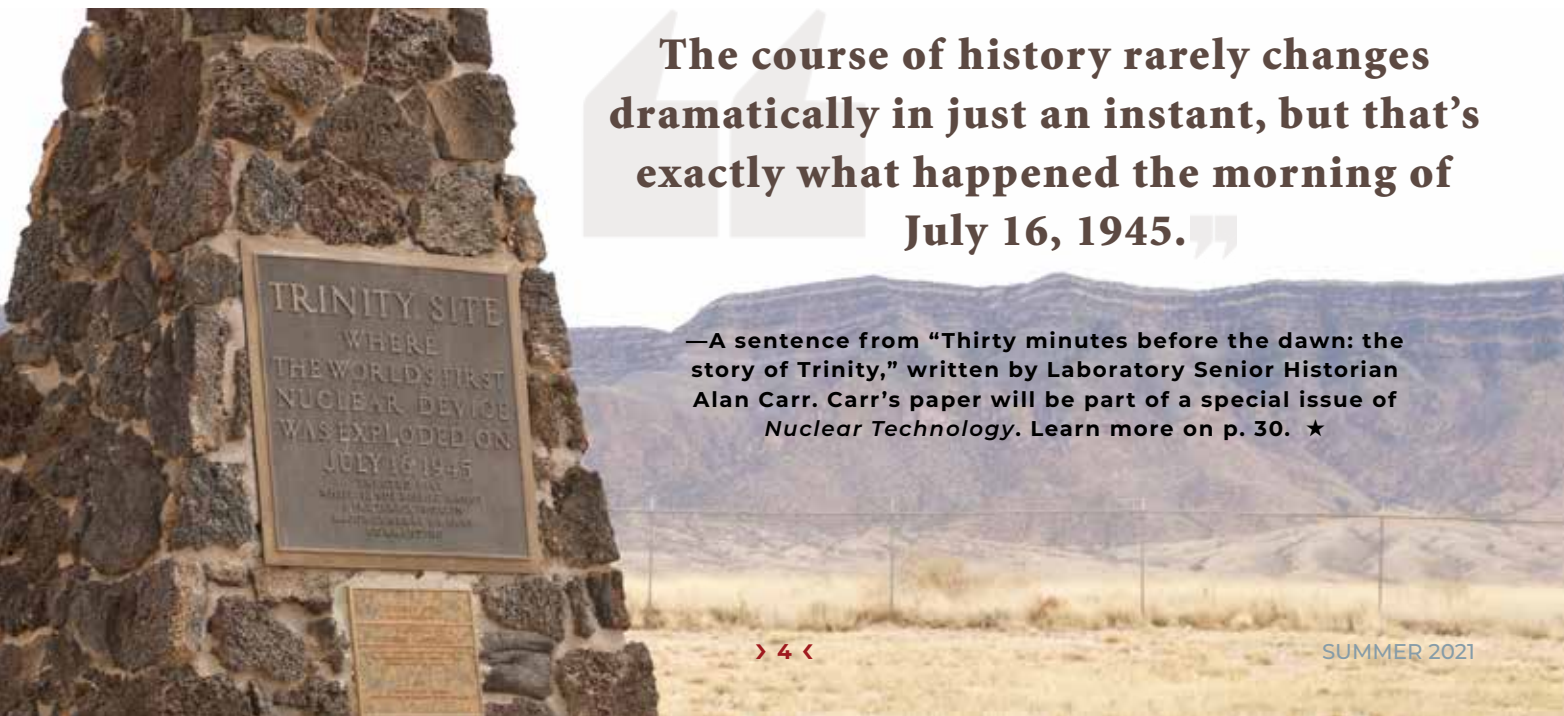
Deputy Laboratory Director Bob Webster hands out Weapons programs challenge coins to thank people administering COVID-19 vaccinations at the Laboratory. As of June 30, 78 percent of Laboratory employees were fully vaccinated.

In January, a mineral was named for two scientists who have revolutionized the analysis of mineral samples. Xuite (pronounced "zoo-ite") is named in honor of Los Alamos mineralogist Hongwu Xu and the University of Wisconsin's Huifang Xu.

QUOTED

The course of history rarely changes dramatically in just an instant, but that's exactly what happened the morning of July 16, 1945.

—A sentence from "Thirty minutes before the dawn: the story of Trinity," written by Laboratory Senior Historian Alan Carr. Carr's paper will be part of a special issue of *Nuclear Technology*. Learn more on p. 30. ★



Thom Mason

STOCKPILE STEWARDSHIP

THE STATE OF THE NUCLEAR STOCKPILE

For more than 25 years, Laboratory directors have penned an annual assessment letter.

BY THOM MASON, LABORATORY DIRECTOR

For 25 years now, Los Alamos National Laboratory has completed an annual assessment of the weapons systems in our nation's nuclear stockpile. Each September, the process culminates in a letter from the Lab director to the secretary of energy, the secretary of defense, and the chair of the Nuclear Weapons Council. This letter informs the president of the United States of our confidence that the stockpile remains safe, secure, and effective now and into the future as a result of our dedicated sustainment and modernization efforts.

In the mid-1990s, the early years of the letter, the concept of science-based stockpile stewardship—maintaining the stockpile using science instead of nuclear testing—was in its infancy but had momentum among the Los Alamos workforce, which viewed stockpile stewardship as a challenging technical problem. Advanced testing facilities were built and began to realize their potential as experiment data was fed into increasingly powerful supercomputers that could simulate the inner working of a nuclear weapon.

The process and content of the annual assessment letter has also evolved from an initial rudimentary concept. Early versions of the letter were heavily influenced by the knowledge of and experiences from the recent nuclear testing program, which was fresh in the collective consciousness of the Laboratory workforce of the

mid-1990s. Several of these early letters were unclassified and only a few pages long. The letters focused solely on certification, which is understandable because the idea of science-based stockpile stewardship was still developing.

As the stockpile stewardship program evolved into the comprehensive, broad-reaching program of today, so did the letter. The letters crafted from the mid-2000s to 2010 explain the technical content as well as the discussion around emerging scientific research and tools that could assess the stockpile without performing underground nuclear tests. These tools included advanced computational platforms and capabilities and advanced experimental testing facilities. Additionally, production plants—throughout what we now call the nuclear security enterprise—continued and improved their surveillance (inspection) efforts to determine how our systems were aging.

For the past 10 years, the annual assessment letter has recognized significant advancements in capability and introduced weapon life extension programs, alterations, and modifications, which each address aging and performance issues, enhance safety features, and improve security. Often the letter captures the status of the execution of such updates because they represent timely examples of success and advancement.

The 2020 annual assessment process was completed despite hurdles caused by the coronavirus pandemic. Weapons and computer code designers, administrative assistants, and others had to comply with Laboratory guidelines for social distancing and telework while meeting reporting deadlines. I addressed those challenges in the 2020 letter: "Every Laboratory activity has been affected to some degree this year."

The 2021 assessment is underway, and although the Laboratory (and the world) is still affected by the pandemic, we remain vigilant in our assessment of the nuclear stockpile. ★



"Radiography conducted on test objects during high-g loading allows us to obtain images to help visualize the effects of these environments, and it also offers a new method of mathematical analysis that compliments the other measurements we make," says CTF test engineer Alex Cusick.

TECHNOLOGY

THE SPINNING IMAGE

The Lab's Centrifuge Test Facility adds a key capability.

BY KEVIN ROARK

To better understand how nuclear weapons will handle high-gravity (high-g) environments—such as a missile launch or the reentry of a warhead into the atmosphere—Los Alamos National Laboratory conducts a variety of tests at its Centrifuge Test Facility (CTF).

Tests at the CTF evaluate the effects of high-g loading on internal components of weapon assemblies, including high-explosive charges, detonators, electronics, and nuclear materials. The test objects are attached to the arm of the centrifuge and spun to high velocities to simulate atmospheric reentry deceleration forces and lateral g-loading. Data are typically acquired using accelerometers, strain gauges, and displacement sensors.

The facility opened in 2016 but recently got an upgrade to its suite of diagnostic tools: flash x-ray radiography. Now, the CTF can image the internal components during these tests, which is a valuable new capability.

"Up to now, it has been impossible to truly visualize the internal components of a weapon system or space system under a high-g environment," says CTF test engineer Alex Cusick. "Now we do not need to rely solely on data to understand the effects of these environments; we have the ability to look at real images to visualize them which is truly unique and exciting."

"These tests are at the core of the weapons development objectives because they allow us to feed results back into our computer models and redesign efforts, and they allow us to qualify design changes before those changes are made to weapons in our stockpile," Cusick continues. "Radiography adds to the existing methods, making our analysis capabilities more powerful than ever."

Beyond the nuclear weapons mission, the CTF is also used to qualify flight electronics and components that will be used for space applications, such as satellite components that are being developed by the Intelligence and Space Research Division and others at Los Alamos.

CTF is also a user facility that supports external organizations for similar, non-weapons related work. Los Alamos is currently collaborating with Texas A&M University, Lawrence Livermore National Laboratory, the Air Force Research Laboratory, and others on future tests. ★



QUOTED

What the newly hired saw was an ugly shanty town, mud in the streets, wash drying on the outside clothes lines, babies bawling in a place secluded, unknown to the outside world. Yet this was the town, under the startlingly clear air of the Northern New Mexico mountains, where clear-eyed young men were busy discerning nature, defying technical difficulties, striving against time to alter a foreboding history."



—Physicist and longtime Los Alamos resident Harris Mayer recalls the beginning of the Manhattan Project in his memoir *People of the Hill: The Early Days*. Mayer turned 100 on February 15, 2021. ★

LISTEN

SUBSCRIBE NOW

Three podcasts from Los Alamos National Laboratory detail nuclear history and cutting-edge science and technology. Available on your favorite podcast platform or at discover.lanl.gov.



LATEST EPISODE:

The fourth atomic spy Senior Historian Alan Carr discusses Oscar Seborer, a recently discovered spy. For more on Seborer, turn to p. 18.



LATEST EPISODE:

Searching for signs of life on Mars Billions of years ago, Mars was warmer and wetter. Could a dried up lake bed harbor secrets of past life?



LATEST EPISODE:

How to make a Fat Man A recently re-discovered manual details how to assemble the atomic bomb released above Nagasaki during World War II.

TECHNOLOGY

NATURE'S STORAGE SYSTEM

By translating massive quantities of digital data into DNA language, information can be stored indefinitely.

BY KATHARINE COGGESHALL AND CRISTINA OLDS

Currently, equipment used for information gathering—cameras and sensors, for example—isn't capable of storing vast amounts of data. Researchers either have to continually retrieve or replace the maxed-out equipment or simply be satisfied with snippets of information. Not an ideal tradeoff—a different approach is needed.

DNA, the biological molecule that lives inside each human cell, embodies everything researchers seek: the ability to preserve massive information in minute space. DNA is nature's storage system, and it has successfully passed on critical information for billions of years, even remaining viable in dinosaur bones. If this robust storage "tech" could be harnessed for digital data, it could change the landscape of intelligence gathering and storage.

Digital data is typically stored in the binary language of ones and zeros. DNA speaks with a four-letter alphabet of nucleotides, so a sophisticated digital translation tool—a codec—is necessary to bridge the gap. Recently, scientists at Los Alamos National Laboratory created such a codec to translate between binary and DNA languages.

"Our Adaptive DNA Storage Codec, or ADS Codex, is the first end-to-end open-source tool for robust digital storage in DNA," explains Latchesar Ionkov of the Lab's High Performance Computing Environments group. "In simpler terms, ADS Codex is a translator, just like you can use Google Translate to go between English and French."

ADS Codex translates binary data to the sequence of nucleotides that make up DNA. From this sequence, which is a digital string of nucleotide letters written in a specific order, a physical piece of DNA can be created. Funnily enough, DNA creation is the easy part—scientists around the world have been doing it for decades through the use of a few chemicals and a polymerase chain reaction machine.

Armed with ADS Codex, researchers are eyeing a new suite of gadgets that can record digital data, translate it into nucleotides, generate the corresponding physical DNA, and store the strands long term. Considering each human cell holds about 6 feet of DNA in 6 micrometers of space (a bit smaller than the width of a human hair), this method will enable massive amounts of data to be stored right in the gadget itself.

ADS Codex will be most useful where big data is generated but access to that data is not needed quickly or routinely. Consider the application of a wild game camera placed on a glacier in remote Alaska for multiple years. The camera continuously records images and audio, all the while translating and synthesizing DNA for storage.

Despite the exciting advancements it offers, however, DNA is unlikely to be the go-to storage solution for everyday tech—cell phones, personal computers, and so on. Storage and retrieval of information using DNA is slow and therefore not likely to be practical for rapid access applications or widespread usage in the near future. ★

TECHNOLOGY

UNCOVERING BIG DATA TRENDS

A new type of artificial intelligence eliminates human bias, allowing the technology to "see" previously unobserved information.

BY KATHARINE COGGESHALL AND GAYLE GEIS-O'DOWD

Remember the *Magic Eye* books? Hidden within swirling patterns and splashes of color were eye-catching 3D images. Of course, the image was always there, but it took a special way of looking at the page to see what was "hidden." Patterns in big data sets are no different. These patterns are buried in massive amounts of noise, less-important information, and intricate webs of interconnected variables. No human eye can see through the mess to identify a pattern, and human-guided software, such as traditional artificial intelligence (AI), is blind to the patterns as well.

As the world becomes awash with data and our scientific equipment records more detailed and complex information, many modern data sets sit unexplored. Demand exists for a tool that can see valuable patterns, such as identifying cancerous mutations in the human genome. That's where Los Alamos researchers Boian Alexandrov and Velimir (Monty) Vesselinov come in. They co-created the first unsupervised AI tool, which operates without human bias.

In traditional AI, humans teach the software what to look for and how to interpret the data. "Traditional AI relies on human influences, such as data labeling, subject-matter-expert opinions, and physics assumptions," Vesselinov says. This is both the foundation of AI and its biggest limitation.

The unsupervised—or free from human bias—tool that Alexandrov and Vesselinov created is named SmartTensors because it harnesses the power of mathematical tensors (algebraic expressions that describe the relationship between sets of objects) to transform millions upon millions of data bytes into bite-sized, manageable cubes of information.

Not only does SmartTensors compress the data, which is ideal for storage, but it hones in on hidden data features, stripping out the noise. Imagine an audio recording of a crowded party. You'll hear a jumble of voices, music, and glasses clinking. Previously, extracting the individual voices from the cacophony would have been close to impossible. But with SmartTensors, individual "voices" can be extracted easily from the collected data.

Since its inception in 2014, SmartTensors has evolved into a suite of unsupervised AI tools that operate on multiple platforms (from personal laptops to supercomputers to quantum computers). Alexandrov and Vesselinov have applied SmartTensors to more than 30 fields already, and that number is growing as members of the public try the technology (just go to github.com and search for "tensordecompositions"). What will you find in your data? ★



■ Jill Hruby



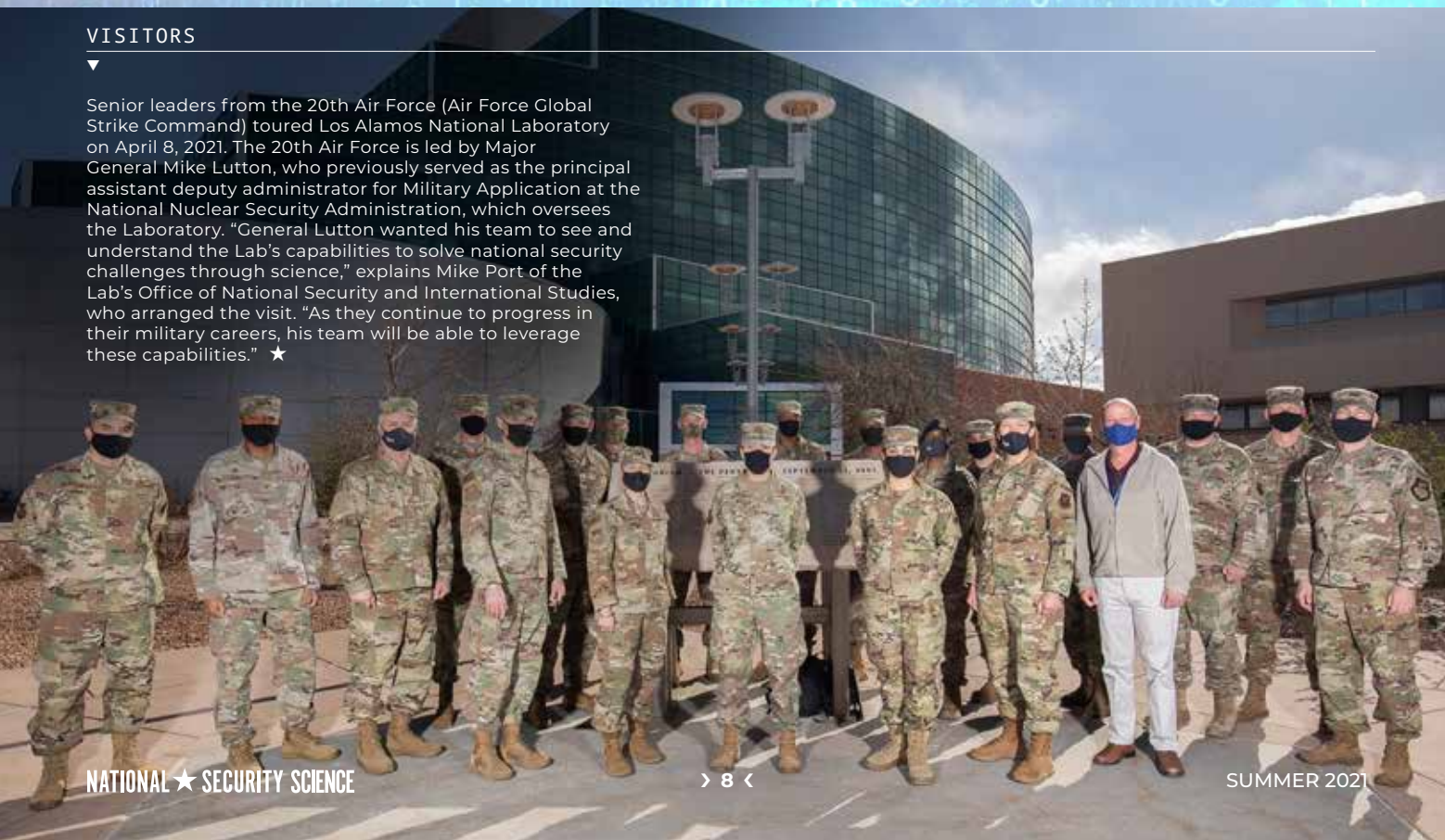
QUOTED

Jill is one of DOE's very best success stories—she rose through the ranks at Sandia National Labs to become the first woman to lead a national security lab, and now she's the perfect person to head up our efforts to maintain a safe and reliable nuclear deterrent and protect our national security."

—Secretary of Energy Jennifer Granholm on the nomination of Jill Hruby to lead the National Nuclear Security Administration (NNSA). The NNSA oversees several national laboratories, including Los Alamos. ★

VISITORS

Senior leaders from the 20th Air Force (Air Force Global Strike Command) toured Los Alamos National Laboratory on April 8, 2021. The 20th Air Force is led by Major General Mike Lutton, who previously served as the principal assistant deputy administrator for Military Application at the National Nuclear Security Administration, which oversees the Laboratory. "General Lutton wanted his team to see and understand the Lab's capabilities to solve national security challenges through science," explains Mike Port of the Lab's Office of National Security and International Studies, who arranged the visit. "As they continue to progress in their military careers, his team will be able to leverage these capabilities." ★



TECHNOLOGY

THE FUTURE OF TRUCKING IS HYDROGEN

A new Los Alamos project could soon bring clean-energy semi-trucks to a highway near you.

BY J. WESTON PHIPPEN

Picture a semi-truck hauling cargo down a highway. Are there clouds of black smoke left in its wake? Not if the truck is powered by hydrogen fuel cells.

But the transition from the combustion engine to fuel cell motors faces an infrastructure hurdle: Only 44 hydrogen refueling stations exist in the United States; 42 of those are in California.

Commercial semi-trailer trucks, however, could be the catalyst for the development of more hydrogen refueling stations. These trucks can drive many miles between refueling, which means they'd require fewer refueling stations along heavily trafficked routes. Transitioning these trucks to clean energy would cut about 20 percent of transportation-related greenhouse gases in the United States. So, developing a dependable, long-lasting hydrogen fuel cell for trucks that can haul everything from food to furniture is the focus of a new Department of Energy project called the Million Mile Fuel Cell Truck (M2FCT), co-led by Los Alamos National Laboratory.

"The hydrogen fuel cell program has been around since the 1970s, and it's the longest-running, non-defense program at Los Alamos," says Rod Borup, program manager for the Lab's Fuel Cells and Vehicle Technology group. "These clean engines could one day power planes, ships, and trips to the grocery store."

Here's how a hydrogen fuel cell engine works: Hydrogen gas is stored in a vehicle's tank (similar to how gasoline is stored in a tank). The hydrogen is then piped to the fuel cell stack, where the oxygen and hydrogen react on separate sides of 10- to 20-micron-thick platinum-coated membranes. These membranes are where electrons are then stripped from hydrogen atoms, the result being electricity. This electricity, combined with electricity from a lithium ion battery and also from regenerative braking, then powers the vehicle.

Why isn't just a battery sufficient? Well, an electric sedan needs about eight hours to charge its battery. Semi-trucks, with the massive batteries they'd require, would take much longer. But refueling hydrogen takes about as much time as filling up a gas tank. So, if a string of hydrogen stations could be built along major interstates, semi-trucks could operate continuously—and cleanly—with minimal extra infrastructure along those routes.

Semi-trucks average about 45,000 miles per year, and all that driving results in a lot of wear and tear. For hydrogen-powered



■ The Million Mile Fuel Cell Truck program, co-led by Los Alamos, will develop long-lasting fuel cell engines for semi-trucks that can greatly reduce national carbon emissions. Photo: Dreamstime

trucks, this especially affects the thin platinum-coated membranes where electricity is created. The heat generated from this process can cause the membranes to degrade.

"For heavy-duty trucks, durability is a big piece of what we're trying to solve," Borup says. "We want to prove it can make one million miles, which is why we've named the project The Million Mile Fuel Cell Truck."

At the Lab, researchers used heat and gases to accelerate the wear and tear on a fuel cell, mimicking the punishment of driving one million miles. Then, they tried different ways to alleviate the wear and tear. Altering the microscopic structure of the platinum, for example, reduces its deterioration. Scientists also introduced cerium, a benign material, into the fuel cell to capture the chemicals that typically degrade the membrane, extending the fuel cell's life.

The M2FCT program has been funded through 2025, at which time Los Alamos hopes to complete its million-mile-capable fuel cell. Meanwhile, to solve the problem of refueling along trucking routes, a second Department of Energy initiative is refining the process of splitting water into hydrogen and oxygen through electrolysis, a process that could be used to create hydrogen fuel from renewable energy sources such as wind and solar.

With these solutions in the works, a new breed of clean-energy trucks may soon cruise American highways. ★



▲ Colonel John Hartke, chair of the Department of Physics and Nuclear Engineering, presents Chitanvis with a United States flag. Photo: West Point

◀ Chitanvis takes a selfie during class in September 2020. Photo: Shirish Chitanvis

EDUCATION

PHYSICIST ON LOAN

Los Alamos scientist Shirish Chitanvis had set foot in many a classroom, but never as a professor. That changed during the last few years of his career.

BY VIRGINIA GRANT

Until recently, Los Alamos National Laboratory had a partnership with the United States Military Academy at West Point, in which a Laboratory physicist held a short-term professorial appointment, conducting his or her research from New York and teaching one or two classes per semester.

In 2017, Los Alamos physicist Shirish Chitanvis and his wife had been considering a move to the East coast, and "the stars aligned," he says. Chitanvis was "handpicked to serve in an Intergovernmental Personnel Act exchange," says Mike Port, director of Mission Integration in Los Alamos' Office of National Security and International Studies. Through this program, Port says, "not only are the West Point cadets learning complex scientific concepts from some of the brightest minds in the country, but they are also learning how Los Alamos can and will provide them with reach-back capability in their future careers in the event that they encounter a particularly vexing national security problem."

Chitanvis says his "interest was piqued by the opportunity to further develop the relationship between the two institutions," and he began teaching in 2018. The transition was challenging at first. "At the Lab,

I'd been thinking for myself and doing my research or working with peers," he remembers. "At West Point, I taught students who might never have heard of the topics I was discussing, so it required a different mindset." Chitanvis was up to the challenge. "I had no idea during the first 33 years of my career at Los Alamos that I would be a good teacher," he says. "But I was well suited to it."

At West Point, Chitanvis taught several different courses, and his favorite was a course he designed on the electromagnetic radiation that occurs after a nuclear blast. "It's an unclassified physics course for undergraduates, so many of whom had not learned the theory of electromagnetism, so I had to master the subject matter well enough to deliver the content to them," he says. There was no textbook for the course, so Chitanvis wrote one himself.

Chitanvis hopes his students have learned "the way to tackle a problem—to think of it from a research physicist's view," he says. "Doing research involves being in a situation that is not always familiar to you. So how would you go about thinking about it? You have to eliminate obstacles to achieve your target."

At his retirement ceremony in May, Chitanvis was presented with a United States flag that was flown over Los Alamos National Laboratory, West Point, and the Nevada National Security Site (where weapons Chitanvis worked on at Los Alamos were tested).

Will retirement mean a break from science? "Oh, heck, no," Chitanvis says. His initial plans are to spend at least a couple of hours a day thinking about Einstein's theory of gravitation. "That's always been one aspect of physics that I never had the time to delve deeper into during my career," he says. "Now is as good a time as any, I suppose." ★

MILITARY

IS TECHNOLOGY REPLACING PILOTS?

Three Air Force pilots discuss the pros and cons of computers in the cockpit.

BY J. WESTON PHIPPEN

As technology advances, it can feel as if computers are edging out tasks performed by humans. To find out if human combat pilots could one day be replaced by artificial intelligence (AI) technology, NSS spoke with three Air Force pilots who've flown nuclear-capable aircraft: B-2 pilots Colonel Geoffrey Steeves and Lieutenant Colonel Dan Knerl and Major Creighton Moorman, who previously flew the B-52H and now pilots the B-1, which carries conventional weapons. Knerl and Moorman are current Los Alamos Air Force Fellows (see opposite page). Steeves is a Los Alamos guest scientist and was an Air Force Fellow in 2019–2020.

When it comes to piloting, how much do you rely on technology versus your own instincts?

MOORMAN: Tech frees up aviators to do other tasks. For example, autopilot and GPS are a great help. Other systems analyze data and make suggestions to aviators who quality check the system. Tech is outstanding at removing simple, mundane tasks that allow aviators to make more informed decisions on complex issues.

In an emergency, a computer is great for helping to diagnose malfunctions. However, it probably won't be able to recommend the best course of action in the broader context of weather, fuel remaining, and runway conditions. A lot of the big picture decisions require risk balancing. To some degree, humans will likely always be in the loop for quality control and to override technology if required.

KNERL: I've been in situations where I know the computer is going to get me to the target a minute late if I don't do something, and more times than not, my decisions resulted in a better solution.

STEEVES: In an emergency, technology does a great job of telling you what's happening. But it's up to the pilot to determine how severe the emergency is and to take the appropriate action in a fluid and complex environment.

Are technological advances benefiting pilots? Will technology ever replace pilots?

MOORMAN: Most large planes used to require a flight engineer to monitor engine and systems performance, but now technology allows these tasks to be accomplished peripherally by the pilot. In 15 or 20 years, what will that look like? I'm not sure. But for the foreseeable future, humans will always be involved, especially when lethal decisions in the battle space are necessary.

KNERL: Recently DARPA [Defense Advanced Research Projects Agency] hosted a simulation that pitted AI versus an experienced Air Force fighter pilot in a series of within-visual-range combat



■ Colonel Geoffrey Steeves was the commander of the 13th Bomb Squadron at Whiteman Air Force Base, home of the B-2 stealth bomber, from 2018–2019.



■ Major Creighton Moorman sits in the cockpit of a B-1B Lancer, a long-range, supersonic, conventional bomber.

maneuvers—commonly known as a dogfight. The computer won 5–0 through its aggressive and precise maneuvers. I think what you'll see is AI being paired with humans, and the first step is as a wingman, where planes flown by computers assist a manned plane during missions.

STEEVES: I agree with Dan that humans will continue to be paired with aircraft going forward. Some mission sets, such as reconnaissance, where aircraft use sensors to gather intelligence, or adversary air, where drones simulate enemy fighters, could eventually be executed with a high degree of autonomy. However, for strike missions that involve the actual weapons with lethal consequences, the military and society aren't yet ready for these types of decisions to be made exclusively by computers. ★



■ Air Force Fellows Lieutenant Colonel Dan Knerl (left) and Major Creighton Moorman stand in front of the Hans Bethe house in Los Alamos, New Mexico. During World War II, Bethe was head of the Theoretical Division at Project Y, the Los Alamos branch of the Manhattan Project.

MILITARY

TOP GUNS

The Laboratory's Air Force Fellows reflect on their time at Los Alamos.

BY J. WESTON PHIPPEN

Although time-honored tradition says that pilots can only divulge the reasoning behind their call signs over a beer, it's safe to say that Lieutenant Colonel Dan "COBRA" Knerl and Major Creighton "Bull" Moorman have led exciting careers in the U.S. Air Force.

The two are the current Los Alamos National Laboratory Air Force Fellows, who, after arriving at Los Alamos in July 2020, will finish their residency this summer. Each year, the Lab welcomes a senior and junior fellow—based on rank and years in the Air Force—with the idea of exchanging knowledge. The fellows get a first-hand look at how scientists develop and maintain the nation's nuclear deterrent. In return, the Lab learns from some of the most accomplished Air Force men and women who work with Los Alamos–designed weapons, once those weapons are in Department of Defense custody.

Prior to coming to Los Alamos, Knerl, the senior fellow, was a B-2 Spirit stealth bomber pilot stationed at Whiteman Air Force Base in Missouri, where he commanded the 72nd Test and Evaluation Squadron. "Test pilots like the late Chuck Yeager are in charge of making sure aircraft manufacturers meet the military's requirements, so they're the first to test out things like new planes," Knerl says. "We're the next step. We develop the tactics, techniques, and procedures for aircraft or weapon systems that will be put to use in the combat environment."

Moorman, the junior fellow, spent the previous three years in South Dakota, at Ellsworth Air Force Base, as chief pilot and evaluator for the 28th Operations Group. Before that, Moorman

started his career piloting the B-52H Stratofortress, a Cold War relic that can deliver both conventional and nuclear strikes. In 2016, he transitioned to the B-1B Lancer, a variable-wing, supersonic jet limited to conventional operations by treaty. "The B-1 may only be a conventional platform, but it's flexibility and large payload are instrumental to the overall Global Strike Command mission," he says.

Like all fellows selected to study at the Lab, Knerl and Moorman are among the top of their classes in the Air Force. Knerl had heard about the program from a former fellow and B-2 pilot, and although he knew of the extensive weapons work done at Los Alamos, he says he was surprised to learn just how expansive the Lab's research truly is. "All the COVID-19 projects, the space and Mars rover programs—it has been really fascinating to see the diverse work here," he says.

Moorman agrees. "One thing that surprised me," he says, "is that beyond all of the science and engineering done here, there's also a lot of policy and strategy discussion." Every month, Moorman participates in the Lab's Condor group, which gathers (virtually) to discuss recent policy documents and deterrence papers.

Moorman has spent much of his time at the Lab researching hard and deeply buried targets, which enemies might use to hide and protect critical capabilities, though he can't say much more about his work. Knerl has researched the nuclear weapon design and certification process. Specifically, he's looking at "the use of modeling, simulation, and artificial intelligence to improve fielding timelines while maintaining nuclear surety," he says.

When they leave the Lab, Moorman is bound for Offutt Air Force Base in Omaha, Nebraska, for a job as the bomber analyst in U.S. Strategic Command's nuclear planning division. Knerl will head to Bolling Air Force Base, in Washington, D.C., to work in the office responsible for the new B-21 bomber requirements.

"My experience at the Lab will help me better work through the nuclear certification requirements for the B-21," Knerl says. "I'm sure the Air Force will benefit from the knowledge I've gained at Los Alamos." ★

INTELLIGENCE

REMEMBERING KRIK KRIKORIAN

The late analyst was part of the Lab's first intelligence unit.



BY LAURA MULLANE

Nerses “Krik” Krikorian was born on a Turkish roadside in 1921. His parents were fleeing the Armenian genocide that would ultimately claim 1.5 million lives. The family spent the next four years moving from country to country with nothing but the clothes on their backs.

They finally settled in Niagara Falls, New York. There, barely speaking English, Krikorian started kindergarten. Sixteen years later, he graduated from college with a bachelor's degree in chemistry and began a job at Union Carbide, working in a lab that made highly enriched uranium. For what purpose, Krikorian wasn't sure. “I'd read a book that speculated uranium was a fission thing, but I didn't know what ‘fission’ meant,” he recalled during a 2018 interview. “I'm a chemist, not a physicist.”

When the United States dropped an atomic bomb on Hiroshima, Japan, Krikorian realized what he'd been working on. It was 1945, and he'd been knee-deep in the Manhattan Project—the top-secret effort to build an atomic bomb to help end World War II.

After the war, Krikorian began working at Los Alamos Scientific Laboratory. “And what do I work with? Stuff I can barely see,” he said. “I went from working with kilograms of uranium at Union Carbide to micrograms of highly radioactive polonium.”

In the mid-1950s, Krikorian worked on Project Rover—the Lab's effort to develop a nuclear-thermal rocket. Krikorian studied materials that could support the demands of nuclear propulsion at high temperatures. “The program was technically challenging and in a temperature domain where little research had been done,” he later wrote.

In 1972, knowing that Krikorian was fluent in Armenian and Russian, Laboratory Director Harold Agnew asked Krikorian to join a newly formed intelligence unit. “As a kid, I thought Armenian was useless,” Krikorian said. “I guess God knew what was coming.”

An intelligence analyst's job is nuanced. “The role of an analyst is to connect all the dots together,” Krikorian said. “You have to make an educated guess based on your own experience and what you observe. None of it is clear-cut.”

When Krikorian retired from Los Alamos in 1991, he held six patents. He was a Laboratory Fellow and the recipient of the Los Alamos Medal (the Laboratory's highest honor), the CIA's Intelligence Community Medallion, and two honorary doctorates. Today, the Nerses “Krik” Krikorian Collection in the Lab's National Security Research Center comprises Krikorian's Union Carbide Corporation papers, Project Rover reports, and other technical notes, memoranda, and photos.

“Things have worked out far beyond what I ever imagined,” said Krikorian, who died in 2018. “My parents instilled in me the importance of doing the right thing and giving back to your fellow man. I hope I've done that.” ★



■ When George Hagedorn deployed to Vietnam in 1968, his intelligence gathering missions sometimes took him close enough to the enemy to smell what they were cooking for dinner.

Photo courtesy of George Hagedorn

INTELLIGENCE

OLD-FASHIONED INTELLIGENCE GATHERING

Before portable computers, detailed satellite photos, and high-tech gadgetry, collecting information often involved brave young soldiers with better-than-average memories.

BY J. WESTON PHIPPEN

In April 1968, George Hagedorn was a 24-year-old Army draftee who landed in Vietnam with orders to collect intelligence. Back then, this meant being dropped by a helicopter or transported by boat into the jungle, where he snuck on foot close enough to the enemy to hear what was being said.

“We were basically walking data collection computers,” says Hagedorn, who now works as a production support specialist in the Weapons Production directorate at Los Alamos National Laboratory. “We went out into the field. We looked, listened, and remembered.”

Hagedorn grew up in Cleveland, Ohio, and earned a bachelor's degree from The Ohio State University. After college, he worked for McDonnell Douglas aircraft, where he developed skills that qualified him for occupational deferment. But this draft exemption would last only six months at a time, and he couldn't find a landlord who'd agree to a short-term lease on an apartment. Plus, his father had fought in World War II, which left Hagedorn with a sense of obligation to serve his country. “So, I went to the draft board and volunteered for the draft,” he remembers.

After basic training, Hagedorn was selected for the Army's intelligence school. Three months later, he flew to Vietnam. As the plane landed amid scorched buildings, Hagedorn remembers asking himself what he'd gotten himself into. But once he reached his assignment with the 9th Infantry Division in the Mekong Delta, his job description was fairly straightforward: collect intelligence.

For the next 14 months, Hagedorn—outfitted with binoculars, a night vision scope, and a poncho to keep out the rain—was part of a small scout unit that would be dropped off near enemy locations, wait for nightfall, walk as close as possible to a location of interest, then covertly observe activities. Sometimes, he'd count heads and types of weapons. Other times, he'd walk 10 miles while scanning the ground for signs of convoys and troop movements. Often, he had to consider whether a village was truly just a village.

“If there was an unusual amount of hay being kept, too much for how many people I saw living there, that could possibly be a weapons cache,” he explains. Eventually, Hagedorn could spot clothing or small details in facial structure that signaled that the “villagers” hailed from another part of the country, which could indicate advancing enemy troops. After a night or two, Hagedorn would slip away and radio for a helicopter. Back at base, he'd write up a report from memory to pass on to command officers.



Photo courtesy of George Hagedorn

■ After serving in Vietnam, Hagedorn (pictured here in 2019) moved to Australia, backpacked the world, and worked at a General Dynamics tank plant. He came to Los Alamos in 1986.

In Vietnam, there were worse duties to have, but intelligence gathering was far from safe. Once, a rocket-propelled grenade exploded 30 feet from where Hagedorn sat beside a tree. After he dusted himself off, Hagedorn noticed a piece of shrapnel wedged into the wood, one inch above where his head had been. “You learned to shrug off those moments because you can't do anything about them,” he says.

Today, Hagedorn keeps a picture pinned above his desk that he took of flashing bullet tracers and flares lighting up the jungle sky. “When I get down, or think things aren't going well,” he says, “I look at the picture and remember that I have been through a lot worse.” ★



■ The Laboratory's Technical Area 3 sits at the base of the Jemez mountains in Northern New Mexico.

COUNTERINTELLIGENCE

SPIES AMONG US

The Office of Counterintelligence works to detect and deter espionage at Los Alamos.

BY VIRGINIA GRANT

A scientist working at Los Alamos National Laboratory met, through his work, another scientist from a sensitive foreign country (one that poses national security challenges to the United States, as determined by the Department of Energy's Office of Intelligence and Counterintelligence). Their professional relationship turned into a friendship and, for years, they spent time together as friends and exchanged correspondence about their families and personal lives.

Because Laboratory employees must report these types of relationships, Los Alamos counterintelligence was aware of this friendship and discovered that the friend had ties to his country's intelligence services. The scientist was skeptical and waved off these warnings time and time again. Then, one day, the friend asked the scientist a question about classified information that only had military application. That was the end of that friendship.

This seems like something that might happen on an episode of *Jack Ryan* or *The Americans*, but this is a true story and the type of scenario that personnel in the Office of Counterintelligence (OCI) at Los Alamos are watchful for every day. "Once my wife asked me how my day went," says OCI Director John Chaddic. "I told her it was

'interesting.' She responded, 'I don't like it when you say you have an interesting day; that's not good for the country.'"

When Chaddic and his colleagues have an interesting day, something has happened that involves what he calls "intelligence activity." Although much of what happens in the office, as one might imagine, may not be written about, the overarching job of the office is to protect the information of Los Alamos National Laboratory.

Before coming to Los Alamos, Chaddic spent 23 years in the Federal Bureau of Investigation (FBI), finishing his career there as an acting special agent in charge of counterintelligence and cyber investigations in the FBI's Los Angeles office.

"Most of the officers and analysts at Los Alamos have counterintelligence backgrounds from the FBI, CIA [Central Intelligence Agency], or U.S. Intelligence Community, but the office occasionally employs locally when the employee has the right skill set," says Jason Allen, group leader for Counterintelligence Activities and Threat Awareness, which falls under OCI. Allen worked for the CIA for 13 years, focusing on cyber operations, hard target operations, and counterterrorism.

A big part of the office's work is to coordinate and facilitate international visitors, usually scientists who come to the Lab to work, give guest lectures, or collaborate with Los Alamos scientists. OCI ensures that the work the Laboratory does with foreign nationals can be conducted safely and securely. "The office has a significant role in helping the Lab maintain access to international talent," Allen says, "and mitigate the risk such talent might pose."

The country posing the greatest espionage threat to Los Alamos—as identified by both the FBI and the Office of the Director of U.S. National Intelligence—is China. Yet the Laboratory employs more than 100 Chinese nationals along with nearly 400 nationals from other sensitive foreign countries. "If the Lab is to retain its international status as a premier science leader," Chaddic says, "we don't want to rule out hiring people from any country if the risk can be mitigated." That's why there are many people involved in deciding who can be allowed to work at the Laboratory. Also, a foreign national is never granted a security clearance unless he or she first renounces his or her original citizenship, or if he or she becomes a dual citizen of the United States and another country. OCI supports leadership at the Laboratory on a routine basis to consider all information and to conduct thorough risk-benefit analyses before making these types of hires.

"We have a robust insider threat program that helps detect insiders who might want to commit espionage or terrorism," Chaddic says. Part of this includes training for all Laboratory employees about insider threat issues—how to be alert to them and what to do if they suspect a colleague of being an insider threat.

The office also helps Los Alamos employees watch out for external attempts at espionage, many of which seem so innocuous that they are difficult to spot. A common scenario is one called a "bump," which is when a foreign intelligence officer is directed to make contact with someone from whom the foreign officer might like to glean information. The foreign officer has to figure out how to meet the target. This could happen in line at Starbucks, at an academic conference, on an airplane, or anywhere that people interact in public. The sole purpose of the initial meeting is to get a second meeting,

which is why it might seem completely harmless. Perhaps someone comments on the target's sweatshirt or a magazine the target is reading. "We tell people," Allen says, "particularly when they're traveling, especially overseas, that they should look out for chance encounters with people they didn't know that afterward leave them with a reason to talk with them again."

This is one reason Los Alamos employees are prohibited from wearing badges offsite and are discouraged from wearing clothing with the Laboratory logo on it while traveling. Although most targets are chosen ahead of time, it's possible that a bump could arise from a foreign intelligence agent seeing a window of opportunity in the form of a coffee mug or a Los Alamos logo jacket.

Another scenario—perhaps even more difficult to spot—is when a mutual friend introduces a foreign intelligence officer to the target. "It could be," Allen says, "that someone you know and trust brings someone else in, and that person is an intelligence officer." The tricky part about this, he explains, is that the friend may not have a choice. If the friend seems uncomfortable or uneasy, these might be signs that the friend's home country is forcing him or her to facilitate a connection between foreign intelligence officer and target.

The iconic status of Los Alamos makes it a high-profile target, for every employee, no matter his or her role. Foreign intelligence officers aren't always looking for scientific secrets or classified weapons information. They might be looking for the layout of a building, the location of a particular office, or something else that seems innocuous to many of those working at Los Alamos but would be useful to a foreign intelligence agency. For preventing espionage, Chaddic says, "Our employees are our best line of defense." ★

HISTORY

THE FOURTH ATOMIC SPY

Some say recently discovered Oscar Seborer was the most-damaging spy. Laboratory documents suggest otherwise.

BY LABORATORY HISTORIANS ALAN CARR AND ELLEN MCGEHEE

It's been long known that Klaus Fuchs, Theodore Hall, and David Greenglass committed espionage at Project Y—the Los Alamos branch of the Manhattan Project—during World War II. Each worked at the secret laboratory charged with creating the world's first atomic bombs, each stole classified weapons information, and each shared it with the Soviet Union. Just recently though, in September 2019, historians confirmed a fourth wartime spy: Oscar Seborer.

Seborer was born in New York City in 1921. He joined the Army in 1942 and, as a member of Army's Specialized Training Program, he was sent to The Ohio State University to study electrical engineering. In 1944, given his academic training, Seborer was assigned to the Army's Special Engineering Detachment, which provided specially trained soldiers to the Manhattan Project. Private Seborer was first sent to Oak Ridge, Tennessee, but by December 1944, he had been transferred to Los Alamos, New Mexico, where he began working for the Detonator Circuit (X-5) group in the Explosives (X) Division.

Seborer's group was tasked with developing electrical equipment for measuring explosives tests and the firing circuits to ignite an implosion bomb's detonators. (Detonators are small devices that ignite the high explosives surrounding the core of a nuclear weapon. The resulting explosion compresses—implodes—the core, which creates nuclear yield.) Significant progress was made on the detonator circuit in early 1945, so in April, freshly promoted Technician Fifth Grade Seborer was loaned to the Research Division to help prepare for the upcoming Trinity test, which would be the first successful detonation of a nuclear bomb.

Research on Seborer and his role at the Lab is ongoing, but we do know that part of his assignment included working on the rehearsal for Trinity, called the 100-Ton test. The same day the rehearsal was completed, May 7, Seborer's X-5 group leader requested his immediate return. Although this was approved, 12 days later Trinity test director Kenneth Bainbridge asked X-5 to return Seborer to the Research Division by mid-June because he was "extremely valuable" to their work. Seborer was in high demand for his electrical knowledge and was sent back to the Trinity site in southern New Mexico to support earth shock experiments associated with the Trinity test, which was scheduled for July 1945.

As of March 1945, Seborer's name was on a list of Los Alamos personnel proposed for the Destination Program, which was tasked with preparing atomic bombs for deployment to Japan. However, by June 1945, his name had been removed from the personnel list, probably due to his work supporting the Trinity test. Soon after the war, X-5 (along with Seborer) was transferred to Z Division, which had inherited many of the Destination Program's responsibilities. By September 1945, Seborer had been promoted

to Technician Fourth Grade and was working as an electrical technician in Z Division. In early 1946, like many in the wartime armed forces, Oscar Seborer was discharged from the military.

Even after his two promotions, Seborer only had a limited view of the overall project. He likely knew a considerable amount about the implosion bomb's firing circuit, and he would have known something about diagnostic measuring equipment and techniques. Because he may have participated in the Destination Program and because he worked in Z Division, Seborer may also have known about the general concept of implosion and atomic bomb assembly procedures.

But, any knowledge Seborer had would have been eclipsed by that of his fellow mole, theoretical physicist Klaus Fuchs.

At Los Alamos, Fuchs was considered a technical staff member; he independently authored several reports and coauthored others with his division leader and future Nobel laureate Hans Bethe. Fuchs knew as much as anyone about the implosion bomb because he played a major role in its development.

Although Seborer's treachery contributes to the story of Manhattan Project-era espionage, the prevailing narrative remains unchanged: The spies at Los Alamos collectively made a valuable contribution to the Soviet nuclear weapons program, and the information provided by Fuchs was almost certainly the most useful.

In 1950, Klaus Fuchs confessed and spent nearly a decade in prison. Shortly after, Julius and Ethel Rosenberg (sister of Los Alamos spy David Greenglass) were sentenced to death for committing espionage elsewhere on behalf of the Soviets. Through an informant, FBI investigators discovered Seborer was a spy in 1955. By then, however, he had already immigrated to the Soviet Union. He died in Moscow on April 23, 2015. ★



■ Clockwise from top left: Los Alamos spies Klaus Fuchs, Theodore Hall, Oscar Seborer, and David Greenglass. In 2019, Seborer's story was unearthed by Harvey Klehr, a retired professor from Emory University, and John Earl Haynes, former historian for the Library of Congress.



ENVISIONING THE W93

By Whitney Spivey

What will the Navy's nuclear deterrent look like in the 2030s? A multi-phase study aims to find out.

■ Ohio-class submarines are undetectable platforms for submarine-launched ballistic missiles that carry the W76 and W88 warheads. One of these submarines has enough firepower to make it the sixth most powerful nuclear power in the world.

Photo: U.S. Navy/Kelsey Hockenberger



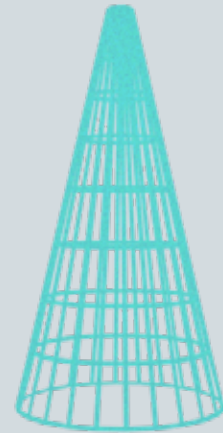
**BETTER SCIENCE =
BETTER SECURITY**

Los Alamos—along with other laboratories, plants, and sites in the NNSA complex—is responsible for the safety, security, and effectiveness of America's nuclear deterrent.



■ According to the NNSA's fiscal year 2021 Stockpile Stewardship and Management Plan, "The W93 will address future Navy ballistic missile requirements. The W93 will incorporate modern technologies to improve safety, security, and flexibility to address future threats and will be designed for ease of manufacturing, maintenance, and certification. DOE/NNSA is coordinating with DOD through the Nuclear Weapons Council in developing the deterrence strategies as defined in the 2018 Nuclear Posture Review." Here, an unarmed D-5 missile is launched from the USS West Virginia.

Photo: U.S. Navy



Since 1981, one or more of the U.S. Navy's Ohio-class submarines (SSBNs) has patrolled the world's oceans, forming the sea-based component of America's nuclear triad. Today, each of 14 SSBNs carries 20 D5 submarine-launched ballistic missiles. These missiles are topped with either W76 or W88 nuclear warheads.

These warheads were designed by Los Alamos National Laboratory—the W76 in the 1970s and the W88 in the 1980s. Over the past several decades, each has been refurbished to extend its service (see p. 29) and remains highly effective today.

But in late 2020, United States Strategic Command (aka STRATCOM, a Department of Defense [DOD] combatant command that plans and executes military missions involving nuclear weapons) raised a question: What would an effective Navy warhead look like in the 2030s and beyond?

To answer this question, STRATCOM, the Navy, and the Department of Energy's (DOE) National Nuclear Security Administration (NNSA) are conducting what's called a Phase 1—or concept assessment—study of a *potential* new warhead they're calling the W93.

The key word here is *potential*. The purpose of a Phase 1 study is to make a preliminary assessment of nuclear weapon design options or concepts, *not* to nail down details on design, production, manufacturing, or cost. Those things will come later, *if* the W93 makes it past the Phase 1 and other phase studies. For context, between 1966 and 1985—the height of U.S. nuclear weapons production—59 Phase 1 studies were conducted. Of those, only 19 weapons (32 percent) passed through the next five phases of the Joint DOD and DOE Nuclear Weapons Life Cycle Process (see p. 24) and entered into the stockpile.

Why now?

Nuclear weapons with "W" in their names are warheads, which are launched on missiles. Weapons with "B" in their names are bombs, which are dropped from aircraft. The numbers in weapons' names reflect the order in which they were conceived. The W93, for example, is the 93rd weapons design being considered for the stockpile. Since 1945, when the United States first developed nuclear weapons, only 63 weapons designs have made it into the stockpile. Los Alamos designed 46 of those 63 (and 29 of the first 30).

The last nuclear weapon to enter the stockpile was the W88 in 1988. Around that same time, four other weapons designs—the W89, B90, W91, and W92—were being explored in phase studies. But when the Cold War ended, so did U.S. nuclear weapons development. "To really show the Cold War was over, the United States also retired many weapons," remembers Michael Bernardin, recently retired associate Laboratory director for Weapons Physics at Los Alamos.

In 1996, President Bill Clinton signed the Comprehensive Nuclear Test Ban Treaty, which prohibits nuclear testing of any kind. The treaty "will help to prevent the nuclear powers from developing more advanced and more dangerous weapons," Clinton told the United Nations General Assembly in 1996. Though never ratified by the Senate, "it points us toward a century in which the roles and risks of nuclear weapons can be further reduced and ultimately eliminated."

This posture continued for the next couple decades. "The United States will take concrete steps towards a world without nuclear weapons," President Barack Obama told an audience in the Czech Republic in 2009. "To put an end to Cold War thinking, we will reduce the role of nuclear weapons in our national security strategy and urge others to do the same."

At its height in 1967, the stockpile contained 26 types of weapons for a total of 31,225 weapons. In 2017, the year that DOD declassified and released stockpile numbers, seven types of nuclear weapons were in the stockpile for a total of 3,822 weapons.

In recent years, however, the geopolitical landscape has shifted, causing many to reevaluate the nuclear deterrent. According to the Nuclear Posture Review (NPR) published by the DOD in 2018:

"While the United States has continued to reduce the number and salience of nuclear weapons, others, including Russia and China, have moved in the opposite direction. Russia has expanded and improved its strategic and non-strategic nuclear forces. China's military modernization has resulted in an expanded

nuclear force, with little to no transparency into its intentions. North Korea continues its illicit pursuit of nuclear weapons and missile capabilities in direct violation of United Nations (U.N.) Security Council resolutions. Russia and North Korea have increased the salience of nuclear forces in their strategies and plans and have engaged in increasingly explicit nuclear threats. Along with China, they have also engaged in increasingly aggressive behavior in outer space and cyber space."

And it's not just other countries bolstering their nuclear arsenals that America has to worry about. Some countries are developing technology—including advanced projectiles and beams of various forms of energy to shoot down missiles in flight—that may have implications for the resilience of America's nuclear deterrent.

That's why, according to the 2018 NPR, the United States must have "modern, flexible, and resilient nuclear capabilities that are safe, secure, and effective until such a time as nuclear weapons can prudently be eliminated from the world."

What STRATCOM wants

STRATCOM has been anticipating the current and future threat environment. "STRATCOM has the big picture," Bernardin explains. "STRATCOM tells the Navy that the United States must be prepared for X. And then the Navy says, OK, to be prepared, we need Y."

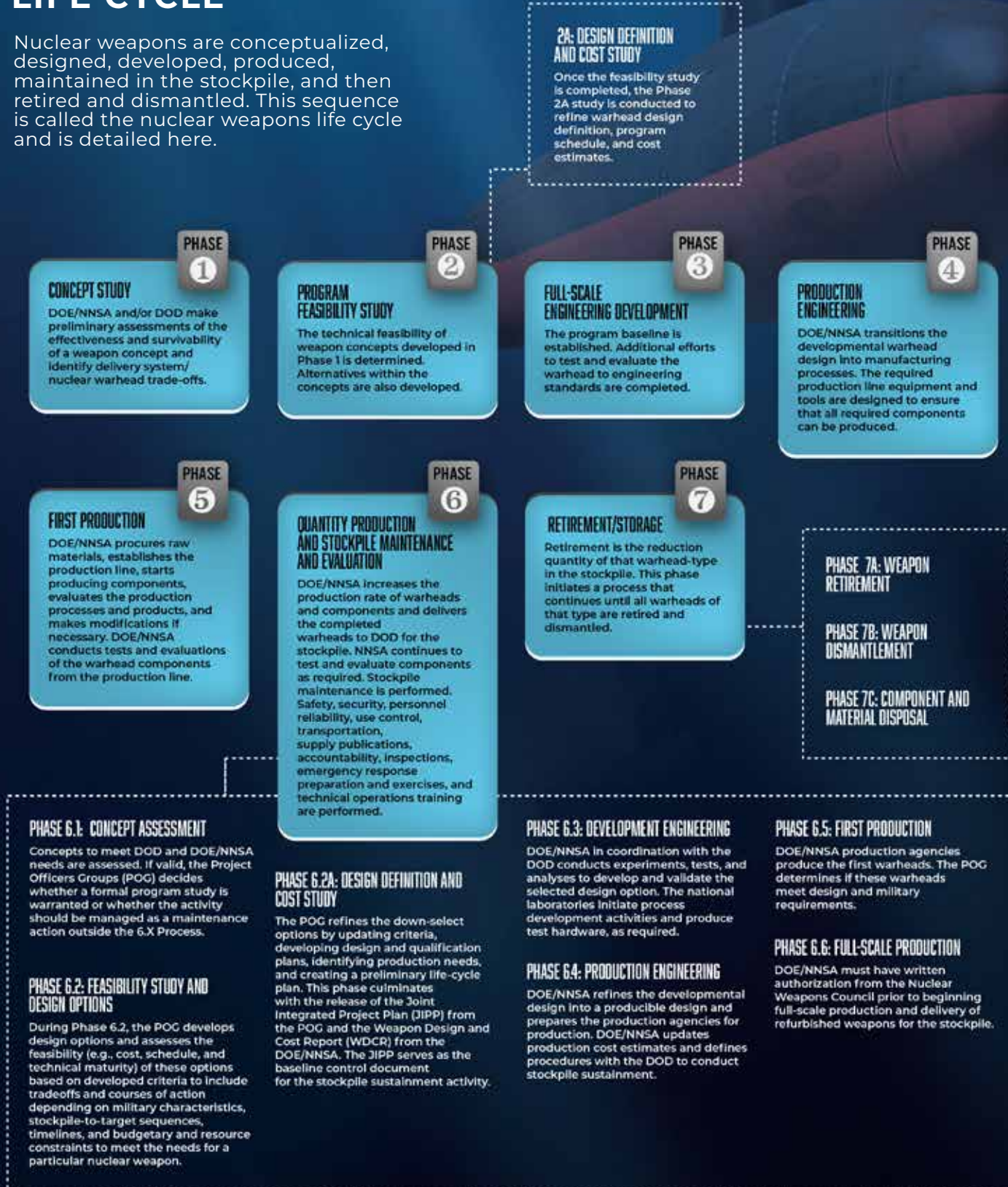
In this case, Y is a new reentry body—the conical tip of a missile that carries nuclear warheads, also called an aeroshell—that must be capable of reaching a variety of targets, some of which didn't exist 30 years ago. Targets could be high-value (a specific location or facility), time-sensitive (struck at specific time), or in hard-to-hit places (in the air, underground, underwater, or in rugged terrain).

Although it hasn't been designed yet, the new reentry body is being called the Mark 7 (Mk7). The Mk7 could differ in size from the current Mark 4 and Mark 5 reentry vehicles, which house the W76 and W88, respectively. "A possible size difference requires NNSA to explore warhead options broader than a life extension of any existing stockpiled warhead type," explains Bob Webster, deputy Laboratory director for Weapons at Los Alamos.

These "warhead options" are what's collectively being called the W93. If (and that's a big if) one of the options moves forward through the entire six-part phase study process, the option will provide STRATCOM and the Navy "a means to address evolving ballistic missile warhead modernization requirements, improve operational effectiveness, and mitigate technical, operational, and

NUCLEAR WEAPONS LIFE CYCLE

Nuclear weapons are conceptualized, designed, developed, produced, maintained in the stockpile, and then retired and dismantled. This sequence is called the nuclear weapons life cycle and is detailed here.



programmatic risk in the sea-leg of the triad,” according to a statement by STRATCOM Commander Admiral Charles Richard to the Senate Committee on Armed Services.

“Without a coordinated, joint effort to develop and field the W93/Mk7 as a system, the bulk of our day-to-day deterrent force will be at increased risk in the early 2040s due to aging legacy systems,” Richard continued. “Research and development efforts ... must begin immediately to deliver a capability in the 2030s that maintains a credible at-sea deterrent through the 2050s and beyond.”

“This work is critical to the future of the nuclear deterrent” agrees Mark Suriano, deputy assistant deputy administrator for the NNSA Defense Programs Office of Research, Development, Test, and Evaluation. NNSA—via its national laboratories, plants, and sites—has the sole responsibility to design, develop, certify, and produce nuclear weapons for the United States.

As conversations about the W93 begin, plans to replace the Navy’s aging Ohio-class submarines are also underway. The 2018 NPR ensures Ohio-class SSBNs will remain “operationally effective and survivable” until they can be replaced, one per year, by a minimum of 12 Columbia-class submarines. These next-generation subs are in development, and the first one is scheduled to be deployed by 2031. All 12 are expected to be operational by 2042. So, because the

W93 (if it goes forward) wouldn’t enter the stockpile until the mid-2030s, it would have to be compatible with two different boats.

“The [Ohio-class] submarines that we have today have 20 [missile] tubes,” Richard elaborated before the House Armed Services Committee in February 2020. “The Columbia has 16. So, I will need capabilities that will address the fact that we don’t have as many tubes in the new class of submarines, and the overall number of warheads [that can be carried on each submarine] is going down.”

What is a Phase 1 study?

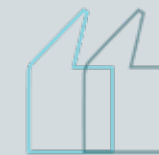
With all of the above in mind, DOD and NNSA are embarking on a Phase 1 study. “The nuclear security enterprise [NNSA and its national laboratories—including Los Alamos—plants, and sites] is preparing to start the Phase 1 concept assessment on the W93,” Suriano says. “Our workforce is full of highly dedicated and well-trained problem solvers who are motivated by the cutting-edge science and engineering required for this study. We have confidence in our ability to meet the mission needs as laid out by the Department of Defense.”

According to Bernardin, who was involved in America’s last Phase 1 study back in 1990, Phase 1 studies have very broad parameters. “It’s like saying, ‘I have a requirement to land Americans on the moon and collect new information, but I’m not sure about the size or precise capabilities of my lunar module. The Phase 1 study says the lunar module needs to fit in this size envelope and have these types of capabilities to meet its mission requirements. If the lunar module makes it past the Phase 1 study, the Phase 2 study would provide something like three to six options for lunar module design.’”

Phase 1 studies typically take 1 to 2 years. During this time, “NNSA provides federal oversight and guidance,” Suriano explains. “NNSA ensures the design agencies—Los Alamos, Lawrence Livermore, and Sandia national laboratories—and production agencies are considering all requirements.”

As the lead physics design agency—the organization responsible for the design of the nuclear warhead package and some of the nonnuclear components—Los Alamos must consider everything from the number of warheads required per missile to the size, weight, shape, and yield of the warhead. Target sets, target-kill effectiveness, and warhead survivability will also be addressed. Additionally, the Los Alamos design options identified must be able to be produced, delivered, and fielded without any underground nuclear explosive testing.

“The opportunity to be the design agency for the W93 will be leveraged on the great competencies we have developed



Without a coordinated, joint effort to develop and field the W93/Mk7 as a system, the bulk of our day-to-day deterrent force will be at increased risk in the early 2040s due to aging legacy systems.”

—ADMIRAL CHARLES RICHARD



■ “I am very proud of where we’re at today,” says James Owen, associate Laboratory director for Weapons Engineering. “I recognize that there’s much work to be done, but I know that we are up to the task of developing a very capable, viable option for the W93.” The W93, if it goes forward, will be carried on both Ohio- and Columbia-class submarines.

Photo: U.S. Navy/James Kimber

in conducting modernization work and in supporting the legacy stockpile,” says James Owen, associate Laboratory director for Weapons Engineering at Los Alamos. “The work we’ve done in the past, the work we do each and every day, and the work that stands in front of us are all vital elements in ensuring that we have a safe, secure, and effective nuclear deterrent.”

“Working with others across the nuclear enterprise and the military, we will develop plausible design concepts,” Webster adds. “These will be evaluated for technology and manufacturing readiness, producibility, impacts to the NNSA complex, and other ongoing warhead acquisitions, development, production schedule, risks, and cost.”

In addition to thinking about concepts for the W93 and Mk7, Los Alamos must take into consideration its current and future work. If the W93 moves forward, it would use the Lab’s plutonium, detonator, and other facilities, which are already plenty busy. “We’ll also need to evaluate the impact across the NNSA complex,” Webster says. “Components would be produced and assembled at various DOE labs, plants, and sites and would have to be handled and shipped between facilities.”

“At the end of the Phase 1 study, a report on identified designs—warhead and reentry body—and an assessment of whether one or more designs can potentially meet mission requirements is provided to the Nuclear Weapons Council, along with a recommendation to either proceed to Phase 2

or terminate at Phase 1,” Webster explains. (The six-person Nuclear Weapons Council is composed of DOE and DOD senior leaders who direct interagency activities to maintain the U.S. nuclear weapons stockpile.) “In the event it is determined we should proceed, the W93 will have to be programmed in the budget, and that will be passed on to Congress for authorization and appropriation of funds.”



Our workforce is full of highly dedicated and well-trained problem solvers who are motivated by the cutting-edge science and engineering required for this study.”

—MARK SURIANO

Stockpile maintenance

For the past 30 years, instead of producing new nuclear weapons, the United States has maintained a subset of its Cold War-era weapons through the stockpile stewardship program. In this program, Los Alamos works in conjunction with other labs, plants, and sites in the NNSA complex to assess and ensure the safety, security, and effectiveness of each type of nuclear weapon in the stockpile. This is done through constantly advancing a combination of surveillance studies and applied research consisting of nonnuclear experiments, computer simulations, and incorporation of data from historical nuclear tests.

For example, the Laboratory’s Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, established in 2000, can take radiographs of materials that implode at more than 2.5 miles per second. These radiographs allow scientists to “see” inside a mock-nuclear weapon as it detonates.

At somewhat smaller scales, the proton radiography (or pRad) capability at the Los Alamos Neutron Science Center (LANSCE) permits 24 high-energy radiographic images of a dynamically imploding or exploding experimental package. High-energy-density facilities, such as the Z pulsed-power facility at Sandia National Laboratories and the National Ignition Facility at Lawrence Livermore National Laboratory, enable experiments using x-ray radiation and thermonuclear-burn or fusion reactions.

Today, data acquired at these and other experimental facilities can be analyzed and visualized using supercomputers that operate at tens to hundreds of petaflops—more than one-million times as fast as computers 30 years ago.

With every technological advance and improved facility comes more exquisite data and a deeper understanding of what’s going on inside nuclear weapons. A deeper understanding leads to higher-fidelity experiments, which leads to more exquisite data, which leads to a deeper understanding, and so on.

“The current state of our understanding of the performance of nuclear explosives compared to 25 years ago is simply remarkable,” says Charlie Nakhleh, associate Laboratory director for Weapons Physics at Los Alamos. “As we embark on this Phase 1 study, we intend to exploit the very large investments made over the past 25 years or so by the stockpile stewardship program.”

The W93’s Phase 1 study is often called a clean sheet study because—although it will incorporate decades of knowledge gained from past nuclear weapons work—the concepts for the warhead and reentry vehicle don’t necessarily hinge on any existing weapons system (however, they may incorporate existing weapons components). High-performance, multi-physics simulations will be underwritten by theory and checked extensively against experimental data from focused experiments to more integrated experiments up through archival nuclear testing data, Nakhleh explains. Using this

solid foundation, scientists can be confident that no new nuclear testing would be necessary to certify the W93 for use in the stockpile.

The next generation

Most of the people who designed the weapons in the current stockpile have either retired or died, taking with them decades of knowledge. “As the people with test experience and design experience age themselves, it becomes imperative to train the next generation of stewards using all the tools we can develop to better understand and to better assess the safety and reliability of the stockpile,” Laboratory Director Siegfried Hecker wrote in his 1996 annual assessment letter. (This letter informs the president of the United States of the Laboratory’s confidence that the stockpile has evolved and that it is safe, secure, and effective; for more, see p. 5.)

Closing the knowledge gap has been a concern appearing in subsequent annual assessment letters. In 2014, Director Charles McMillan raised a point about the workforce and the stockpile of the future. “Attracting, training, retaining, and establishing confidence in the stewards of the future stockpile is of principal importance,” he wrote. “Nurturing the intellectual capital to design a modern nuclear weapon, if needed for the future stockpile, is the greatest concern.” In other words, if the Lab ever got the opportunity to participate in another Phase 1 study, McMillan wanted to make sure his workforce was prepared.

In 2018, Director Terry Wallace agreed. “Creation of the stockpile of the future will require the vision and will to unleash the creative energy of the workforce,” he wrote. “Sustainment of the existing stockpile through [life extension programs] has been necessary but not sufficient ... I have seen what Los Alamos scientists and engineers can accomplish, and it has been impressive. Nurturing and empowering the intellectual capital to design and certify a modern nuclear weapon, when needed for the future stockpile, is the next step.”

The W93 Phase 1 study marks the very early stages of that next step, which will introduce a new generation of scientists and engineers to the process of nuclear weapons development. These men and women have a strong foundation, thanks to their work in stockpile stewardship. “The capabilities in computing, theory, and experimentation that have been put in place as a result of this stockpile stewardship program are world leading and will enable us to field the W93 without needing any additional nuclear testing,” Nakhleh says.

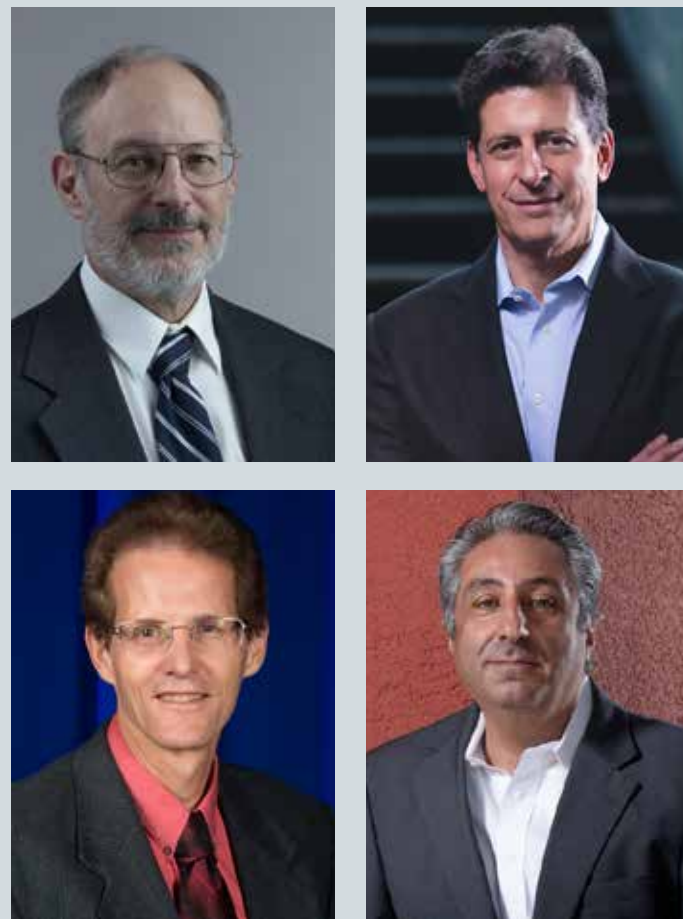
A team effort

The Los Alamos scientists involved in the Phase 1 study will help all parties involved better understand the pros and cons of potential design choices. “While it has been a long time

since Los Alamos was tasked with a Phase 1 study, a number of focused efforts over the past several years have enabled us to update and modernize our physics design tools as well as work through the process of quickly designing integrated and more easily manufacturable hypothetical systems tailored to the capabilities of the NNSA complex,” explains one physicist. “Thanks to these efforts, we are prepared to start the Phase 1.”

Some of the creative energy that goes into Phase 1 studies is fueled by the partnerships forged during the process. During a Phase 1 study, working groups are formed to address certain areas—such as requirements, design, surety (safety and security), target vulnerability, and mission effectiveness. Many Los Alamos scientists and engineers, as well as representatives from other NNSA sites and the military, make up these 8- to 10-person working groups.

“We’ll partner with STRATCOM, the Navy, Sandia, Livermore—in fact the entire nuclear weapons enterprise—to develop a suite of compelling and executable options for the nation that meet the STRATCOM requirements for the W93,” Webster says. “The next year or two is going to be very intense.” ★



■ Clockwise from top left: Bob Webster, Charlie Nakhleh, James Owen, and Michael Bernardin.

WHAT’S ON BOARD NOW?

The Navy’s current warheads have been updated over the years.

The W76 and W88, the two types of nuclear warheads that can be launched on missiles from Ohio-class submarines, were both designed at Los Alamos National Laboratory. In the decades since, they’ve also been maintained primarily by Los Alamos through life extension programs (LEPs), modifications (Mods), and alterations (Alts).



W76-1 LEP

LEPs address aging and performance issues, enhance safety features, and improve security. Through an LEP, scientists and engineers analyze a weapon’s components and, based on that analysis, reuse, refurbish, or replace certain components.

Completed in January 2019, the W76-1 LEP was a refurbishment of the W76-0 warhead, which entered the stockpile in 1978. The LEP extended the warhead’s service life from 20 to 60 years. The W76-1 continues to meet all missions and capabilities of the original W76-0 warhead but does not provide new military capabilities.



W76-2 Mod

Modifications change a weapon’s operational capabilities. A modification may enhance the margin against failure, increase safety, improve security, replace limited-life components, or address identified defects and component obsolescence.

The W76-2 Mod, a Los Alamos program, is a modification of the W76-1 warhead. The W76-1 produces a high nuclear yield; the W76-2 provides a low-yield, sea-launched ballistic missile warhead capability. The first W76-2 was produced on February 22, 2019, at the Pantex Plant in Amarillo, Texas.



W88 Alt 370

Alterations are changes to a weapon’s systems, subsystems, or components. Not as extensive as an LEP, an alteration is a limited-scope change that affects the assembly, maintenance, and/or storage of a weapon. The alteration may address identified defects and component obsolescence without changing a weapon’s operational capabilities.

The W88 nuclear warhead entered the stockpile in 1988. Deployed now for more than 30 years, the warhead requires several updates to address aging issues and to maintain its current state of readiness. Started in 2012, the W88 Alt 370 program replaces the arming, fuzing, and firing subsystem, adds a lightning arrestor connector, and refreshes the weapon’s conventional high explosives to enhance nuclear safety and support future LEP options. The W88 Alt 370 is in the first production phase, with delivery of the first production unit scheduled for July 2021. ★





**BETTER SCIENCE =
BETTER SECURITY**

During the Manhattan Project, Los Alamos scientists were pioneers of nuclear science. The Laboratory continues to be a leader in the field today.

► Ground zero is viewed from the top of Compañía Hill (also called Compañía Hill or Cerro de la Colorado) in 2021 and 1945. The entire 1945 photo will be published for the first time in a forthcoming book by the Lab's National Security Research Center.

Deep analysis of the first atomic blast sheds new light on the origins of nuclear science.

BY ARTHUR BISHOP AND WHITNEY SPIVEY

TRINITY

REVISITED



▲ From left: Jennifer Talhelm, of the Lab's Public Affairs group; Nicholas Lewis and Alan Carr, both of the National Security Research Center; and Mark Chadwick, of the Weapons Physics directorate, leave the McDonald Ranch House, where the Trinity device was assembled in 1945.

IN THE MIDST OF A GLOBAL pandemic, how do you commemorate the 75th anniversary of one of the most impactful scientific achievements of all time? In the spring of 2020, Mark Chadwick, chief operating officer and chief scientist for the Weapons Physics directorate at Los Alamos National Laboratory, asked himself that question.

The scientific achievement under consideration was the Trinity test—the detonation of the world's first atomic device in New Mexico's Jornada del Muerto ("Journey of the Dead Man") desert on July 16, 1945. Manhattan Project scientists based at a then-secret laboratory in Los Alamos, New Mexico, had designed, assembled, and detonated the device. The resulting explosion changed the course of history in numerous ways. The scientists developed a weaponized version of the device that was detonated above Nagasaki, Japan, on August 9, 1945. Several days later, an armistice was declared, and on September 2, World War II officially ended. The then-secret laboratory eventually morphed

into Los Alamos Scientific Laboratory and then Los Alamos National Laboratory. Designing and maintaining nuclear weapons has remained its primary mission (see p. 20).

With this legacy in mind, Chadwick organized a virtual lecture series to explore the science behind the Trinity test. To orient listeners, one lecture focused on history, but most dug into deeply technical aspects of the test. Lecturers explained the science behind Trinity—techniques and experiments that had never been done before because atomic weaponry had never been pursued previously. They also explained the various ways that applying modern-day data analysis and computer simulation techniques to 75-year-old data had helped them to understand the test better.

As each lecture unfolded, Chadwick was inspired to capture and share the information. At the conclusion of the series, Chadwick challenged the speakers to write up their presentations as technical papers. He also invited colleagues at other nuclear science institutions (including Lawrence Livermore

National Laboratory, Sandia National Laboratories, and the United Kingdom's Atomic Weapons Establishment [AWE]) to contribute additional, related papers.

In a few short weeks, 120 people had agreed to write or collaborate on what would become 46 individual papers. "The project became contagious," Chadwick recalls. "As people saw their colleagues signing up to write on different topics, they were inspired to join in the project with their own papers."

"This was our chance to go into more detail than what the existing scholarship addressed," he continues. "The goal of these papers was to clarify the nature of the breakthroughs made, correct previous misunderstandings in the open literature, illuminate fascinating aspects of the underlying research, and illustrate how science from 75 years ago has proven foundational for the peaceful use of nuclear energy and today's nuclear technology."

The end result is twofold. In May 2021, all 46 papers (including 27 classified papers) were

published in a 550-page, Trinity-focused edition of *Weapons Review Letters* (WRL)—a monthly electronic journal internal to Weapons Physics. Later this year, 23 unclassified papers will be published in a special issue of the American Nuclear Society's *Nuclear Technology* journal.

Exploring the archives

For the majority of the coronavirus pandemic, the Laboratory conducted "normal operations with maximized telework," which meant that many researchers who had previously worked in classified environments were working at home several days a week. Researching and writing their papers for Chadwick was a good way to fill that time. (Classified papers, of course, had to be written in a secure area at the Laboratory.)

If and when researchers did go on site, some visited the National Security Research Center (NSRC), the Lab's classified library. The NSRC contains approximately 20,000 documents relating to Project Y—the Los Alamos branch of the Manhattan Project. With assistance from people including Senior Historian Alan

Carr—who authored a paper on the history of Trinity and its impacts—and Senior Archivist Danny Alcazar, researchers pored over pages of hand-typed records, manuscripts, photographs, and more. Often, they found more than they bargained for.

“Once you look and dig, you find things that allow you to point to other things that haven’t been appreciated,” Chadwick says. “There’s so much information; you often don’t quite know what you’re going to stumble across.”

Even Carr, who has worked for the Lab for almost 20 years, was surprised by some of the finds. “I was able to use records I had never seen before,” Carr says. “I imagine some of them had not seen the light of day in decades.”

To facilitate reviews of all the information collected, Chadwick dispatched each paper to experts at Los Alamos, Livermore, and beyond. Their feedback identified gaps or weaknesses in the writing that could then be rectified through additional investigation at the NSRC.

▼ Glassy, green Trinitite was formed during the Trinity test—likely as sand from the desert floor was drawn into the fireball.



“As people saw their colleagues signing up to write on different topics, they were inspired to join in the project with their own papers.”

—MARK CHADWICK

“The project introduced a new way to do peer review—a crowd sourcing approach in which all draft papers were sent to all coauthors participating in the project, inviting their feedback,” Chadwick says. “This meant that we were able to take advantage of a broad range of expertise as the papers were being developed.”

Many of the unclassified papers are highlighted by subject area below (see p. 42 for the complete list of paper titles and authors).

Nuclear science and technology

Chadwick, of course, contributed to the project. He authored a paper that documents the neutron cross-sections (used to express the likelihood of interaction between a neutron and a nucleus) measured with increasing accuracy during the Manhattan Project.

“Project Y scientists did some very clever measurements to infer what the key quantities might be,” Chadwick explains. “It was fascinating to figure this out. I said, ‘I need to turn this into a paper—it’s important and needs to be documented.’”

Accurate neutron cross-sections were needed to determine critical masses—the minimum amounts of fissile material needed to maintain nuclear chain reactions—of plutonium and highly enriched uranium. At Project Y, this work was necessary for the development of a plutonium implosion bomb—a device that would use high explosives to rapidly compress and increase the pressure and density of a spherical plutonium core, pushing the core to critical mass. The resulting nuclear chain reaction produced a powerful explosion.

To measure neutron cross-sections, four university accelerators were disassembled and reassembled at Los Alamos, and methods were established to make measurements on extremely small samples owing to the initial lack of availability of plutonium and enriched uranium-235.

In just two years, advances in experimental methods led to measured nuclear data that are surprisingly close to today’s best values in the Evaluated Nuclear Data Files—America’s nuclear reaction database that is developed by national laboratories and universities in collaboration with the International Atomic Energy Agency (IAEA). Many of the key



▲ Manufactured in Ohio by Babcock & Wilcox, Jumbo was originally 25 feet long, 10 feet in diameter, and weighed 214 tons. Scientists planned to use Jumbo to contain the Trinity test but then changed their minds. (For more, see “About the cover” on p. 1.)

original papers and numerical values have now been archived through a collaboration with the IAEA and Brookhaven National Laboratory in the internationally available Experimental Nuclear Reaction Data database.

A paper on the first fast critical assemblies (metal assemblies—reactor cores—that do not contain materials that can moderate and slow down the neutrons) by Jesson Hutchinson (of the Los Alamos Advanced Nuclear Technology group) and colleagues and another on pulsed and solution assembly experiments (which involve neutrons moderated by hydrogen atoms in the assembly) by Robert Kimpland (also of the Advanced Nuclear Technology group) and others provide details about how critical masses were determined, and how they influenced subsequent research across the world on nuclear criticality and criticality safety. The Los Alamos “water boiler” assembly was the world’s third reactor to become operational (in 1944, after Chicago’s CP-1 and Oak Ridge’s X-10 piles), the first to use a solution, and the first to use enriched uranium fuel. It assembled a critical mass of enriched uranium in a solution, with a chain reaction of neutrons slowed down to thermal energies.

During the Manhattan Project, bare critical masses (experiments that made metal nuclear

material critical without using a reflector around it) were not measured directly because of a lack of time and material; instead, the bare critical masses were estimated using subcritical measurements and reflected assemblies—spherical critical masses surrounded by neutron reflectors. Using neutron reflectors, scientists could make critical masses that used smaller amounts of fissile material, providing a snapshot of what a final bare critical mass would look like.

Avneet Sood, of the Lab’s Radiation Transport Applications group, describes the evolution of neutronics calculational capabilities—computer simulations that describe the motion and chain reactions of the neutrons—from early neutron diffusion work to subsequent refinements by physicists Robert Serber and Alan Wilson and the postwar innovations of so-called “Sn deterministic” and Monte Carlo neutron-transport simulations.

Stephen Andrews (of the Lab’s Verification and Analysis group), Madison Andrews (of the Lab’s Radiation Transport Applications group), and Laboratory Director Thom Mason (who was born in Canada) describe the Canadian work at the Montreal Laboratory and Chalk River and the essential role Canada played in supplying nuclear materials for the

Manhattan Project. The authors also tell of the contributions of the Canadians who came to work on the Manhattan Project in the United States. The Montreal Laboratory's work was focused on neutronic criticality theory and heavy-water-moderated reactor experimentation—research that proved to be important for postwar CANDU reactor development.

Without British (see below) and Canadian expertise and resources, Mason argues, Trinity might not have happened until much later, or it might not have worked. “An unsuccessful test might have had far-reaching implications,” he says. “It would have taken time to understand the origins of failure, any changes needed to mitigate, and the conduct of a second test to confirm this analysis and design or fabrication changes. Furthermore, the materials ultimately used in World War II would, instead, have to be used for a second test.”

Of course, Trinity was a success, and the design used to pull it off helped bring a quick end to World War II in the form of Fat Man. Little Boy, a gun-type nuclear weapon that scientists were confident would work, was detonated above Hiroshima, on August 6, 1945. “It has been said that the most significant nuclear weapons secret was—for the time period between Trinity and Hiroshima—that they work,” Mason says. “Trinity revealed that a nation with sufficient resources and persistence could develop a weapon.”

Hydrodynamics

Nathaniel Morgan (of the Lab's Applied Mathematics and Plasma Physics group) and Bill Archer (of the Lab's Weapons Physics directorate) describe Los Alamos' Theoretical Division's Lagrangian hydrodynamic shock calculations. Performed on IBM punched-card machines, the calculations helped scientists model the physical motion of metals that flow like liquid when heated under pressure; this helped them understand what happens inside a nuclear device when it's detonated.

Their paper presents the algorithmic advances made during the Manhattan Project by mathematician and physicist John von Neumann who led to the late-1940s formulation of computational fluid dynamics. Today, the algorithms developed by von Neumann and physicist Robert Richtmyer are the basis of simulations for everything from climate change to nuclear reactor design.



Morgan and Archer also illuminate the less appreciated, but very influential, roles of Manhattan Project physicists Rudolf Peierls and Tony Skyrme. The authors describe that the first usage of “artificial viscosity,” a concept central to computational hydrodynamics. In fact, based on a letter from Peierls to von Neumann found in the NSRC archives, artificial viscosity appears to have originated with Peierls in 1944.

When examining fluid flow to learn how explosions behave, shock propagation processes severely complicate the research because they add discontinuities to mathematical equations for explaining fluid motion. In other words, because the discontinuities are not mathematically continuous, it's virtually impossible to get a totally accurate value. By introducing viscosity, Peierls demonstrated that thickening and flattening these otherwise unruly shock zones could help resolve them computationally.

As Project Y moved toward the design of an implosion-type weapon, hydrodynamic modeling became crucial to understanding how the Trinity device (and Fat Man) would work. Today, hydrodynamic modeling remains essential for maintaining the U.S. nuclear stockpile.

Skyrme is well known to nuclear and particle physicists, but few know of his research in shock physics (the study of materials in extreme conditions). Indeed, it was Project Y Director J. Robert Oppenheimer seeking expertise in this area that brought two dozen British scientists to New Mexico in 1944.

Other papers describe the history of the Los Alamos computing facility; Nicholas Lewis of the NSRC wrote about the Laboratory's human computers (many of them women). Archer described the IBM punched-card computations needed for hydrodynamics and neutronics.

High explosives

The implosion design of the Fat Man atomic bomb relied on precision-engineered high explosives (HE) to symmetrically compress a plutonium core. Focusing the effect of an explosive's energy like this is called shaping a charge. Eric Brown and Dan Borovina

◀ The Trinity test was detonated atop a 100-foot tower, perhaps to help ensure clear photos of the expansion of the fireball. These photos were used to help determine the device's yield and other blast effects.

describe this work, its subsequent impact on broader shaped-charge technology, and its use in mining, oil recovery, and even SpaceX multistage rocket separation.

AWE's Richard Moore describes pioneering British work on shaped charges that influenced von Neumann, Seth Neddermeyer, and James Tuck's HE lens design that controlled the shape and velocity of the HE detonation around the plutonium core of an implosion device. The trio determined that simultaneously exploding faster- and slower-burning explosives in a certain configuration within a weapon would produce a specific compressive wave that would focus enough shock inward on the plutonium core to increase its density several times over. Doing this would reduce the core's critical mass and make it supercritical at the right time to start a chain reaction.

Jonathan Morgan, of the Laboratory's Integrated Weapons Experiments group, authored a paper that describes Jumbo, the steel vessel pictured on the cover of this magazine that would contain the Trinity test if the HE detonated but the plutonium



"I was able to use records I had never seen before. I imagine some of them had not seen the light of day in decades."

—ALAN CARR

core did not implode. Jumbo would allow scientists to recover the precious plutonium. In the end, Jumbo was not used for Trinity, but the vessel was valuable for later containment-vessel work and reactor engineering.

Plutonium materials and metallurgy

Joseph Martz (of the Lab's Materials Science and Technology group), Franz Freibert, and David Clark (both of the Lab's National Security Education Center) trace the process through which plutonium was discovered in 1940 at University of California–Berkeley. The first plutonium was characterized there and at Chicago's Metallurgical Laboratory, before U.S. research efforts were consolidated at Los Alamos in 1943. Particularly interesting is the early confusion caused by the widely varying density measurements and the subsequent discovery of the many complex phases of plutonium. This work collects the historical records and reconstructs the history of the rapidly advancing field of plutonium metallurgy and chemistry. The authors show that the idea of using gallium as an alloying agent to stabilize the malleable delta phase of plutonium was first raised only a few months before the Trinity test, a reflection of the intense pace of the project.

Another paper by Scott Crockett (of the Lab's Physical Chemistry and Metals group) and Freibert describes the rapid wartime expansion of experimental and theoretical work on the equation of state (a quantity that describes a given set of physical conditions, such as pressure, volume, or temperature) of plutonium, uranium, and other materials. The authors describe the foundational equation of state research needed to understand the hydrodynamic behavior of these materials.

Today, Los Alamos is the nation's Plutonium Center of Excellence for Research and Development and is the only place in the United States that can use plutonium to make everything from plutonium cores to heat sources that power Mars rovers. These capabilities are a direct result of the scientific achievements of the Manhattan Project—specifically the Trinity test.

Nuclear energy and yield

Susan Hanson and Warren Oldham (both of the Lab's Nuclear and Radiochemistry group) review the foundational radiochemistry methods



▲ The Compañía summit (elevation 5,700 feet) provided a good spot for scientists to watch the Trinity test in 1945.

developed to measure the yield of Trinity and how the techniques evolved in subsequent years. David Mercer (of the Lab's Physical Chemistry and Applied Spectroscopy group), Katrina Koehler (of the Safeguards, Science, and Technology group), and others describe recent measurements of radionuclides in trinitite rock from Alamogordo. Their paper describes traditional radiation-detection methods used in the training of IAEA inspectors at Los Alamos as well as the novel decay energy spectroscopy method.

Immediately after the Trinity test, the first estimate of the device's yield was about 18 kilotons (the equivalent of 18 kilotons of trinitrotoluene, or TNT), with an estimated 20 percent uncertainty. In the years following World War II, the yield of the device was recalculated to be 21 kilotons. However, after examining archival calculations and recent measurements of radionuclides in rock samples originally taken from near the city of Alamogordo—located just outside the blast zone—Hugh Selby (of the Lab's Nuclear and Radiochemistry group) and others share in their paper that Trinity's yield was higher still, approximately 24.8 kilotons.

"The new value comes from the powerful combination of advanced inorganic

separations chemistry with high precision mass spectrometry—an analytical tool useful for measuring the mass-to-charge ratio of molecules," Selby explains. "The former purifies the element containing fission fragments of interest from the sea of chemical interferences present in debris. The latter quantifies the minute amounts of bomb-produced isotopes of the element present in the purified sample, relative to the natural background. The level of precision necessary to make such measurements and to reanalyze 75-year-old data was made possible by major advances in both chemistry and mass spectrometry."

Other papers examine early prompt assessments of Trinity's yield: Jonathan Katz (of the Weapons Physics directorate) sought to understand how physicist Enrico Fermi might have determined the yield when he observed the blast wave's impact on small pieces of falling paper; Roy Baty and Scott Ramsey (of the Lab's Theoretical Design division) revisit G. I. Taylor's 1950 determination of the yield from the growth of the fireball. Using Lie group symmetry techniques, they rederive Taylor's two-fifths law relating a blast wave's position, time, and explosive energy.

During the Manhattan Project, physicists Hans Bethe and Richard Feynman developed an analytic formula to predict the yield of a fission

explosion from some elegant considerations. This work has had an enduring influence over the past 75 years; six classified papers were written on different aspects of the formula—three from Los Alamos, one from Livermore, and one from AWE. A short “tri-lab” paper by John Lestone (of Los Alamos’ Radiation Transport Application group), Mordy Rosen (of Livermore’s Design Physics division), and Peter Adsley (of AWE) describes, for the first time, the formula and its relationship to earlier wartime British work by physicists Rudolf Peierls, Otto Frisch, Paul Dirac, and Maurice Pryce.

For Rosen, the research hit close to home. “As someone who loves studying history, it was fun to ‘re-live’ Trinity through modern eyes,” he says. “On a personal note, my late father-in-law served in the U.S. Navy in the Pacific Theater of Operations in World War II and was preparing for the invasion of Japan. Trinity and its aftermath saved millions of

U.S. and Japanese lives by bringing the war to a rapid end. Thus, my wife and our 11 grandchildren are likely beneficiaries of this event.”

Technical history

The Trinity papers include several technical history papers, including those mentioned above on the beginnings of computing. Another discusses the origins of the plutonium core design and describes the invention patent located in the NSRC archives, resolving longstanding disputes about who originated the idea. (It was Robert Christy.)

In a second paper, Moore introduces Peierls’ 1945 summary of the British contributions to the “Tube Alloys” project, the codename for the British effort to build an atomic device, before the project transferred to Los Alamos. The author provides Peierls’

summary in full—with Sir James Chadwick’s marginal notes. Moore’s useful introduction and footnotes shine light on the activities of the time and the progress by the British researchers toward establishing the feasibility of an atomic bomb.

Trinity’s legacy

In 1947, physicist Robert Wilson wrote that the Trinity test “was for a specific military purpose. It will be gratifying to all those who participated in the work when it takes its more proper place as a contribution to the general structure of scientific knowledge.”

More than seven decades later, Trinity’s legacy is indeed felt across numerous technical fields, and Chadwick’s Trinity papers project helps solidify its influence. The papers likely represent the most in-depth analysis of the test ever completed; they include never-before-seen information and data that further ratify

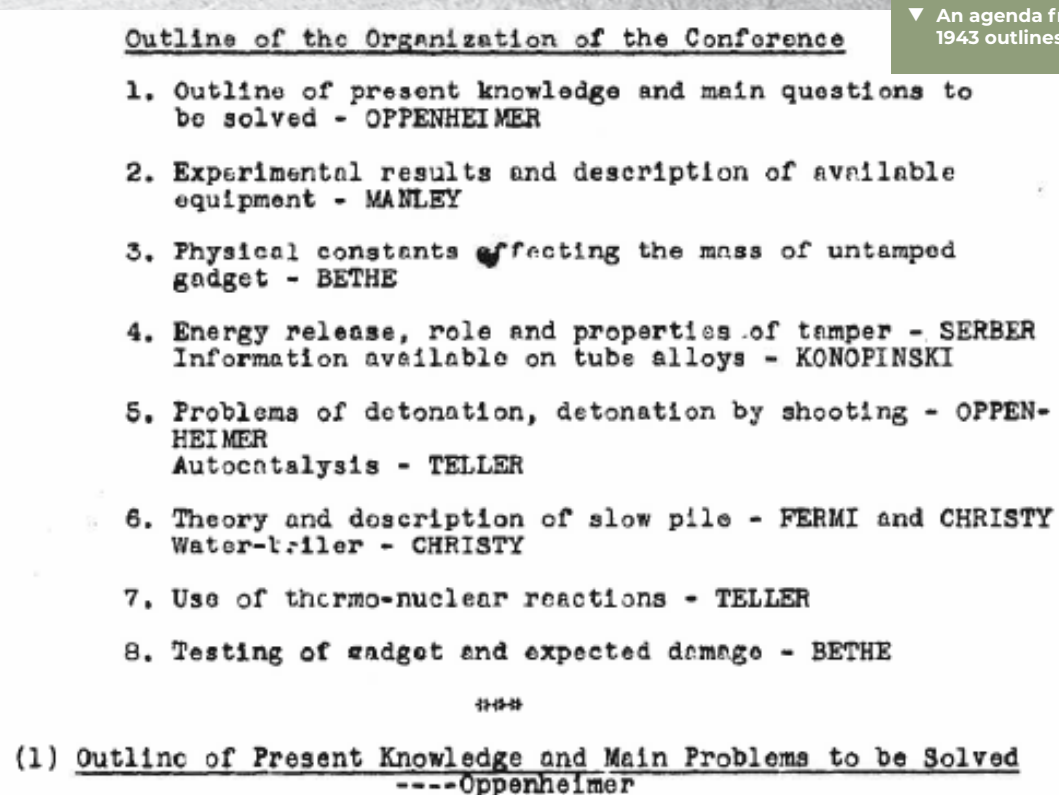
the event as one of the most important scientific experiments of all time. The papers also solidify Los Alamos’ place in history.

“In the process of researching and writing these papers, we confirmed that Los Alamos largely 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.”

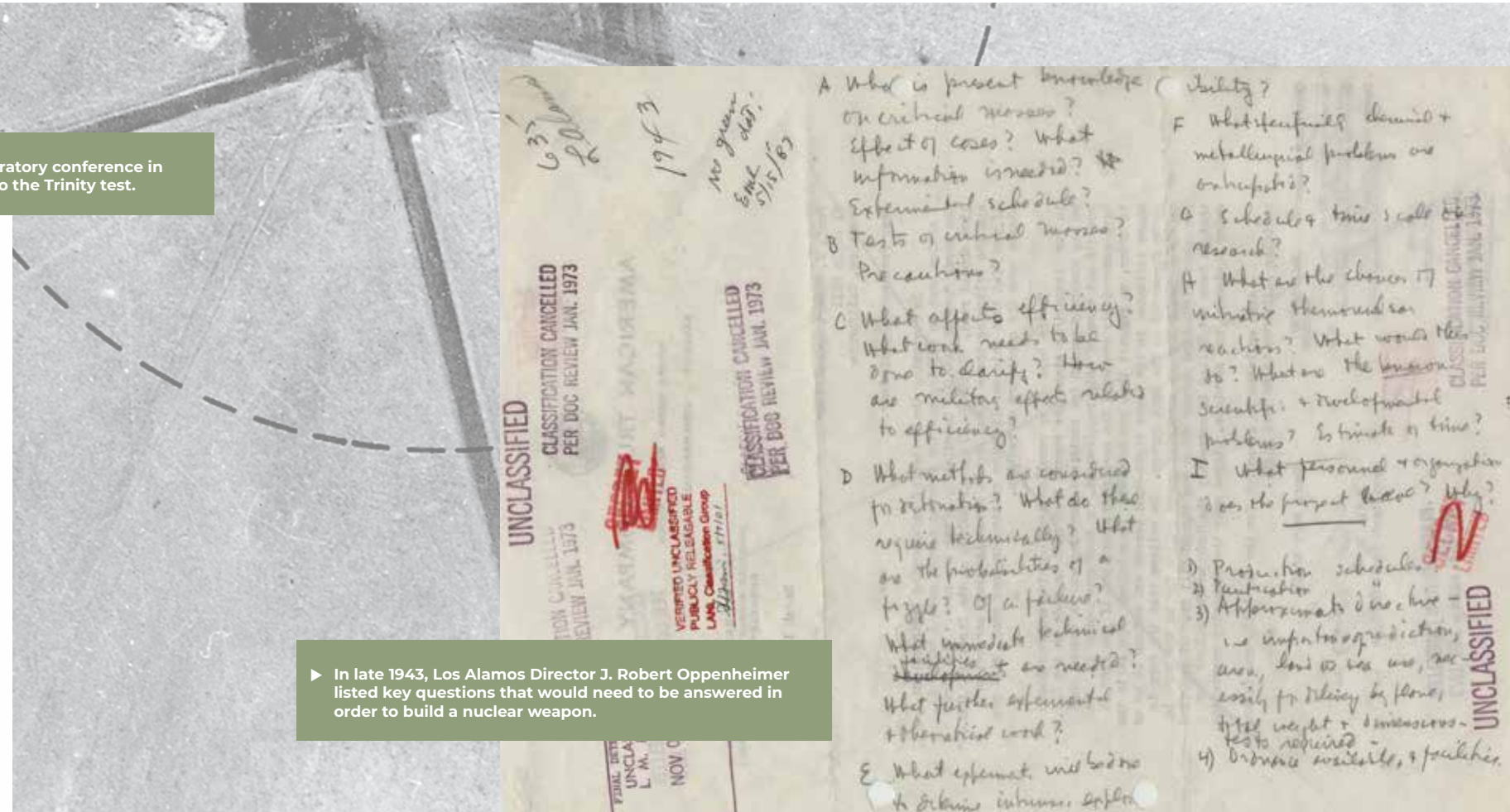
“I can speak for all the authors when I say that we had fun writing these papers and that we learned many new things in the process,” Chadwick continues. “I trust that this collection is indeed a contribution to both the history of science and to the advancement of science.” ★

FROM THE ARCHIVES

A couple examples of archived documents used in the Trinity papers.



▼ An agenda from a Laboratory conference in 1943 outlines the path to the Trinity test.



► In late 1943, Los Alamos Director J. Robert Oppenheimer listed key questions that would need to be answered in order to build a nuclear weapon.

THE TRINITY PAPERS

The following papers were published in issue 80 of the Laboratory's Weapons Review Letters (WRL) journal. Individuals with permission and security clearances may access the WRL papers by emailing editor Craig Carmer (csc@lanl.gov). Many of these papers will also be published in the Nuclear Technology journal, which is accessible to all at ans.org.

TITLE	AUTHORS
(U) Introduction to Trinity 75th Anniversary Issue	MARK CHADWICK, CRAIG CARMER
HISTORY	
Thirty Minutes Before the Dawn*	ALAN CARR
Peierls's 1945 Paper "Outline of the Development of the British Tube Alloy Project"*	RICHARD MOORE
Canadian Contributions to the Manhattan Project and Early Nuclear Research*	STEPHEN ANDREWS, MADISON ANDREWS, THOM MASON
Jews in Theory: Jewish Scientists in Theoretical Division at Los Alamos During the Manhattan Project	JACK SHLACHTER
(U) The Evolution of Early Soviet Bomb Designs	STEPHEN BECKER
DESIGN	
(U) Notes on the Design of Trinity	DAVID BECKER
(U) Modern Safety Assessment of the Trinity Device	ADAM COLEMAN, NICK DENISSEN, IAN FLEMING, ANDREW NELSON, ERIK SHORES
(U) 3D Simulations of the Trinity Device	NICHOLAS DENISSEN
(U) Modeling Trinity Using New Radiochemistry Results	LAURIE TRIPLETT, WILLIAM DEARHOLT, KEVIN BUESCHER, HUGH SELBY, PETER MARCY
(U) Who Invented the Trinity Nuclear Test's Christy Gadget? Patent Images Added*	THOMAS CHADWICK, MARK CHADWICK
EFFICIENCY AND BETHE-FEYNMAN	
(U) Bethe-Feynman Formula and WWII Atomic Bombs	J. P. LESTONE, C. R. BATES
(U) An Analytic Derivation of the Bethe-Feynman (BF) Formalism	MORDECAI ROSEN
(U) Bethe-Feynman Formula and Applications in the Modern Era	BAOLIAN CHENG
(U) War-Time Theoretical Work in Britain on the Atomic Bomb by Pryce, Fuchs, Davison & Dirac	J. CORNER (EDITED BY P. J. ADSLEY)
(U) Trinity Analytics	SCOTT RAMSEY, JOE SCHMIDT
Comparison of Historic Nuclear Explosion Yield Formulas*	J. P. LESTONE, MORDECAI ROSEN, P. J. ADSLEY
HIGH EXPLOSIVES, DETONATORS, FIRING SET, AND VESSELS	
(U) The Trinity High Explosive Implosion System: A Foundation to a Decades-Long Design Legacy*	ERIC BROWN, DAN BOROVINA
(U) Woolwich, Bruceton, Los Alamos: Munroe Jets and the Trinity Gadget*	RICHARD MOORE
(U) The Trinity Detonator Initiation System: Innovations for Decades of Nuclear Weapon Design	DAN BOROVINA, STEVEN CLARKE
(U) The Elegant Fat Man Firing Set and a Real "Barn Find" Story	JOHN HOGAN
The Origins of Blast Loaded Vessels*	JONATHAN MORGAN
IMPLOSION HYDRODYNAMICS AND COMPUTER SIMULATIONS	
(U) Los Alamos Hydrodynamic Simulations During World War II	B. J. ARCHER
(U) The First Strong Shock Hydrodynamics Code	B. J. ARCHER, N. R. MORGAN
On the Origins of Lagrangian Hydrodynamic Methods*	NATHANIEL MORGAN, BILLY ARCHER
(U) Hydrodynamic Instability in Trinity and Early Assemblies	G. D. PORTWOOD, N. DENISSEN

IMPLOSION HYDRODYNAMICS AND COMPUTER SIMULATIONS (CONTINUED)

Trinity by the Numbers: The Computing Effort that Made Trinity Possible*	NICHOLAS LEWIS
(U) The Computing Facility at Los Alamos During the Manhattan Project*	B. J. ARCHER

NUCLEAR SCIENCE, CRITICALITY, AND NEUTRONICS CALCULATIONS

Nuclear Science for the Manhattan Project & Comparison to Today's ENDF Data*	MARK CHADWICK
(U) Criticality Tests in Support of Little Boy and Trinity	JESSON HUTCHINSON, JENNIFER ALWIN, ALEX MCSPADEN, WILLIAM MYERS, MICHAEL RISING, RENE SANCHEZ
Criticality Experiments with Fast 25 and 49 Metal and Hydride Systems During the Manhattan Project*	JESSON HUTCHINSON, JENNIFER ALWIN, ALEX MCSPADEN, WILLIAM MYERS, MICHAEL RISING, RENE SANCHEZ
(U) "Tickling" the Dragon†	ROBERT KIMPLAND, TRAVIS GROVE, PETER JAEGER, RICHARD MALENFANT, WILLIAM MYERS
(U) Water Boiler Reactors at Los Alamos and Beyond†	ROBERT KIMPLAND, JEFF GOETTEE, TRAVIS GROVE, RICHARD MALENFANT, LUIS MORALES, WILLIAM MYERS, NICHOLAS WYNNE
(U) Trinity Initiation Considerations	SCOTT RAMSEY, PETER JAEGER
Feynman's Theory of Fission Chains	NEAL SNYDERMAN
Neutronics Calculation Advances at Los Alamos: Manhattan Project to Monte Carlo*	AVNEET SOOD, R. ARTHUR FORSTER, B. J. ARCHER, R. C. LITTLE

PLUTONIUM METALLURGY AND EQUATION OF STATE

The Taming of Plutonium: Plutonium Metallurgy and the Manhattan Project*	JOSEPH C. MARTZ, FRANZ FREIBERT, DAVID CLARK
(U) The History of the Equation of State Effort and the Plutonium Equation of State*	SCOTT D. CROCKETT (WITH FRANZ FREIBERT AS COAUTHOR OF THE UNCLASSIFIED VERSION)

YIELD: RADIOCHEMISTRY, RADIONUCLIDES, BLAST, AND FIREBALL

A New Assessment Statement for the Trinity Nuclear Test, 75 Years Later*	HUGH SELBY, SUSAN HANSON, DANIEL MEININGER, WARREN OLDHAM, WILLIAM KINMAN, JEFFREY MILLER, SEAN REILLY, ALLISON WENDE, JENNIFER BERGER, JEREMY INGLIS, ANTHONY POLLINGTON, CHRISTOPHER WAIMANN, ROGER MEADE, KEVIN BUESCHER, JAMES GATTIKER, SCOTT VANDER WIEL, PETER MARCY
Weapons Radiochemistry: Trinity and Beyond*	SUSAN HANSON, WARREN OLDHAM
(U) A Brief History of Radiochemical Diagnostics Seen Through the Lens of the Trinity Nuclear Test	HUGH SELBY
(U) Inference and Uncertainty Quantification Using Modern Radiochemical Trinity Measurements	PETER MARCY, SCOTT VANDER WIEL, HUGH SELBY
First Measurements of Nuclear Detonation Debris with Decay Energy Spectroscopy‡	MARK CROCE, KATRINA KOEHLER, VERONIKA MOCKO, ANDREW HOOVER, STOSH KOZIMOR
Gamma Ray Measurements of Trinitite and Trinity Site Soil‡	DAVID MERCER, PHILIP HYPES, PAUL SAEY
Fermi at Trinity*	J. I. KATZ
On the Symmetry of Blast Waves*	ROY BATY, SCOTT RAMSEY

(U) classified article (with an unclassified title) † articles that were combined into a single article for Nuclear Technology
 * article or related unclassified article published in Nuclear Technology ‡ articles that were combined into a single article for Nuclear Technology



**BETTER SCIENCE =
BETTER SECURITY**

Wargames help leaders consider national security-related scenarios. During a wargame, Los Alamos brings its nuclear expertise to the table.

BY VIRGINIA GRANT

WARGAMES

Simulating wartime decisions helps prepare for the real thing.



“It takes a nuclear weapons designer to catch a nuclear weapons designer.”

—TIM GOORLEY

On August 17, Alaskan officials reported 81 cases of an unidentified hemorrhagic fever, similar to but more contagious than the Ebola or Marburg viruses, on the Alaskan island of St. Paul in the Bering Strait. Within a day, 24 infected people had died. The outbreak occurred two weeks after the United States was accused of sinking the Russian ship *Ulana*. Americans had attempted to search *Ulana* because they suspected it of carrying biological warfare materials to Russia's recently solidified ally North Korea. Four U.S. Marines died in the skirmish, as well as almost all of the Russian ship's crew. In addition, a group of South Korean tourists—one of whom had North Korean ties—visited St. Paul three days before the first infection was discovered. These combined events

have led to an increasingly volatile situation between the United States, Russia, and multiple countries in the Asian-Pacific.

If you're thinking you missed some major breaking news, you can breathe a sigh of relief. This all takes place in a fictional version of 2039; it's a tabletop exercise (TTX)—a mini-wargame—titled St. Paul Syndrome II, in March of 2021.

Pieces on a board

A wargame, according to deceased wargaming expert Francis J. McHugh of the United States Naval War College, “is a simulation, in accordance with

predetermined rules, data, and procedures, of selected aspects of a conflict situation.” It's essentially a pretend war.

Wargaming has been around for hundreds of years. “John Clerk, a landsman with no actual experience in the ways of the sea, revolutionized British 18th-century naval tactics by using a tabletop for an ocean and wooden blocks to represent ships,” McHugh explained in *Fundamentals of War Gaming*, which was published in 1960. The United States has used similar techniques for a long time. According to a 2015 article by then Deputy Secretary of Defense Bob Work and Vice Chairman of the Joint Chiefs of Staff General Paul Selva, during the 1920s and 1930s, “militaries the

world over struggled to adapt to new inventions such as radar and sonar, as well as rapid improvements in wireless communications, mechanization, aviation, aircraft carriers, submarines, and a host of other militarily relevant technologies.” During this time, the United States military began to lean heavily on wargaming to play out the possibilities of these new developments and their impact on warfare.

“Wargaming is strategic analysis,” says Rich Castro, the retired director of the Strategic Analyses and Assessments Office at Los Alamos National Laboratory. “The Lab's participation is important because wargaming is an analytical tool that brings together many different thoughts, combining the expertise of the Department of Defense, Department of Energy, and the national laboratories.”

Wargames help leaders consider different scenarios and think about how they might play out so they can prepare to make quick decisions in the event that a similar scenario actually takes place. “Things are moving so fast, technology moves so fast, you have to think faster,” Castro says. “We don't have the luxury of thinking about these problems in the long-term. There are a lot of changes in our adversaries—cyber, space, nuclear, conventional—that didn't exist during the Cold War. They all come together now in an escalation ladder. You have to play this out or you're caught completely off guard.”

Full-scale wargames are played at different locations in the United States, often at the Naval War College in Rhode Island, with hundreds of participants present from all across the country. The basic structure is that a group of analysts from the organization running the game write a scenario—usually focused on a particular region, technology, or situation that is pertinent to current concerns—to be played out over the course of one or two weeks. Preparation for the game usually takes several months.

Players are assigned to teams that represent countries; a control group determines the outcome of team decisions, actions, and interactions with other country teams. The control group also represents countries that do not have assigned teams. More than 30 large-scale wargames are held annually across the nation, and players from Los Alamos are invited for a particularly important reason—their nuclear expertise.

The nuclear niche

According to Tim Goorley, Los Alamos' lead wargaming consultant for nuclear effects, Los Alamos provides expertise on what happens to people, aircraft, sea vessels, and satellites, for example, in the event of a nuclear detonation. That information is then fed into the game to help the players on both sides understand what possible actions they could take next.

Laboratory personnel provide expertise in person at wargames, and they're consulted ahead of the games during the long, complicated process of scenario creation. For example, one game incorporated whether it was possible to have a new weapon, and, if such a weapon existed, how many the United States might own. Goorley called some Los Alamos engineers to see whether such a weapon could be produced in the timeframe required by the game and whether it could be deployed and used in the way the game planners wanted.

Experts from Los Alamos are also able to give particular insight into adversaries' policy and technical capabilities. “It takes a nuclear weapons designer to catch a nuclear weapons designer,” Goorley explains.

Another way in which wargames are useful is that they help debunk commonly believed myths about nuclear weapons. Many wargames end with the detonation of a nuclear

weapon, assuming that's a game-over event. But, according to Goorley, that's not true at all; things are just getting started. “People don't realize how much you can still do just a few miles or days out from ground zero,” he says. “You need to keep going through the game for about a week or two after the detonation to fully understand the effects.” Although many films show city blocks being instantly vaporized by a nuclear weapon, or show an electromagnetic pulse sending a huge part of the country back to the dark ages, those scenarios are not realistic, and realism is vital to productive wargames. As Goorley puts it, the Laboratory “takes the falling sky and puts it back up.”

The Los Alamos scrimmage

Although full-scale wargames are the longest and most detailed versions, smaller versions referred to as tabletop exercises exist, in which fewer people play out a scenario in a shorter timeframe. Los Alamos has been conducting tabletop exercises for several years, the most recent being the St. Paul Syndrome II scenario.

St. Paul Syndrome II was a collaboration between the Laboratory's Office of National Security and International Studies (NSIS) and the Center for Strategies and International Studies (CSIS), a Washington, D.C., think tank with whom the Lab has partnered. In fact, the most recent TTX was a replay of a scenario (St. Paul Syndrome I) that different participants played out in the summer of 2020. By keeping that scenario secret, Los Alamos and CSIS were able to use it again with new players who, through their different decisions, revealed entirely new options and pathways for the unfolding events. “I have learned never to expect particular outcomes,” says Ian Williams, an International Security Program fellow and deputy director for the

CSIS Missile Defense Project. “Even when running the same scenario with participants of similar professional backgrounds, we see teams take a wide variety of strategies and actions.”

St. Paul Syndrome I and II were developed “to explore how decision makers respond to a multi-domain national security conflict,” says Paula Knepper, an NSIS program manager. “In this case, we have nuclear and bioweapons as well as an issue related to the Arctic.”

The scenario was “the most complex one that we have done so far,” Williams says. “Rather than have one major crisis that all the teams were focused on, the scenario had each team facing a different issue that overlapped with the vital interests of the other

“The TTX provided unique insight into how effective the weapons can be without ever actually detonating.”

—CALEB SCHELLE

country teams. This dramatically increased the potential friction points between countries.”

NSIS is in charge of choosing Laboratory participants and filling each team roster. An invitation is quite desirable at Los Alamos; for St. Paul Syndrome II, the rosters were filled in less than 24 hours. “One of our objectives is staff development,” Knepper says. “We keep in mind creating opportunities for Laboratory staff to extend their professional networks. We also look for team diversity—experiences, organizations, technical backgrounds, etc. We find

that diverse teams have the most insightful and creative outcomes.”

Wargames are as realistic as possible and are based on current intelligence, so most are conducted at top secret levels so real intelligence agents can attend and contribute what they know. The recent TTX between Los Alamos and CSIS, however, was not classified, so the lessons learned from it can be put to broader use. TTXs can be unclassified because they focus on scenarios that take place years in the future, in a world that is only a possibility.

Los Alamos is a particularly useful ecosystem for wargames and small-scale exercises alike because of the close proximity and working relationships of people from many areas of expertise, including engineers, infrastructure experts, policy experts, and scientists from myriad fields. “The Laboratory is a unique place,” Castro says, “in that it can pull together a team to quickly address multi-domain issues, and everyone can be sequestered in an area just to concentrate on one problem. I don’t know other places that you can do that.”

The coronavirus pandemic threw a wrench into that unique capability in that teams were not able to sequester in person for the past two TTXs, but CSIS and NSIS quickly adapted to build a virtual game space. Personnel from CSIS ran the game and were assigned to help the country teams, but all of the players were Lab employees. Some were scientists from fields including nuclear engineering, astrophysics, geophysics, and biosecurity and public health. Others were from intelligence systems, international studies, and international threat reduction.

Most Los Alamos players had never participated in a wargame before. “It was really neat hearing how people with different academic and professional backgrounds approached

problems,” says Caleb Schelle, a shock and vibration testing engineer. “I was one of the younger members on the team, and I appreciated learning how more experienced scientists and engineers chose their words and actions thoughtfully.”

Amanda Evans, a scientist in chemical and biological threats, also valued the insight of her colleagues during the TTX. “Building our team’s interactions was a very positive experience,” she says, “as was learning from more experienced colleagues.”

Kickoff

Before the TTX began, participants were divided into teams, each team representing a country—the United States, Russia, China, and Japan. Team members prepared by reading historical background information that was available to all teams plus some country-specific information provided by their countries’ intelligence services. Teams also received information about their own countries’ military

capabilities and strategic positions, along with information about that of other countries—to the best of their intelligence agencies’ knowledge. They then began to make decisions to play out the scenario, all over the course of just four days.

On the first day of the TTX, after meeting all together, the country teams broke into separate groups and got to work examining the current state of the scenario and determining their main objectives. At the end of each day, each team must submit its “turn,” which includes its objectives and actions—both public and covert. The time spent in groups is used to discuss how to make those decisions, to read and discuss new information as it comes in throughout the day from the control group, and, at times, to communicate with other countries.

Early in the day, the United States team learned from the Centers for Disease Control and Prevention that the St. Paul virus was a form of Marburg virus that had been developed in a Soviet laboratory in the 1980s, meaning that the outbreak



was a bio-attack made by either Russia or Russian-aided North Korea. The American team’s response to this news was much more peaceful than many might have guessed. “It was interesting to see how the U.S. team did not really view it as an attack,” observes NSIS Director John Scott. “They appeared to be most concerned about containing the outbreak on the island.”

Meanwhile, the Russian team began to launch misinformation campaigns to place blame on the United States for the *Ulana* sinking, China worked to disrupt American power in the Pacific, and Japan, faced with growing anti-American sentiment among its citizens, strategized the best ways to restore peace to both the region and its own people.

Over the next four days, teams worked to destabilize relationships between other countries, solidify their allies, secure military positions, avoid war, gather and decipher intelligence, get their political parties re-elected, and stop an outbreak of a disease with a 99 percent fatality rate. They moved their military ships around, demanded that each other remove ships from certain areas, and communicated with each other via confidential channels. They issued public statements to each other and to their own citizens.

Teams also received a great deal of information that threw them for loops.



■ At 43 square miles, the Alaskan island of St. Paul is the largest of the Pribilof Islands, a group of four volcanic islands in the Bering Strait.



For example, uncovered intelligence determined that the Russians had scuttled the *Ulana* (sunk their own ship) and blamed it on the Americans. Information was also revealed that the *Ulana* was carrying equipment for bioweapons, yet it seemed that Russia was not directly involved in releasing Marburg on St. Paul Island.

“Truth, justice, and apple pie”

Wargames are played under the Chatham House Rule, which means that information, quotes, decisions, and ideas from the game cannot be attributed to any individual player.

The dynamics of the TTX were complex. At one point, for example, the Russian team considered bombing one of its own islands and blaming it on the United States as a ploy to gain global sympathy. In contrast, during a discussion of attempting to separate China’s alliance with Russia, a player argued that the concept of ethical responsibility would not sway the Chinese. “Whether truth, justice, and apple pie are on our side, China is going to side with Russia,” the player said.

Some of the Laboratory participants noted the chance to consider the real-life implications of nuclear

weapons—to think of them in more than a conceptual way. Jason Haynes, a global security analyst at Los Alamos, is a Naval War College graduate who has participated in wargames through the Navy and the Department of Defense, but St. Paul Syndrome II was his first TTX at the Laboratory. “The Lab has many smart people who are experts in their respective fields,” he says. “These kinds of exercises give them the ability to see how their work plays into strategic decision making, and to think about the kinds of pressures decision makers face.”

Lawrence Daugherty, an executive advisor in the Lab’s Weapons Production directorate, agrees. “Exposing staff to the bigger picture of why we do what we do here” was, he says, the most valuable part of the TTX.

Karen Schultz Paige, a program manager in weapons survivability, says, “I learned a lot about international relations that I never knew before. I am more concerned about and aware of the international problems that affect the U.S.”

And Schelle notes that “being forced to think about how nuclear weapons are used as diplomatic tools and the implications of ‘flexing’ them” was the most valuable part of the exercise. “Many people at the Lab are familiar with nuclear weapons,” he continues,

“but the TTX provided unique insight into how effective the weapons can be without ever actually detonating.”

Joshua Carmichael, a scientist specializing in Arctic and Antarctic geophysics, notes that the techniques used in the TTX would also be valuable for non-conflict scenarios. “My own team at Los Alamos could use an exercise like this to better strategize how to detect, attribute, locate, and identify an underground nuclear explosion in a hypothetical scenario in the future,” he says.

The final whistle

Most TTXs have a predetermined number of turns that the teams take, usually one at the end of each day. In this case, the TTX ended with a fourth turn, after which the control team introduced a surprise fifth turn, giving the players a mere half hour to decide their next course of action. After that, the game was over.

In the end of St. Paul Syndrome II, no shots were fired and the outlook was fairly hopeful, with the announcement of a historic Pacific peace summit to take place

in the near future. Scott notes that Los Alamos personnel are particularly interested in resolving TTXs without military conflict—especially without any nuclear component. “On average,” he says, “I find that Los Alamos staff want to find peaceful outcomes to conflict. So, I was not surprised in this TTX that even though the scenario provided many opportunities for military conflict, there was basically none.”

The outbreak on St. Paul was contained, although the devastation of the attack left a lasting impact on international relations. Things were more tumultuous in the United States, where the withdrawal of naval forces from areas near Japan, Taiwan, and Alaska was met with resistance from the American public, and the policies for dealing with North Korea resulted in the resignation of the United States’ defense secretary.

But this fictional scenario could have played out in myriad ways, from completely peaceful negotiations to nuclear war. Williams notes that, although St. Paul Syndrome I and II were

identical TTX scenarios, the results were quite different because of the different players. “Some teams of St. Paul Syndrome II played more aggressively, others more cautiously” than the country teams in St. Paul Syndrome I, he says, which is because of “different personalities and different risk tolerances. Different people can receive the same set of facts yet come to different conclusions on how to act. It just again shows that deterrence is much more complex than many think it is, and no outcome is inevitable.”

Scott agrees, noting that the timing of the TTXs affected the outcomes; St. Paul Syndrome I was held early in the pandemic, while St. Paul Syndrome II was a year later. “You can see in the response of the teams how the pandemic impacted how they approached the TTX scenario and its biowarfare component,” he says. “I found it fascinating how real-life events were reflected in the actions of the teams.”

When the games are over, the results are compiled, analyzed, and used in various ways. For NSIS, the TTX provides an opportunity to examine the role of Los Alamos staff in these types of scenarios. “Part of the NSIS portfolio involves understanding the implications of policy choices, including weapons

of mass destruction and, in particular, nuclear weapons,” Scott explains. “Exercises like these demonstrate how bright people like those who work at the Lab choose to use these instruments of force in particular scenarios. The kinds of choices that are made and how these scenarios play out can help guide how we should view the use of these weapons and what role they play in escalating a conflict or avoiding conflict.”

At CSIS, the results will be considered as part of the large collection of wargames that have been played over time. “TTXs are experiential learning tools,” says Williams, “and they have limited ability in predicting how states might behave in a given situation. That being said, they often shake out new questions and possibilities that have not been previously considered, which can serve as a starting point for future research.”

Wargames enable decision makers to consider multiple possibilities, because although they might think they know the most likely outcome of any scenario, no outcome is guaranteed, and a lot could happen to change the path of events. And, in the words of many a sports fan, that’s why you play the game. ★





**BETTER SCIENCE =
BETTER SECURITY**

The Laboratory's National Security Research Center houses the world's most comprehensive collection of nuclear weapons and national security materials dating to the Manhattan Project.

THE ARCHIVES OF THE FUTURE

Artificial intelligence is the solution to digitizing, cataloging, and searching nearly 80 years' worth of classified materials at Los Alamos National Laboratory.

By Rizwan Ali



■ Archivist John Moore of the National Security Research Center.

The term “artificial intelligence” (AI)—essentially programming machines to think like humans—conjures up different emotions in different people. Some view it with fear, imagining a malevolent AI similar to Skynet in the *Terminator* movies. Others see something benevolent, such as the character Data in *Star Trek: The Next Generation*. Still others see it as a means to advance the frontiers of science, engineering, and technology to new levels not possible through traditional means. At the National Security Research Center (NSRC or the Center), which is the classified library at Los Alamos National Laboratory, we see AI as a tool to help us go through the monumental tasks we have in digitizing, cataloging, and searching our collections.

Broadly speaking, AI involves developing smart machines that demonstrate human intelligence and cognition. The current state of AI is nowhere near anything we can classify as having sentience similar to Skynet or Data,

and it's anyone's guess if machine consciousness will ever happen. Speculation about that possibility might be best left to futurists and science fiction authors.

However, a branch of AI, called machine learning, has made significant progress over the past couple decades. Machine learning, sometimes written as AI/ML, uses algorithms to recognize relationships in data. The algorithms, or sets of instructions to perform a certain task, “learn” from data rather than using a predetermined equation. An example is image recognition on smart devices that can identify who we are.

In fact, many of us use AI/ML on a daily basis and don't think twice about the technological sophistication needed for devices and services to learn our behavior and make accurate predictions about our preferences. Digital assistants, such as Siri and Alexa on our smart devices, use AI/ML to learn the types of news we like

to listen to and locations we typically travel to on the weekends, among other preferences in our routines. YouTube uses AI/ML to deliver the most-relevant videos for you based on your recent watch and search history. Smart thermostats know when we usually come home from work, adjusting the temperature so we arrive at a warm, toasty house in the cold months.

One significant limitation with AI/ML systems, however, is that they are very specific in terms of what function they can perform. For example, there is no chance, at least for now, that a smart thermostat's AI/ML algorithm could be used to predict stock market trends. An AI/ML system must be developed and taught the specific set of tasks for which it was designed.

Those tasks, however specific, are quite remarkable and were not possible just a generation ago. This is why the NSRC is exploring this technology—to revolutionize the way we operate, and more importantly, the way we contribute to our nation's security.

Machine learning and the Los Alamos mission

The NSRC opened its doors in 2019, transitioning from what was a repository of archival materials to a dynamic, vibrant library that researchers regularly access. Already, the nascent NSRC is one of the largest research libraries in the United States.

The NSRC's specialized team of 40 historians, archivists, librarians, and digitizers partner with the Lab's scientists and engineers as they conduct research. They also curate the reports, films, photographs, lab notebooks, engineering drawings, and more that led to the dawn of the Atomic Age. These early collections are among the NSRC's tens of millions of materials, which span the entire history—more than 75 years—of the nuclear enterprise. These historical documents and artifacts, classified research, and weapons information do not exist anywhere else.

Implementation of AI/ML technology in the NSRC is a priority for its leadership team so that we can better serve our researchers—the scientists and engineers at Los Alamos whose work supports nuclear deterrence. Nuclear weapons physicists, engineers, and production specialists use the collections daily in support of weapons' design and development to help maintain our nation's reliable and effective nuclear weapons stockpile. The materials are far from antiquated and dusty.

However, fewer than 10 percent of the holdings have been digitized, and fewer than 10 percent of those digitized holdings have been cataloged. This affects the speed with which the Center is able to provide researchers with the Lab's one-of-a-kind materials that are so vital to their work. Without employing AI/ML technologies in multiple areas of the Center, it is unlikely the NSRC will make significant progress in digitizing and cataloging our collections.

Some may be asking why it's important for us to digitize, catalog, and make searchable this vast collection of nuclear weapons material. The short answer: It saves a lot of time and even more money. Implementing AI/ML is a mission-critical task for the Center's collections to be accessible to researchers. The collections have reports and analyses that save the Lab tens of millions of dollars annually because they preclude countless hours in redundant research, studies, and experiments. Furthermore, the majority of these records do not exist elsewhere; if researchers need them, the Center is the only option to get them.

Modernizing equipment and processes

The NSRC is exploring a variety of AI/ML technologies to digitize our vast collections of physical material, to automate tasks to capture metadata and catalog the digitized information, and to implement a natural (colloquial)-language search system. This will make digitized documents easier for researchers to find.

This technology is not entirely new to us. In 2020, we piloted an AI/ML system to digitize some of the documents in our microfilm and microfiche collections. These collections contain information relevant to nuclear weapons modeling and simulation, weapons designs, and plutonium pit production, which are a key part of warheads and must be replaced as they age. This work is critical to the Lab's stockpile stewardship mission (ensuring a safe, effective nuclear deterrent in the absence of weapons testing) and pit production benchmarks. Now, we want to extend our application of AI/ML technologies even further.

The Center's microfiche and microfilm number in the hundreds of thousands and contain well over 50 million pages of information. Using our current, non-AI/ML-capable equipment, software, and processes, it would take us an

estimated 90-some years to digitize the microfiche collections, and more than 2,000 years to digitize our microfilm collection. The absence of AI/ML means significant labor is required to operate the outdated equipment and perform the cumbersome, manual quality-assurance (QA) process required for each digitized page. In the manual QA process, once the microfiche or microfilm is digitized, every single page needs to be reviewed to ensure the focus, contrast, alignment, proper resolution, and other factors were adjusted properly to ensure each page was readable. Each microfiche sheet can have nearly 100 pages and each microfilm reel can have up to 4,000 pages. The process to do this manually and adjust each page on a single microfilm reel, for example, could take several weeks. With the AI/ML-based



We see AI as a tool to help us go through the monumental tasks we have in digitizing, cataloging, and searching our collections.

system, the process takes less than a minute. The computer automatically performs nearly all necessary adjustments and only flags a small handful of pages that the operator needs to review.

Modern AI/ML-based equipment and software, coupled with improved processes, has a high likelihood of reducing the amount of time necessary to digitize this material to less than two decades. The AI/ML systems could decrease the time to digitize the microfiche collection by as much as 80 percent and the microfilm collection by as much as 99 percent by automatically detecting individual frames and performing highly sophisticated image corrections to automatically flag the dozen or so images out of several thousand that the AI/ML system was not able to automatically correct. This dramatically reduces the time our six archivists spend performing QA reviews on the finished digitized products.

But digitizing and performing QA on the documents are just two of several steps where AI/ML can be employed. The ultimate goal is not to just digitize the material, but to present researchers with materials that have been cataloged and are easily searchable using a natural-language search system.

A solution to a 400-year backlog

Once the content is available digitally, it can be cataloged. Currently, cataloging in the Center is a manual, time-consuming process where our librarians or archivists upload metadata information into one of our classified digital repositories. The metadata contains information such as the document's title, date, author(s), report number, organization, abstract, and keywords. This process can take anywhere from 10 to 30 minutes per document depending on the complexity of the document and speed of the system that particular



day. However, if the information isn't cataloged, it isn't discoverable to researchers.

If the NSRC continued to manually catalog its current backlog of 2.4 million digitized documents, it would take more than 400 years to complete. Meanwhile, as we begin to increase the rate at which we are digitizing our physical collections, the total number of digitized documents will continue to grow at a rapid pace. The NSRC doesn't have enough staff to manually catalog these vast collections of digitized documents.

To automate the cataloging process, an AI/ML-based system needs to be implemented. This system would perform a sophisticated optical character recognition process and parse the information in each document into metadata, which could then be cataloged. After the metadata is parsed, it would pass the information to an AI/ML-based, natural-language search system. These distinct processes will involve the NSRC's partnership with several companies that specialize in AI/ML.

The NSRC's documents date back more than 75 years to the inception of the Manhattan Project and contain older typewriter fonts that cannot be searched using industry-standard document viewing software, such as Adobe Reader. The AI/ML system needs to read each document regardless of its format and fonts and then extract the required metadata so it can be cataloged. The metadata extraction system scans the digitized

documents and, through an AI/ML process, teaches itself where to find the relevant metadata information.

This information is then passed to another system that uses AI/ML to implement a natural-language search tool. The natural-language search tool uses contextual clues in the way a researcher would phrase a search query to discern the intent of the search, rather than deliver just a simple list of documents that contain the words in the search field.

To illustrate this point, suppose a researcher wanted information about the word "plant." The system would use contextual clues in the full search string to determine if the researcher wanted to know about the biological entity "plant," a manufacturing "plant," or how to "plant" something in the ground. Each meaning would yield vastly different results, and the use of an AI/ML-based natural-language search system would deliver only the most relevant results to the researcher.

To address this metadata/search challenge, the NSRC initiated a large-scale AI/ML project to automatically catalog our digitized information and provide a natural-language search system to help researchers find relevant information. Companies that do this highly specialized type of AI/ML are rare. To find these companies, the NSRC reached into the U.S. Intelligence Community, which has a very similar problem set—namely that it has vast quantities of digital information to catalog and search in a rapid and efficient manner.

If the NSRC continued to manually catalog its current backlog of 2.4 million digitized documents, it would take more than 400 years to complete.

After a fairly lengthy process, the NSRC found a set of companies that specialize in using AI/ML to extract metadata from digitized documents and use natural-language, AI/ML-based systems to search through materials.

A successful test run

Bob Webster, the deputy Laboratory director for Weapons, provided the NSRC funding to test the system in a six-month pilot study on the Lab's unclassified network, using unclassified digitized nuclear power plant material. The system's AI/ML system successfully captured the required metadata automatically, to include keywords, and populated the cataloging system. Because this system was also used within the Intelligence Community, it passed the Lab's classified analysis, which confirmed it can be installed and used securely on the Lab's classified network.

The end goal for this AI/ML installation on the Center's classified network, an initiative called Titan on the Red, is to extract metadata from various digital data repositories and present researchers with a natural language,

AI/ML-based interface to search through the NSRC's entire digitized collection. Because many of the documents within the NSRC are protected through stringent security and need-to-know protocols, the search system will enforce these protocols and only deliver documents that the researcher has the appropriate approvals to view.

What this means for researchers is that the large backlog of documents that are currently not cataloged and not searchable will become accessible in a matter of months once the system comes online, rather than in double-digit decades. Plus, the process to search through the NSRC's digital repositories will become dramatically easier than the current process, which requires contacting one of our librarians to have him or her manually search through our collections.

For the 2021 fiscal year, the Center's goals are to install Titan on the Red on the Lab's classified network and begin integrating the system into at least one of the digital repositories. Additionally, the Center intends to begin the process of training the AI/ML to extract necessary metadata from the documents as well as to identify words and terms specific to our collections.

In the beginning, the system will only be available to the NSRC's staff and a select group of researchers, as we fully test the system. The eventual goal is to make the system available to everyone in the Lab's Weapons program and others who have a need to access Weapons program material.

AI/ML is new, yet proven. The Laboratory has embraced this advancement, which is really the only solution to making its one-of-a-kind collections searchable to its researchers. Investing in AI/ML saves countless hours and many millions of dollars, while directly contributing to the Lab's mission success and our nation's security. ★



ABOUT THE AUTHOR

Rizwan Ali is the director of the National Security Research Center (NSRC), the classified library at Los Alamos National Laboratory. As the NSRC director, he sets the strategic direction for one of the largest libraries in the United States. Ali assumed the position in 2020 and brings with him 30-plus years of military, national security, cyber security, nuclear weapons, and engineering experience. He is a retired U.S. Air Force colonel, whose career included commanding multiple, large units in the United States and in combat zones. He has extensive international work experience with NATO and U.S. partners in the Middle East and Africa.

IS YOUR BOSS A BLACK BEAR?

To answer this question (and determine if you should change your telework status to permanent), consider some problems and processes in intelligence analysis.

Is Japan planning a sneak attack on the American fleet stationed at Pearl Harbor? Are terrorists planning to fly commercial airliners into the World Trade Center buildings? Unthinkable possibilities need to be considered, not because they are particularly likely, but because of their incredible potential to change the world. Policymakers may pose questions like these to intelligence analysts, who must navigate a minefield of cognitive biases to provide objective, timely, well-reasoned, and well-sourced answers.

The analysts pursuing these answers work within 18 U.S. government organizations, each with unique specialties. One of these organizations is the Department of Energy's Office of Intelligence and Counterintelligence, whose mission is to "protect, enable, and represent the vast scientific brain trust resident in DOE's laboratories [including Los Alamos] and plants."

Availability bias

Imagine for a moment that you are an intelligence analyst asked to evaluate the likelihood of a low-probability, high-impact scenario: Your boss is a black bear masquerading as a human. Where do you start?

You rack your brain for any shred of evidence that could support such a ludicrous claim. Bears are intelligent, inquisitive, and generally peaceful. So is your boss.

Then there's the pungent smell of salmon in the break room. Vivid, easily recalled details like these can be a source of bias, figuring prominently in memory because of their recency and our tendency to think easily recalled information must be important. When evaluating a problem using hundreds of sources, intelligence analysts should consider whether a report is important because they remember it, or they remember it because it is important. Perhaps it's better to set aside anecdotal evidence and try another, more mathematical approach.

Illusory correlation and misinterpreting randomness

From November through March, your boss was absent from the office. November through March coincides with bear hibernation season. In a low information environment, correlations might appear significant when in fact no relationship actually exists. Intelligence analysts need to be alert to patterns that might actually be the result of random chance. Flipping a coin eight times, which sequence is more likely to occur?



Counterintuitively, these sequences are equally likely—eight heads in a row is no oddity compared to any other eight flip sequence—yet the illusion persists that somehow the streak must mean something. Psychologist Daniel Kahneman explains in his book *Thinking Fast and Slow*: "We are pattern seekers, believers in a coherent world ... We do not expect to see regularity produced by a random process, and when we detect what appears to be a rule, we quickly reject the idea that the process is truly random." Extend this idea to an intelligence problem where the coin flips represent some chance posture or characteristic of adversary forces, and it is easy to see how an analyst could incorrectly extrapolate from meaningless data.

Anchoring

When available information is poor, judgments should stay close to the base rate, or prior probability, without taking into account other evidence. Perhaps we could establish the base rate of black bears masquerading as management. To do that, we need a few key details. Say you work at Los Alamos National Laboratory in New Mexico. Is the number of black bears in New Mexico higher or lower than 800? What is your best guess for how many black bears live in New Mexico? (You will get more out of this if you hazard a guess.)

The answer is actually around 8,000, but experimental evidence suggests that your guess was probably closer to 800 due to an anchoring bias. In a low information environment, a tendency to "anchor" to a given number drives

quantitative estimates higher or lower depending on an initially presented value. Interestingly, this bias persists even when the initial anchor is obviously uninformed and therefore irrelevant. You can imagine the implication for analysts attempting to estimate quantities of troops, missiles, or anything else.

Base-rate fallacy

Say that you establish with certainty that 15 percent of management are bears. What next? Naturally, it is time to deploy your bear detector, which boasts 80 percent accuracy at detecting managerial bears. After surreptitiously using it on your boss, it shows bear! Given this test and your estimate of the base rate, what is the probability that your boss is a black bear, assuming you are right about your detector's accuracy? Experiments have shown that people are generally awful at answering this question, guessing somewhere around 80 percent, often ignoring the base rate (15 percent) altogether in their reasoning.

The best use of information in a situation like this is to combine the test result and prior probability taking into account false positives, which gives you 41 percent chance bear. Therefore, using the prescribed terms, you assess that it is "unlikely" that your boss is a black bear.

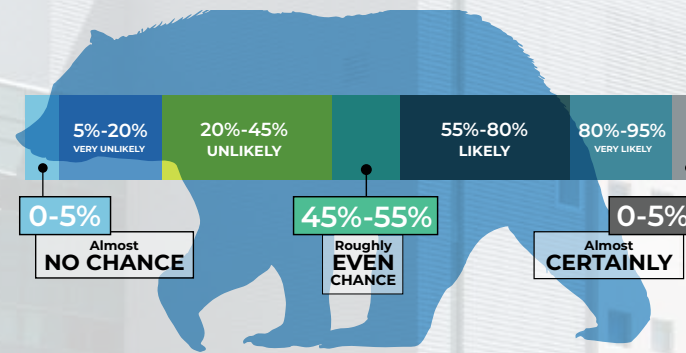


Table adapted from *Intelligence Community Directive 203*—the official, publicly available document that governs the production and evaluation of intelligence products.

Still, it cannot hurt to take precautions. Especially after a long time out of the office, you should calmly identify yourself as human. Do not surprise your manager with shouts or loud noises because such actions could provoke an attack.

Analysis of alternatives

U.S. law dictates that intelligence analysts reconsider their positions through an explicitly stated analysis of alternatives. This kind of analysis explores alternative interpretations of the available evidence and demonstrates to the reader that the analyst considered possibilities other than the main analytic position. The text identifies any evidence consistent with the alternative theory, and explains why the analyst ultimately deemed the scenario less likely. It also identifies any indicators that, if observed, may cause the alternative interpretation to displace the main assessment.

In this case, you would be wise to include the alternative that your boss is almost certainly human (note the different language from "unlikely a bear"). Perhaps it would be worthwhile to note that

your main assessment is likely the product of months of isolation and deranged bear scholarship.

Layering

Layering describes when new assessments cite other, finished intelligence assessments instead of the undergirding primary sources, potentially propagating erroneous conclusions based on one source or analysis that no one thought to question. The commission tasked with analyzing the intelligence community's work on the Iraqi weapons of mass destruction (WMD) issue described how "previous assessments based on uncertain information formed, through repetition, a relatively unquestioned baseline for the analysis in the pre-war assessments." Layering creates the illusion of multiple corroborating analyses and can inflate confidence in a given judgment. If the original source or analysis turns out to be wrong or misleading, an entire assessment can come crumbling down.

To avoid this, you decide to go directly to the source, asking your boss to review your findings. Feedback is immediate: "No one approved this. Your research question and findings are absurd. Clean out your desk."

Exactly what a bear would say. The WMD commission warned about situations like this, stating that "An intellectual culture or atmosphere in which certain ideas were simply too 'unrespectable' and out of sync with prevailing policy and analytic perspectives pervaded the Intelligence Community."

Conclusion

Plenty of evidence not presented in this article would confirm that your boss is not a black bear. Unfortunately, no one alerted you to a basic precept of intelligence analysis: Identify potential hypotheses and proceed by elimination—often it is the hypothesis burdened with the least contra-indicators that is correct. Further, according to Kahneman, we are all susceptible to a "what you see is all there is" bias that can lead to overconfidence in seemingly well-supported assessments, but those assessments are wrong because of a critical, overlooked piece of information. Analysts often cannot immediately know what they do not know, and it often falls to reviewers to help identify these unknown unknowns.

The intelligence analyst blends the methods of scientist and historian, the former who eliminates hypotheses by seeking disconfirmatory evidence, the latter who uses incomplete information to construct a coherent narrative. Intelligence assessments are by definition subjective best guesses, and occasional inaccurate calls are part of the job. As long as analysts earnestly characterize their sources, forthrightly express any uncertainties, explicitly state their assumptions, and explore alternative interpretations of the data, then their product is sound. ★

To report bears on Laboratory property, email bears@lanl.gov. 🐻

Content in this article was adapted from books by Daniel Kahneman (*Thinking Fast and Slow*) and Richard Heuer (*The Psychology of Intelligence Analysis*). The article also references the unclassified *Report of the Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction from March 2005*. The "bear detector" Bayesian inference problem is a modified version of the blue and green taxicab question used by Kahneman and Tversky in their 1972 paper "On Prediction and Judgment."



■ Rich Taylor displays the buckle he earned for being rodeo director.

NOT HIS FIRST RODEO

Rich Taylor, director of the Nuclear Weapons Cyber Assurance Lab at Los Alamos, is the president of the New Mexico Gay Rodeo Association.

BY OCTAVIO RAMOS

When Richard “Rich” Taylor turned five years old, he started riding horses on the family ranch in Kerrville, Texas. When he was older, he and his sister would go to the 4-H Club, where they would hone their skills in barrel racing and other rodeo events.

“Back then, I really got into horse-riding skills known as ‘western pleasure,’” Taylor explains. “It’s a western-styled competition that shows a horse is calm, disciplined, and responsive to a rider’s commands. Through a series of movements, such as the horse backing up and easily moving to the left and to the right, you demonstrate the horse is a ‘pleasure’ to ride.”

COMPUTER SECURITY AT LOS ALAMOS

Taylor came to Los Alamos National Laboratory in 1994, where he began working as a radiation control technician for the Laboratory’s Plutonium Facility. In 1998, he had an opportunity to help with computer security, and he found that he had a natural knack for the technology.

After various years working in information technology, including an 18-month stint at Lawrence Livermore National Laboratory, Taylor was hired as the director of the Nuclear Weapons Cyber Assurance Laboratory (NWCAL) in 2019. After only three months on the job, he took on the additional responsibility of group leader for the Laboratory’s Secure Networks and Assurance group (of which NWCAL is a part), when the previous group leader retired.

“I didn’t really want to be a group leader,” Taylor says, “but I had to admit I had the experience and expertise for the job, so I took it to see what I could do. I was particularly excited about directing NWCAL, as it was a new initiative using the latest computing technologies available anywhere.”



■ Rich Taylor (right) and husband Ryan Taylor take a moment to share a photo between rodeo events.

The principal objective of NWCAL is to mitigate risks associated with critical manufacturing equipment and engineering software tools used to carry out facets of stockpile stewardship—that is, ensuring that the nation’s nuclear weapons stockpile remains safe and secure.

“Both equipment and software are vulnerable to tampering,” Taylor explains. “We perform a number of services to counter such tampering. For example, we reverse engineer malware within existing engineering packages so we know what we’re looking for in new packages. We conduct cyber-physical analysis and assessments on equipment and software, and we also respond to suspicious system behavior, working with collaborators from various other Laboratory organizations, such as the Security Inquiry Team and Counterintelligence.”

MEANWHILE, BACK AT THE RODEO

In 2012, Taylor started hanging out with friends who were into the rodeo scene, which brought back many good memories.

“That’s when I found out about the New Mexico Gay Rodeo Association, which was established in 1984 as a nonprofit organization fostering the western lifestyle within the gay community,” Taylor says. “I started attending the rodeos, and in 2016 I was asked to coordinate a rodeo event known as the Zia Rodeo in Santa Fe.”

His love of rodeo renewed, Taylor accepted more leadership opportunities, subsequently serving as rodeo director, vice president, and currently president of the New Mexico Gay Rodeo Association.

“There are lots of events at these rodeos, from bull riding and chute dogging to team roping and barrel racing,” Taylor says. “There are also special events created specifically for gay rodeo, and these are kind of fun.” Taylor laughs. “One event is known as goat dressing, which is exactly what it sounds like. Now, I must stress that this event causes no harm to the animal—the association has strict guidelines associated with animal welfare. Another audience pleaser is called the wild drag race, and you have to see it to believe it.”

As Taylor sees it, his various roles at the Laboratory have helped him manage large rodeo events and serve as the president of a large rodeo association. It’s too soon to tell how his current role will carry over into the world of rodeo, however. “I took the group leader and director job five months after my last rodeo, and we haven’t had one since because of the coronavirus pandemic,” Rich says. “I don’t know how my experience managing programs at the Laboratory will help me better run the New Mexico Gay Rodeo Association, but I suspect I will benefit greatly from my experience. Heck, like they say, this ain’t my first rodeo.” ★

THE DISTINGUISHED ACHIEVEMENTS OF LOS ALAMOS EMPLOYEES

Kathleen McDonald is the new program director for the Feynman Center for Innovation, which accelerates connections between research, corporate, and entrepreneurial communities; builds partnerships and mechanisms that deliver the Lab's technology to solve our nation's biggest challenges; and creates a trusted external network to extend and enhance the Laboratory's ability to meet its core mission.

Global Security Chief Operating Officer **Evelyn Mullen** was recognized by the U.S. Department of the Army for her outstanding contributions to the Army Science Board. Mullen was honored with the Civil Service Commendation Medal, which provides Army field commanders the ability to acknowledge exceptional civilian performance and achievement.

Fred Mortensen and **Bette Korber** were awarded the Los Alamos Medal, which is the highest honor given to a Laboratory employee. Mortensen was recognized for his impact on stockpile stewardship science and Korber for her groundbreaking research on HIV vaccine discovery and her response to the coronavirus pandemic.

David Chavez, deputy group leader of the High Explosives Science and Technology group, was added to a newly formed editorial advisory board for the *Journal of the American Chemical Society*.

Graduate student **Jessica Lalonde** won first place in the Technology, Engineering, and Math category of the 2021 American Association for the Advancement of Science annual meeting student poster competition. Her poster was titled "A Machine Learning Approach to Investigate Degradation of Poly(hydroxyalkanoates)" and describes her work using machine learning to accelerate biopolymer design and development.

Laboratory postdocs **Eric Bowes** and **Chung Hyuk Lee** are the recipients of the Natural Sciences and Engineering Research Council of Canada Postdoc Fellowship, which provides financial support to promising researchers. Bowes' research is focused on understanding actinide-ligand bond covalency; Lee designs and develops high performing fuel cell cathodes by tuning their porosity.

Michael Prime of Advanced Engineering Analysis was nominated as a fellow in the Society for Experimental Mechanics. Prime's nomination comes "in recognition of distinguished contributions in developing methods to probe the mechanics of residual stress including contour method and diffraction methods, and service to the field of mechanics through the Society."

Ellen Cerreta, division leader for Materials Science and Technology, was named president of The Minerals, Metals, and Materials Society, a professional society for scientists and engineers in those fields.

Ida DiMucci, an Agnew National Security Postdoc Fellow in the Lab's Inorganic, Isotope, and Actinide Chemistry group, was recognized with the 2021 American Chemical Society Division of Inorganic Chemistry Young Investigator Award for her PhD thesis.

Laboratory researchers **Earl Lawrence** and **James Wendelberger** were named fellows by the American Statistical Association. Lawrence was selected "for innovative methodological development, promotion of statistical methods in high consequence challenges in science and national security, outstanding service to the statistical profession, and mentorship of the next generation of statistician." Wendelberger was selected "for sustained impact to statistical applications in business, industry, and government, dissemination of statistical knowledge to diverse audiences, and service to the American Statistical Association as a leader of multiple sections and chapters."

Dina Siegel of the Lab's Occupational Health and Safety Division will lead one of the nation's premier organizations for protecting workers after being elected vice president of the American Industrial Hygiene Association. Siegel joined the organization in 1983 and has served on the board since 2015, previously as director-at-large and secretary.

Minority Engineer magazine recently named its "Top 20 Government Employers" based on a survey sent to a randomly selected group of



BETTER SCIENCE = BETTER SECURITY

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

readers. Los Alamos placed tenth on the list and was the top-ranking national laboratory.

The Southwest Science Writers Association recognized *National Security Science* (NSS) magazine during its annual awards ceremony on April 10. For the second consecutive year, art director **Brenda Fleming** took home the Visual Science Communication Award for the three issues she designed in 2020. Writer **Virginia Grant** received the award for short (fewer than 500 words) writing for her article "The mystery flash that changed astrophysics," about gamma ray bursts.



NSS also won the Communications Resilience category in the Granicus Digital Government Awards. In 2020, the NSS team started a podcast and used interactive graphics online to reach new audiences and keep old audiences engaged during the pandemic. ★

IN MEMORIAM

Peter Lyons

Peter Lyons passed away on April 29, 2021, following a year-long battle with cancer. Lyons was a scientist at Los Alamos for more than 30 years, a former commissioner at the Nuclear Regulatory Commission, and the assistant secretary of the Department of Energy's Office of Nuclear Energy.

In 2020, Lyons received the American Nuclear Society's Dwight D. Eisenhower Medal "for his influential leadership in nuclear technology policy over five decades and for the vital role he played in the nuclear renaissance of the early 21st century." ★

LOOKING BACK



72 YEARS AGO

Los Alamos County was officially established on June 10, 1949, after its identity as the Secret City had been revealed at the end of World War II. Land for Los Alamos county was combined from land previously belonging to Sandoval, Santa Fe, and Rio Arriba counties. This photograph shows New Mexico Governor Thomas Mabry (pointing) with men from Los Alamos who are holding a cutout of the shape of the county that features an artist's depiction of the Trinity test mushroom cloud. ★



THEN + NOW

Between 1943 and 1957, Los Alamos was a closed city because of the sensitive nature of the national security work being done there. All property was owned by the government, and all residents had to show identification at checkpoints such as this one to enter.

In 2016, the county of Los Alamos resurrected the main gate building as part of its annual ScienceFest event. The pseudo main gate is located on the primary road into Los Alamos and is a popular spot for tourists to stop and take photos. ★

Photo: Los Alamos County